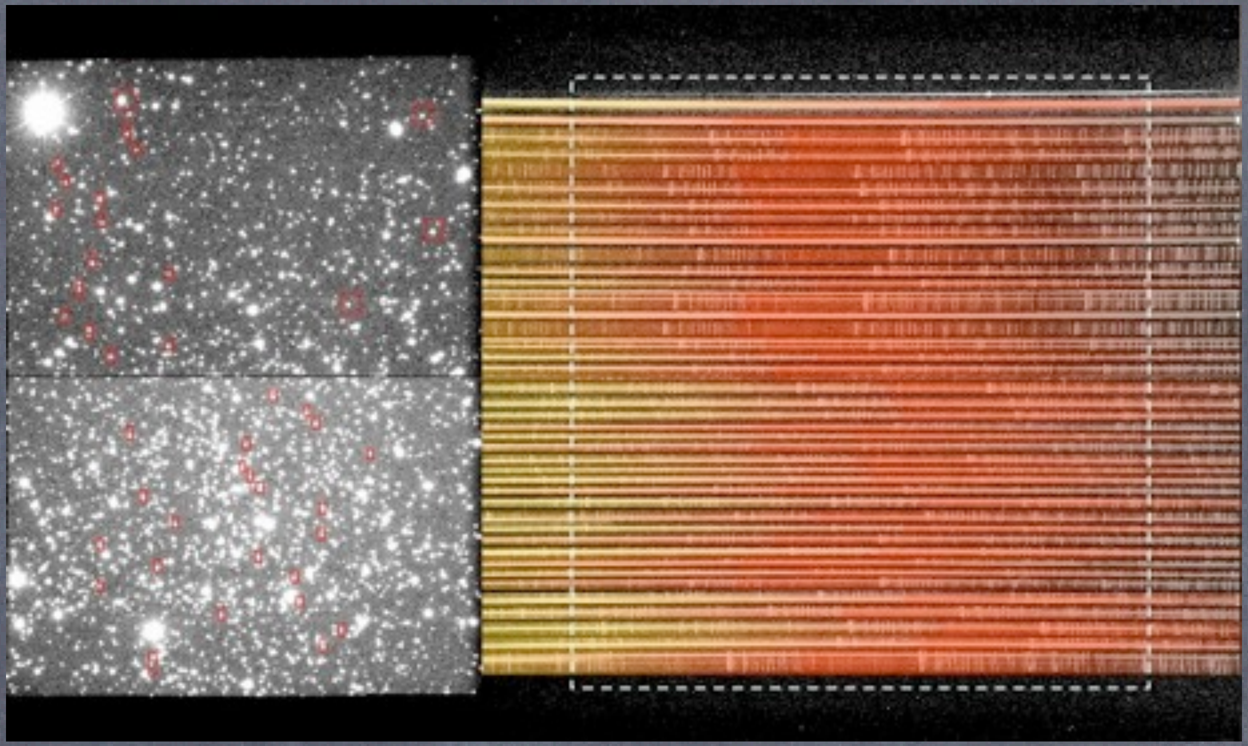
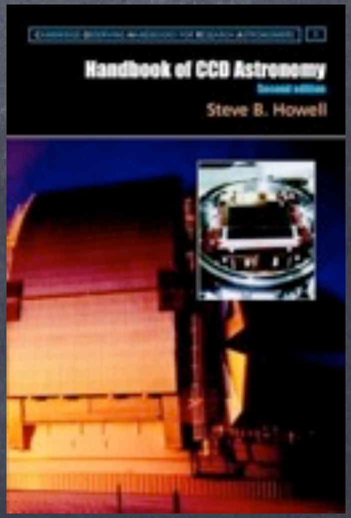
Exploring Data



Keck LRIS spectra

Handbook of CCD Astronomy
by Steve Howell
Chap. 4, parts of 6



FITS: Flexible Image Transport System

Digital file format used to store astronomical images, data, and catalogs. Files consist of text header(s) and one or more data blocks, which can be images, tables, or arrays of varying size.

Some Tools for Examining FITS Data

ds9: imaging and data visualization tool for examining fits data. A lot of functionality if you play around with the menus enough.

FTOOLS: software package for general manipulation of fits files and data analysis. Most used by X-ray astronomers, but many general purpose tools. Also includes mission specific software.

IRAF: general purpose software for astronomical data analysis. Widely used and a lot of functionality, but not the most user friendly software.

IDL: OK, this is a programming language, but the astronomy library includes routines for handling fits data.

And many telescope specific software packages ....

FITS Image

The basic structure of a FITS file includes one or more data blocks with associated header information:

```
> fstruct image.fits
    No. Type      EXTNAME    BITPIX Dimensions(columns)    PCOUNT GCOUNT
     0  PRIMARY                16     177 177                  0     1

IDL> a = mrdfits('image.fits',0)
  MRDFITS: Image array (177,177)  Type=Int*2
IDL> help, /struc, a
  A               INT       = Array[177, 177]
```

Examining a FITS image:

```
> fv image.fits
> ds9 image.fits
```

FITS Table

Catalogs or data can also come in the form of FITS tables.

NYU SDSS DR7 Value Added Galaxy Catalog:

```
> fstruct table.fits
  No. Type     EXTNAME      BITPIX Dimensions(columns)      PCOUNT
GCOUNT
   0  PRIMARY                  8     0                          0    1
   1  BINTABLE                 8     84(19) 2506754              0    1

   Column Name                Format     Dims       Units     TLMIN  TLMAX
   1 OBJECT_TAG                  J
   2 RA                        D
   3 DEC                       D
   4 SDSS_IMAGING_TAG                J
   5 SDSS_IMAGING_POSITION             J
  etc.
```

FITS Table

X-ray (and gamma-ray) data comes in the form a table listing the individual photons detected and their properties.

```
> fstruct xray_event_table.fits

  No. Type     EXTNAME      BITPIX Dimensions(columns)      PCOUNT  GCOUNT
   0  PRIMARY                 16     0                          0     1
   1  BINTABLE EVENTS          8     78(19) 632051              0     1
  Column Name                Format     Dims       Units     TLMIN  TLMAX
  1 time                       1D                   s
  2 ccd_id                     1I                              0       9
  3 node_id                    1I                              0       3
  4 expno                      1J
  5 chipx                      1I                 pixel        1    1024
  6 chipy                      1I                 pixel        1    1024
  7 tdetx                      1I                 pixel        1    8192
  8 tdety                      1I                 pixel        1    8192
  9 detx                       1E                 pixel        0    8192
 10 dety                       1E                 pixel        0    8192
 11 x                          1E                 pixel        0    8192
 12 y                          1E                 pixel        0    8192
 13 phas                       9I      (3,3)      adu      -4096    4095
 14 pha                        1J                 adu          0   36855
 15 energy                     1E                 eV           0 1000000
```

FITS Header

The FITS file header contains information about the observation and file, including what instrument was used, coordinate translations, history of what was done to the file, etc.

Sometimes different blocks in the file will have their own header.

```
> fkeyprint NGC_0720_I_IIIaJ_dss1.fits EXP
  EXPOSURE=  6.000000000000E+01 /Exposure time minutes
> fkeyprint NGC_0720_I_IIIaJ_dss1.fits TELE
  TELESCOP= 'UK Schmidt (new optics)' /Telescope where plate taken
> fkeyprint NGC_0720_I_IIIaJ_dss1.fits DATE
  DATE    = '05/12/96           ' /Date of FITS file creation
  DATE-OBS= '20/08/82           ' /UT date of Observation
```

Basic Steps in Optical Imaging Calibration

To types of instrumental effects to remove:

- Additive:
  - Bias level
  - Bias structure
  - Dark counts
- Multiplicative:
  - Quantum efficiency variations

Basic Steps in Optical Imaging Calibration

Data:

- Bias frames: CCD image with zero exposure time. Used to measure the underlying read noise level. 10 or more bias frames used sample average bias level.

- Dark frames (optional): images taken with the shutter closed for same time as target images to measure dark current level. Can also measure bad pixels and rate of cosmic ray hits. Not necessary for many modern instruments.

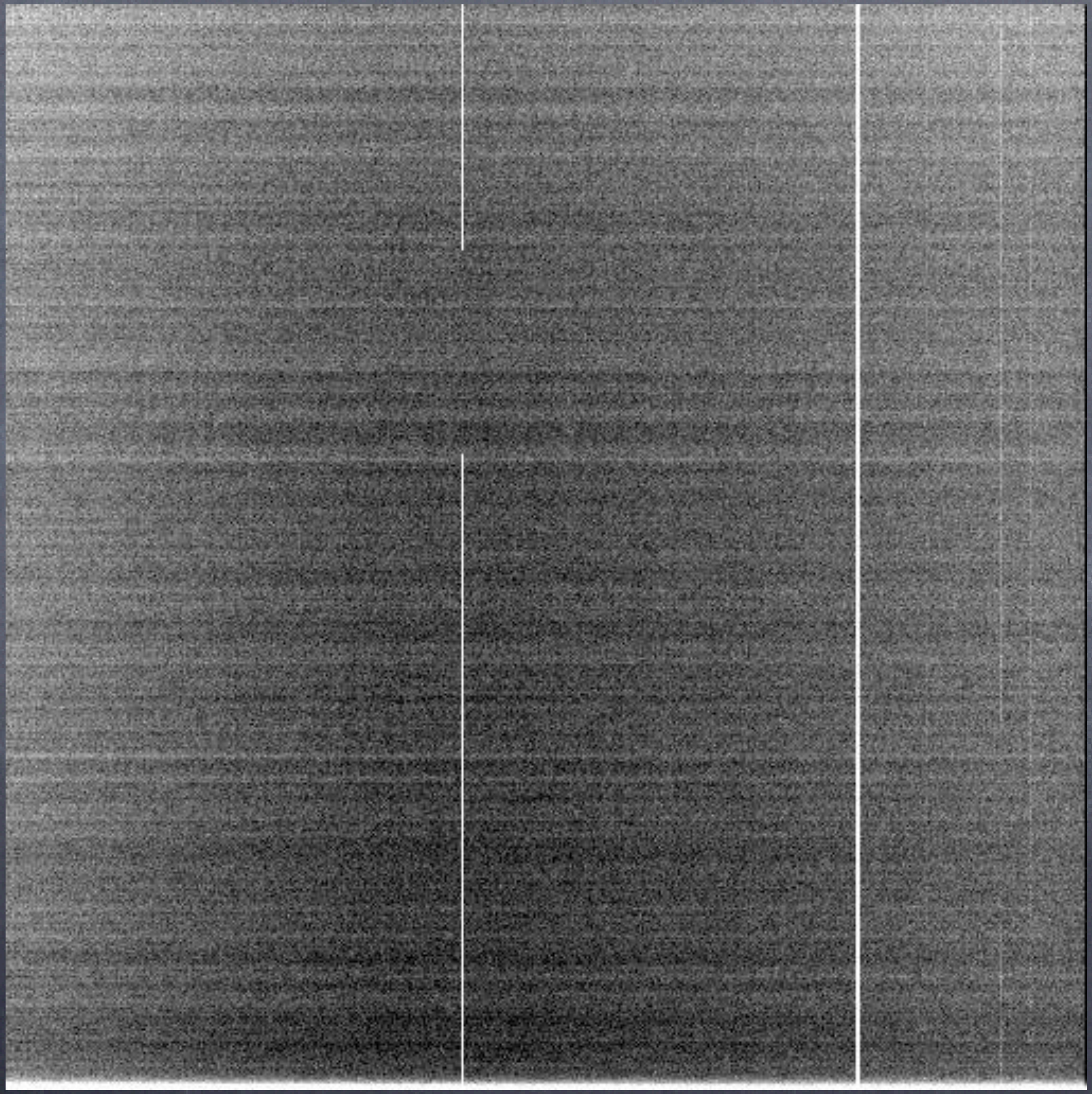
Basic Steps in Optical Imaging Calibration

- Flat field frames: used to correct for spatial variations in detector response (QE). These can be:
    - dome flats (lamp illuminating dome or screen)
    - twilight flats
    - dark-sky flats

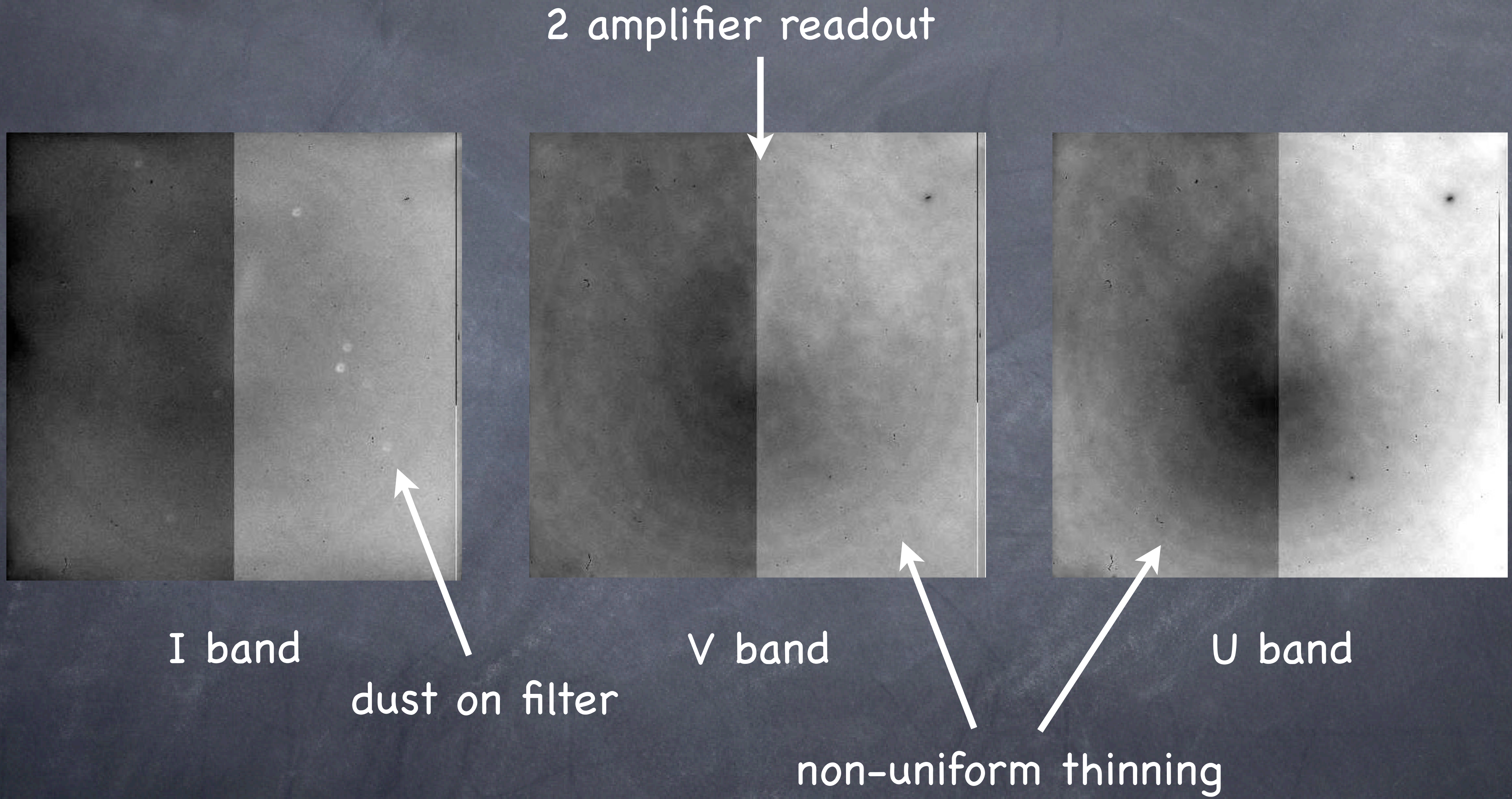
Dome flats give high S/N but illumination different than sky and lamps typically too cool. Dark-sky flats work well, but use observing time and have low S/N. Take five or more and average.

- Target images!

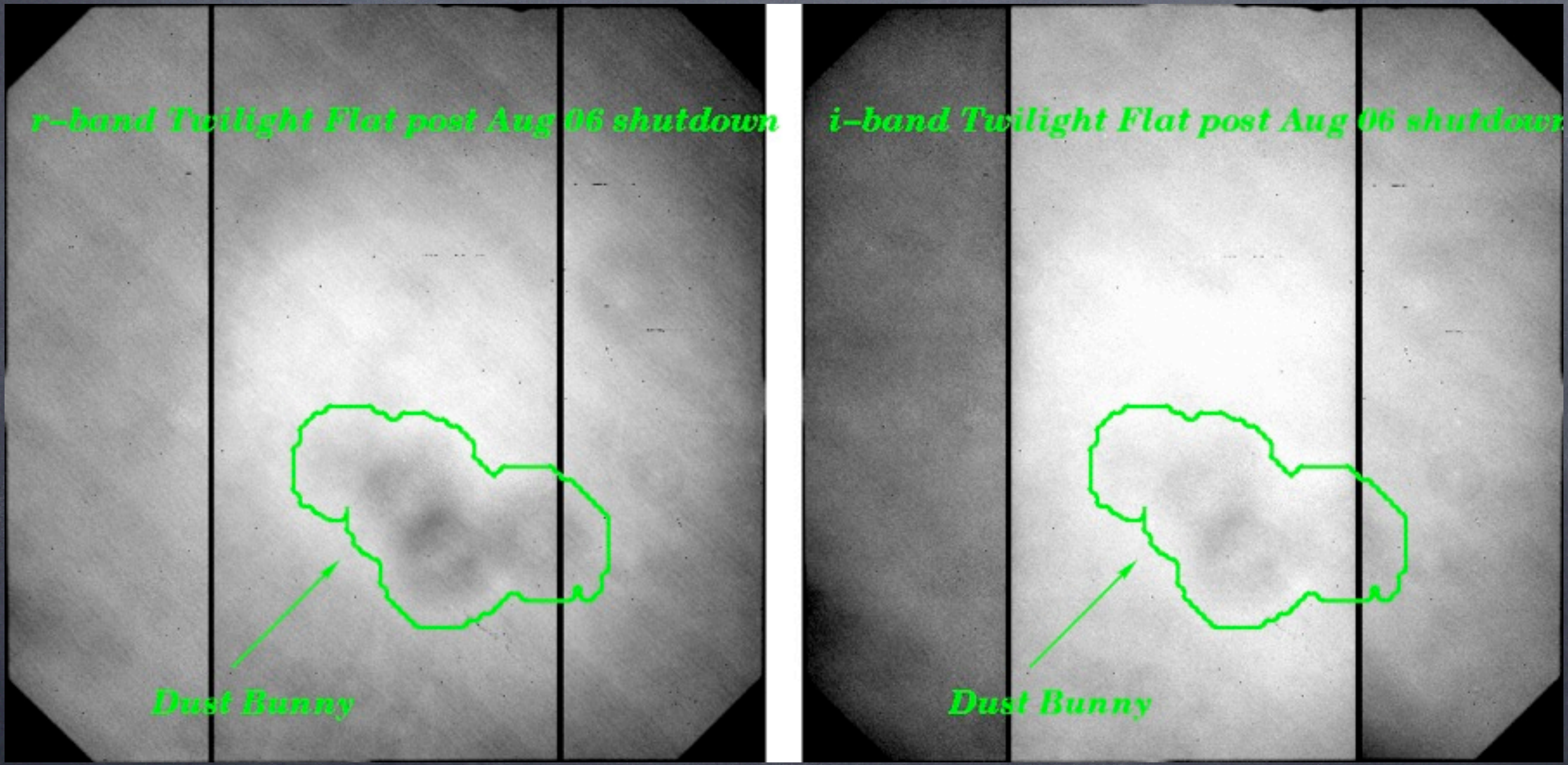
Example Bias Frame



Example Flats: Band Dependence



Example Twilight Flats from Gemini-North



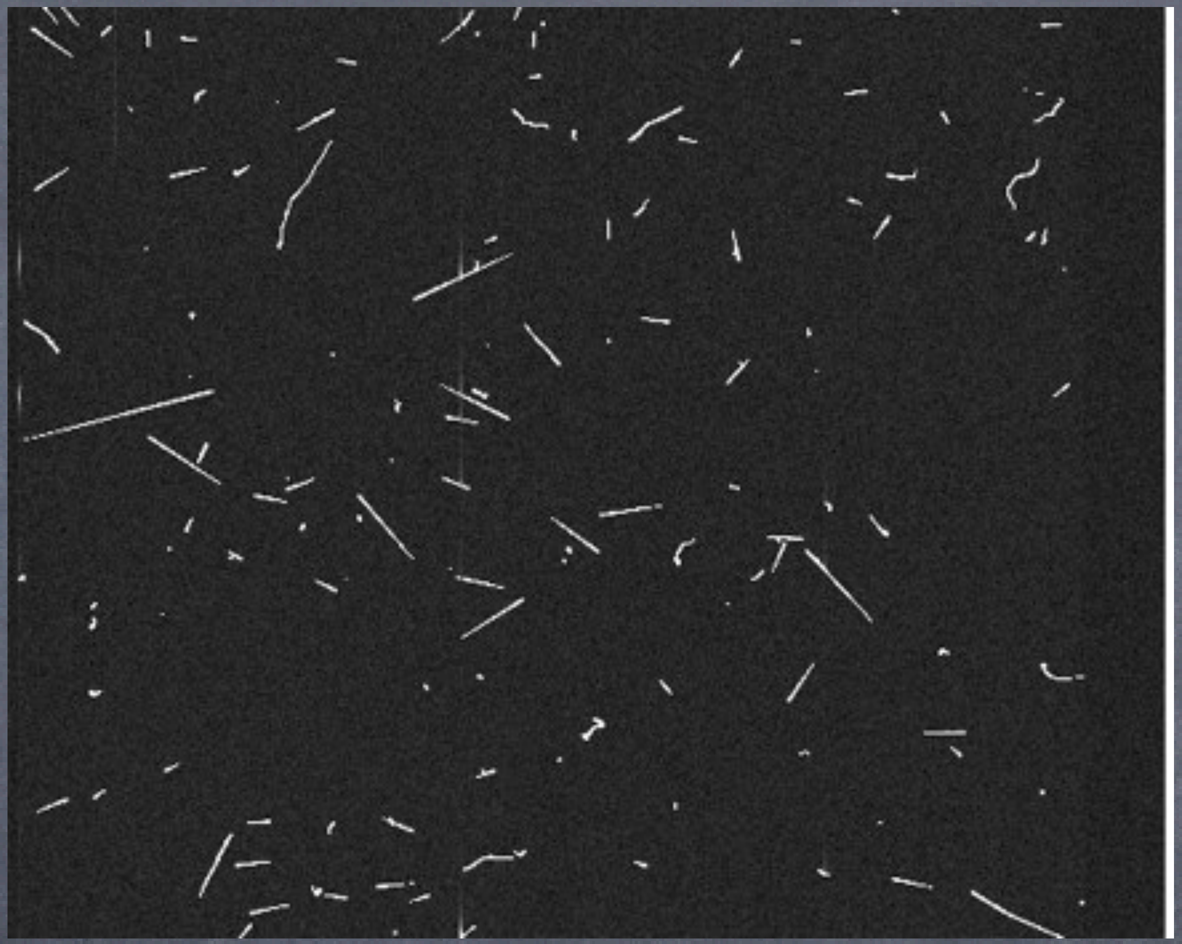
From Gemini Observatory GMOS page

Basic Steps in Optical Imaging Calibration

1. Combine biases to create average bias frame
2. Create normalized, bias subtracted flat field
3. Reduced image = (raw image - bias)/flat field

In more detail, you fit the data in the overscan region of the CCD and use this to subtract the average bias level from the data and average bias frame. Then the average bias is used to correct for bias structure. You may or may not need to subtract dark frames. The flat fields are bias subtracted and combined to get average flat and then normalized to have a mean of 1.

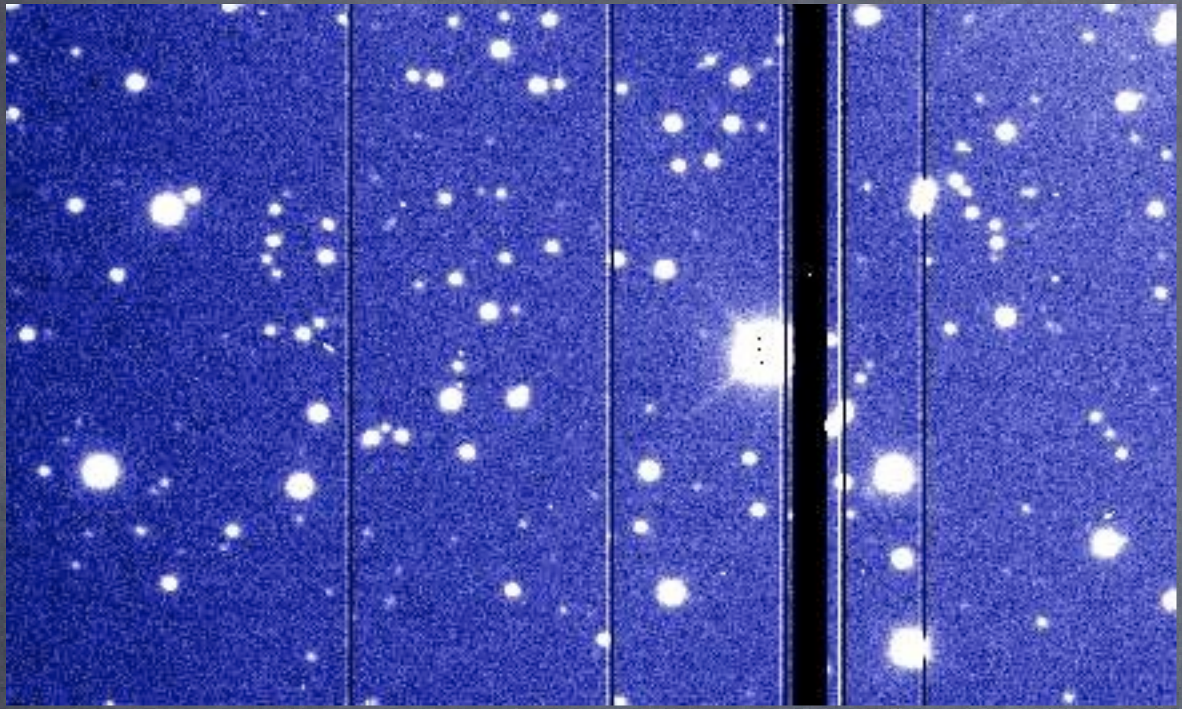
Cosmic Rays in LRIS Dark Image

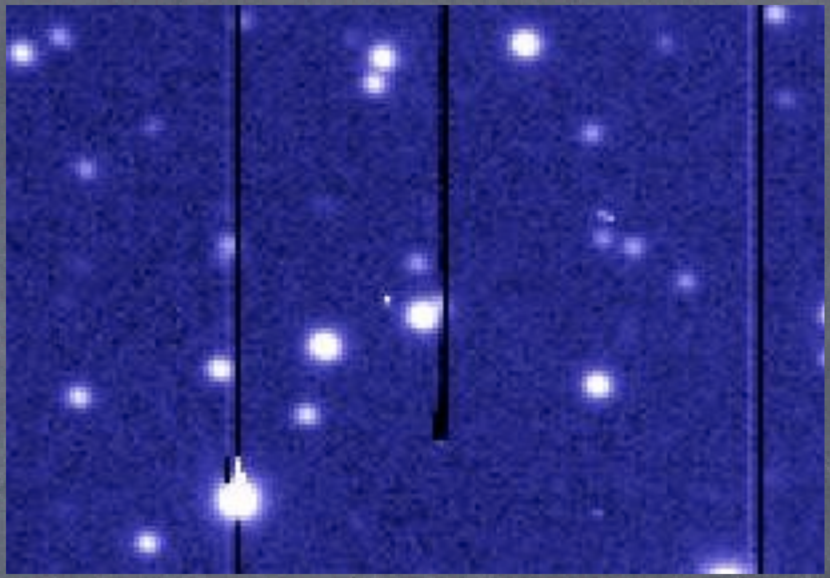


From Keck LRIS red upgrade page

The longer the observing time the more cosmic ray hits. Can take multiple images and median filter to remove them.

Bad Columns/Traps

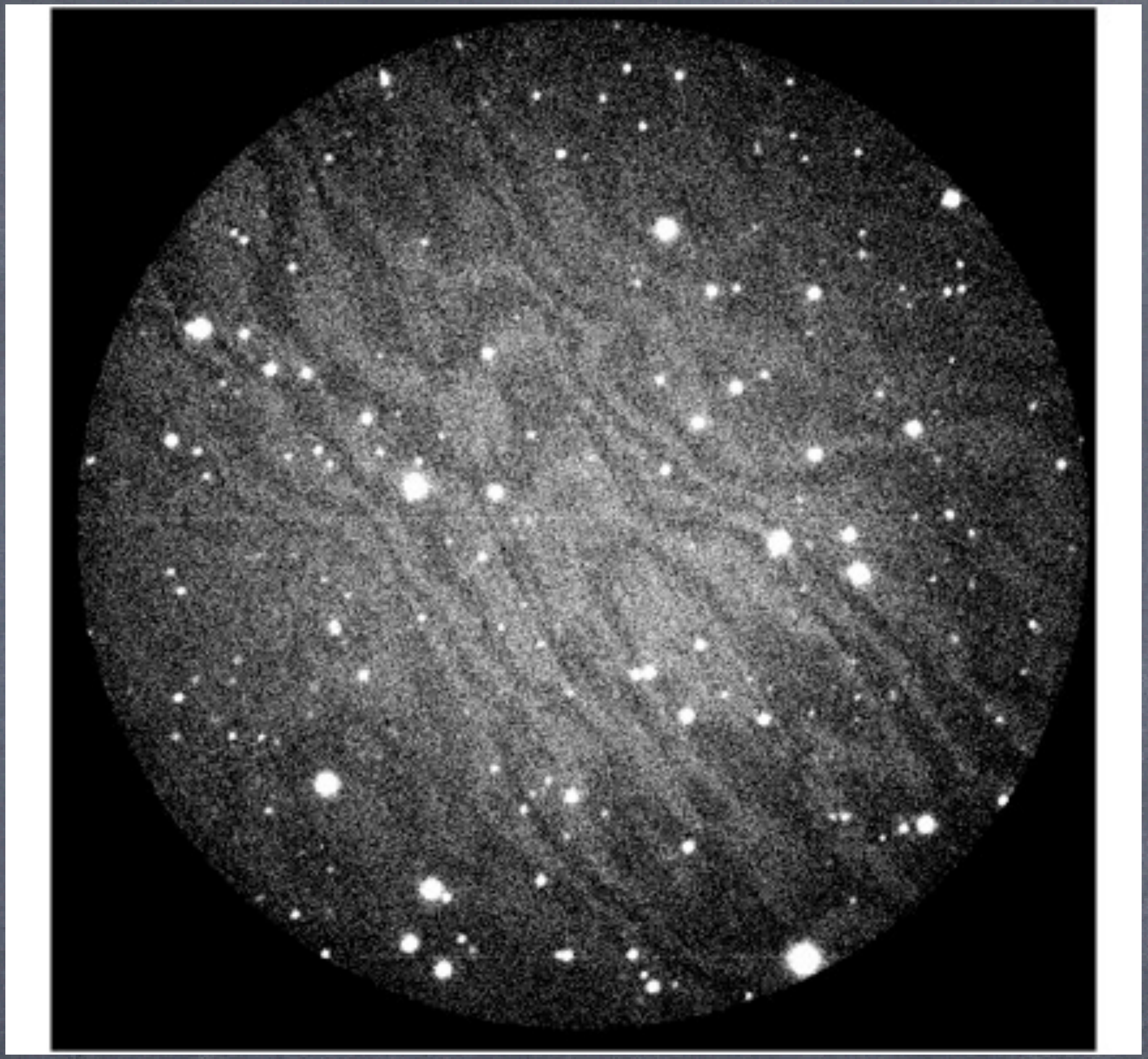




O.Hainaut, Basic Image Processing, http://www.eso.org/~ohainaut/ccd/

Some columns are dead and others read too high ("hot"). If only a small region is affected you can interpolate over them. Some pixels may be damaged such that they don't transfer energy giving a partial bad column where pixels above the bad one are lost.

Fringing



Caused by interference between light waves that reflect within the CCD or by long wavelength light that passes through the CCD and is reflected back by the rear surface (back-illuminated CCDs). Worst in red/IR and for narrow-band filters.

Saturation

O.Hainaut, Basic Image Processing, http://www.eso.org/~ohainaut/ccd/

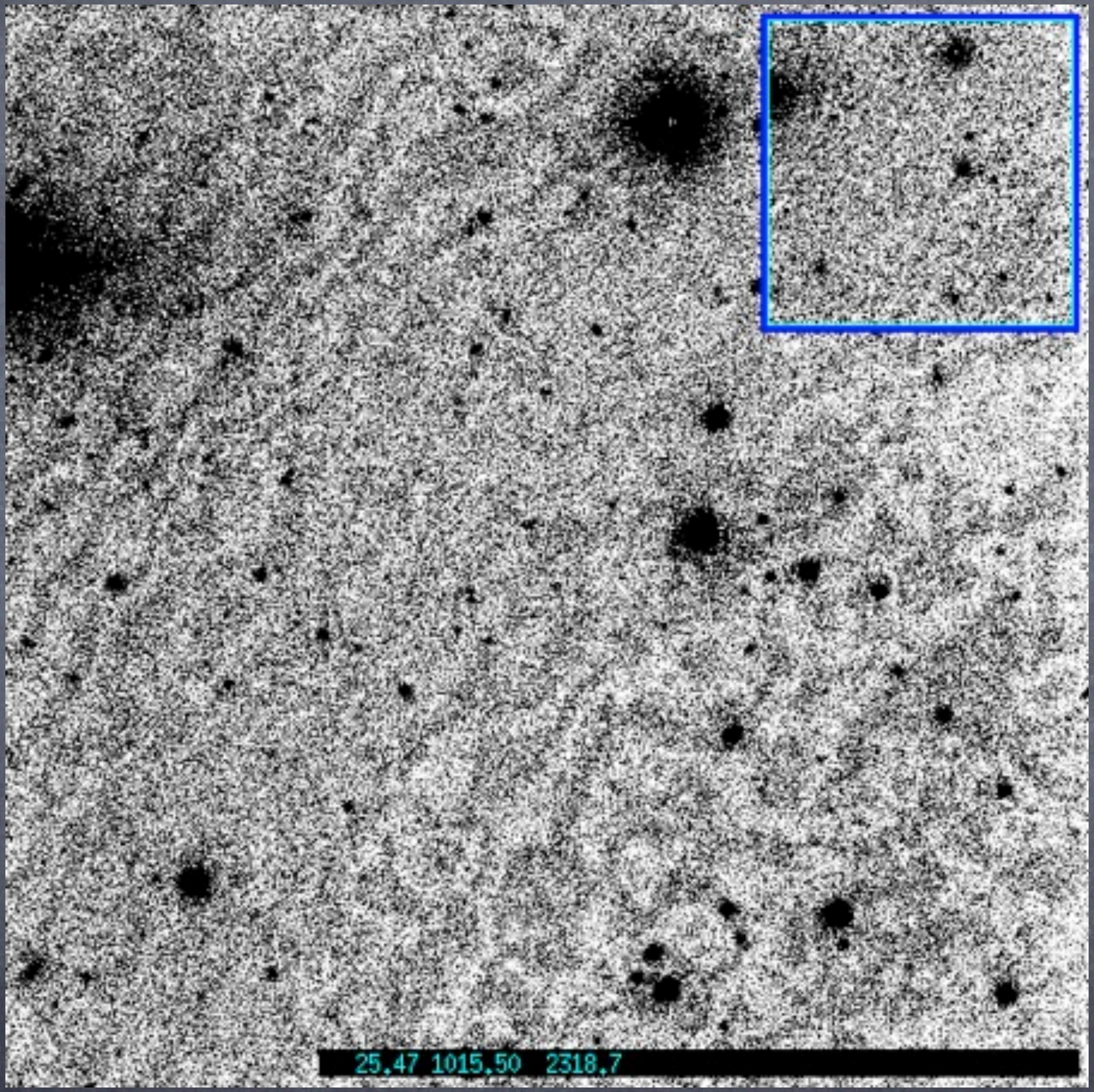
CCD pixels have a finite full-well depth and can be overfilled in long enough exposure of bright sources leading to charge bleeding in to neighboring pixels.

An Amusing Website

Observational Mishaps

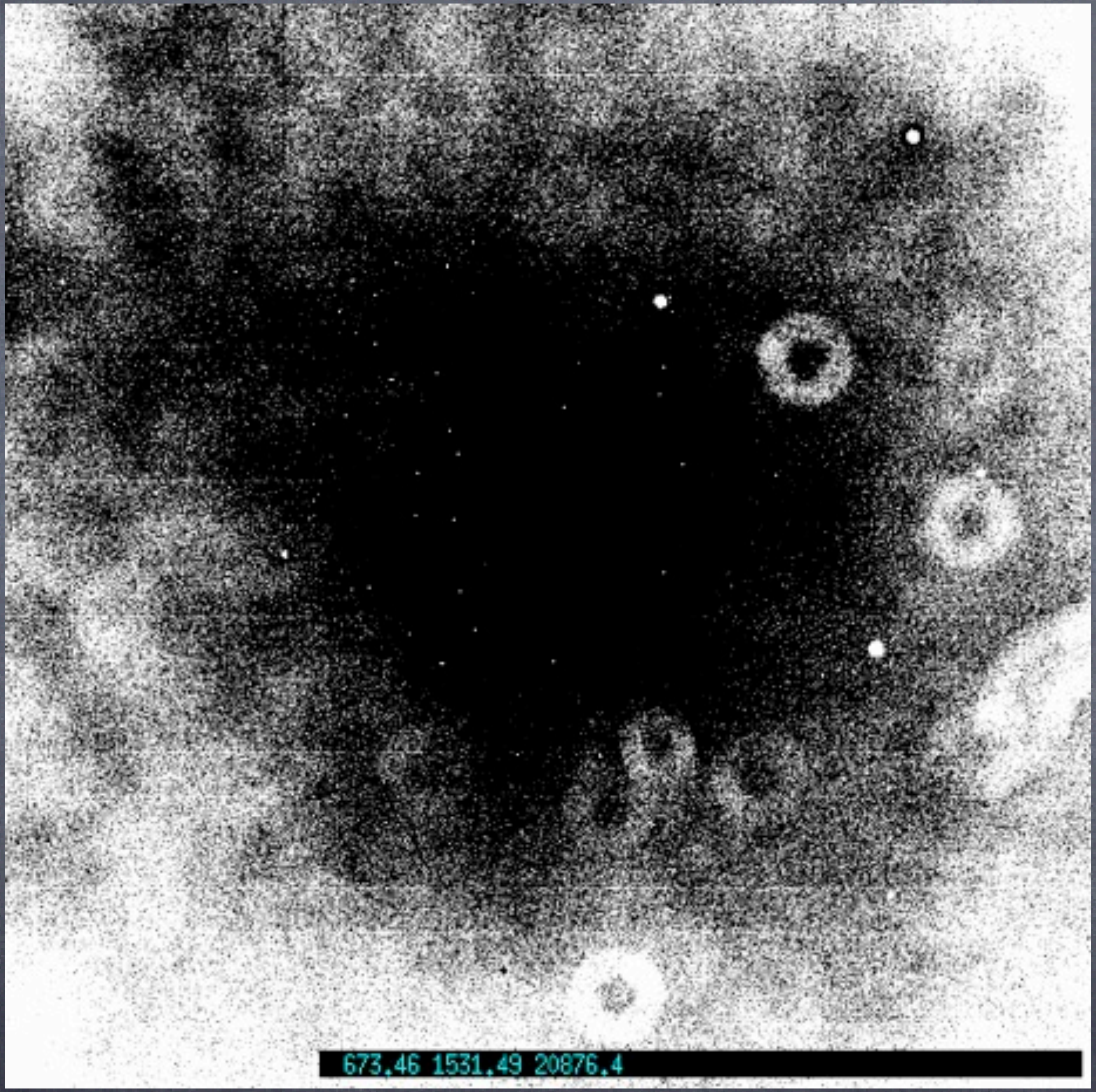
http://spider.ipac.caltech.edu/staff/kaspar/obs_mishaps/mishaps.html

Common Problems



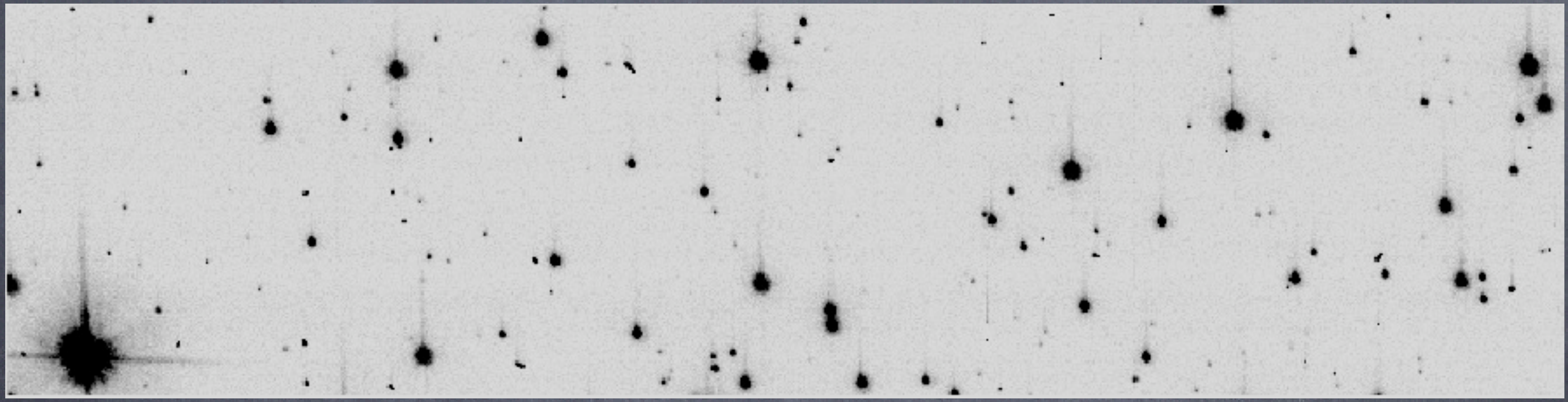
Fringing

Common Problems



Dust

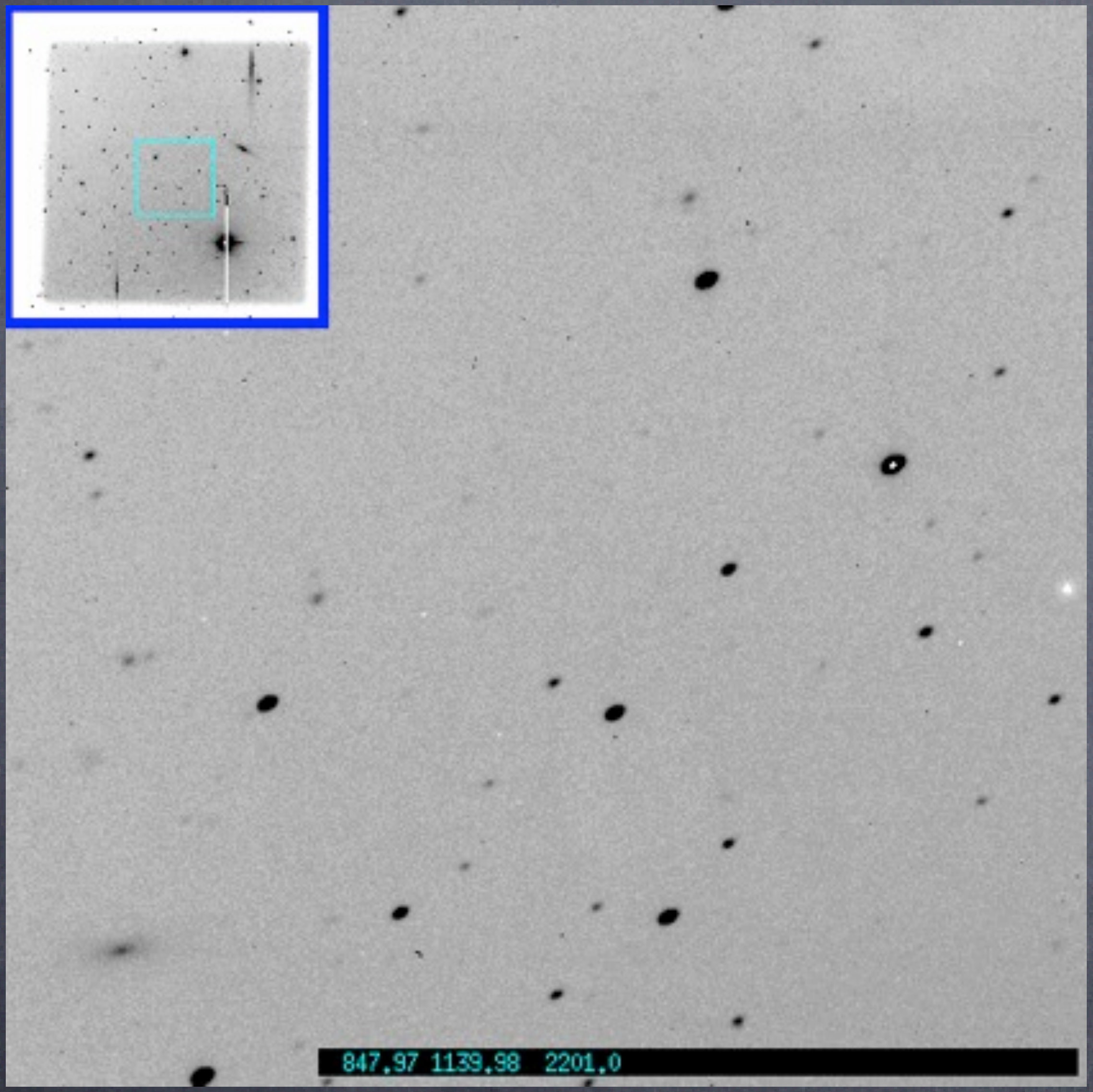
Common Problems



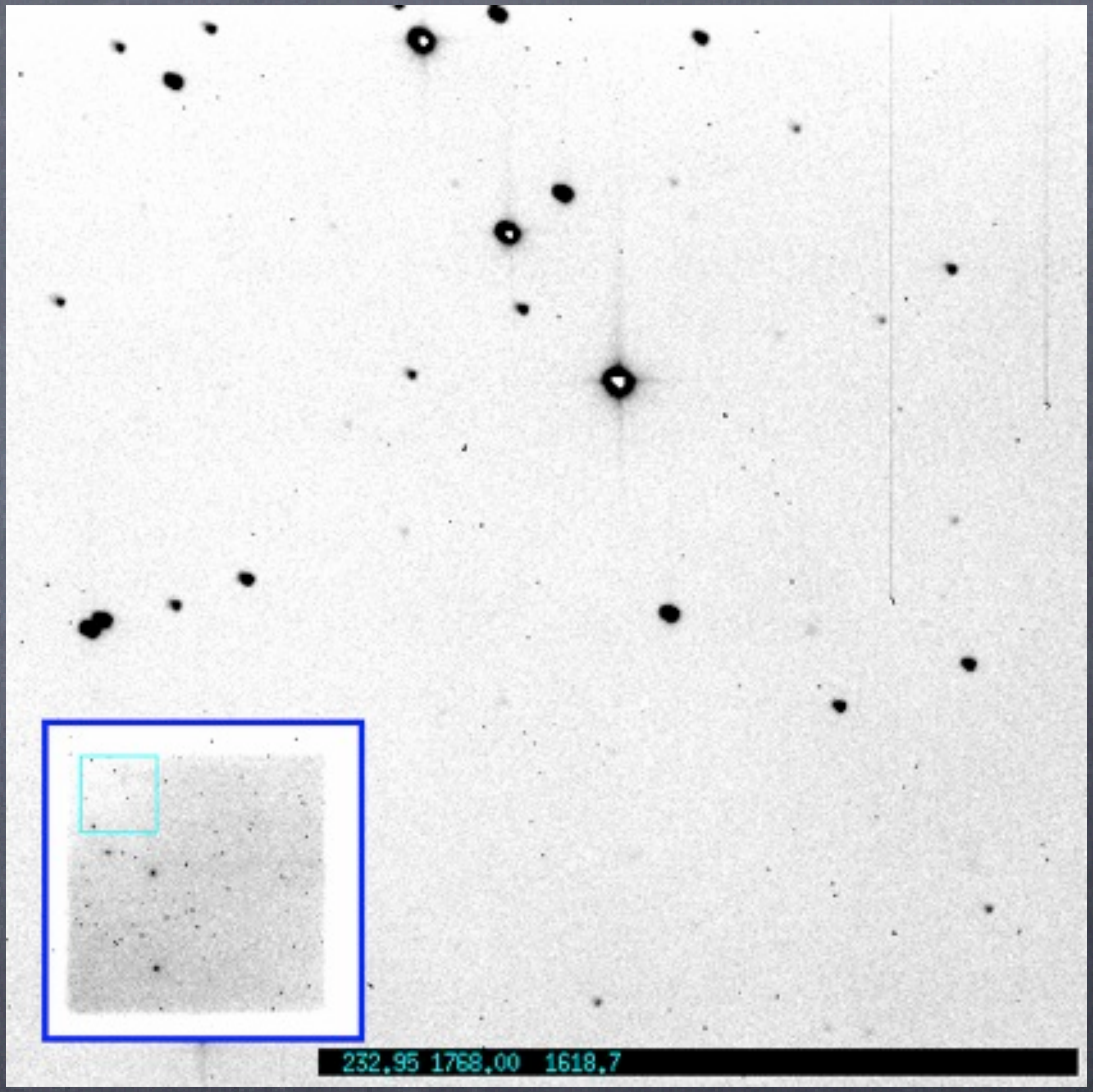
deferred-charge trails
induced by CTE losses

diffraction
spikes

Common Problems

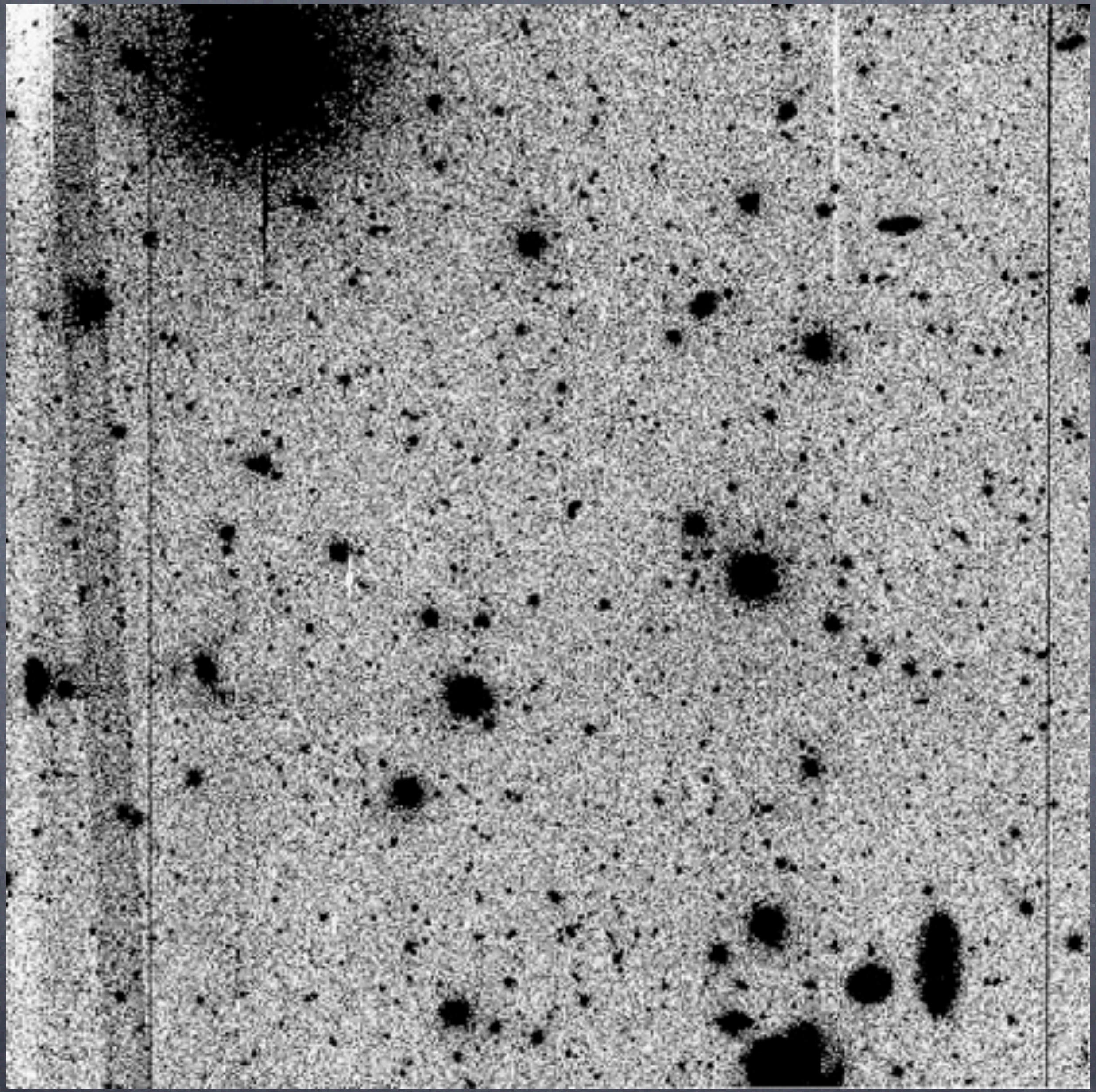


Astigmatism



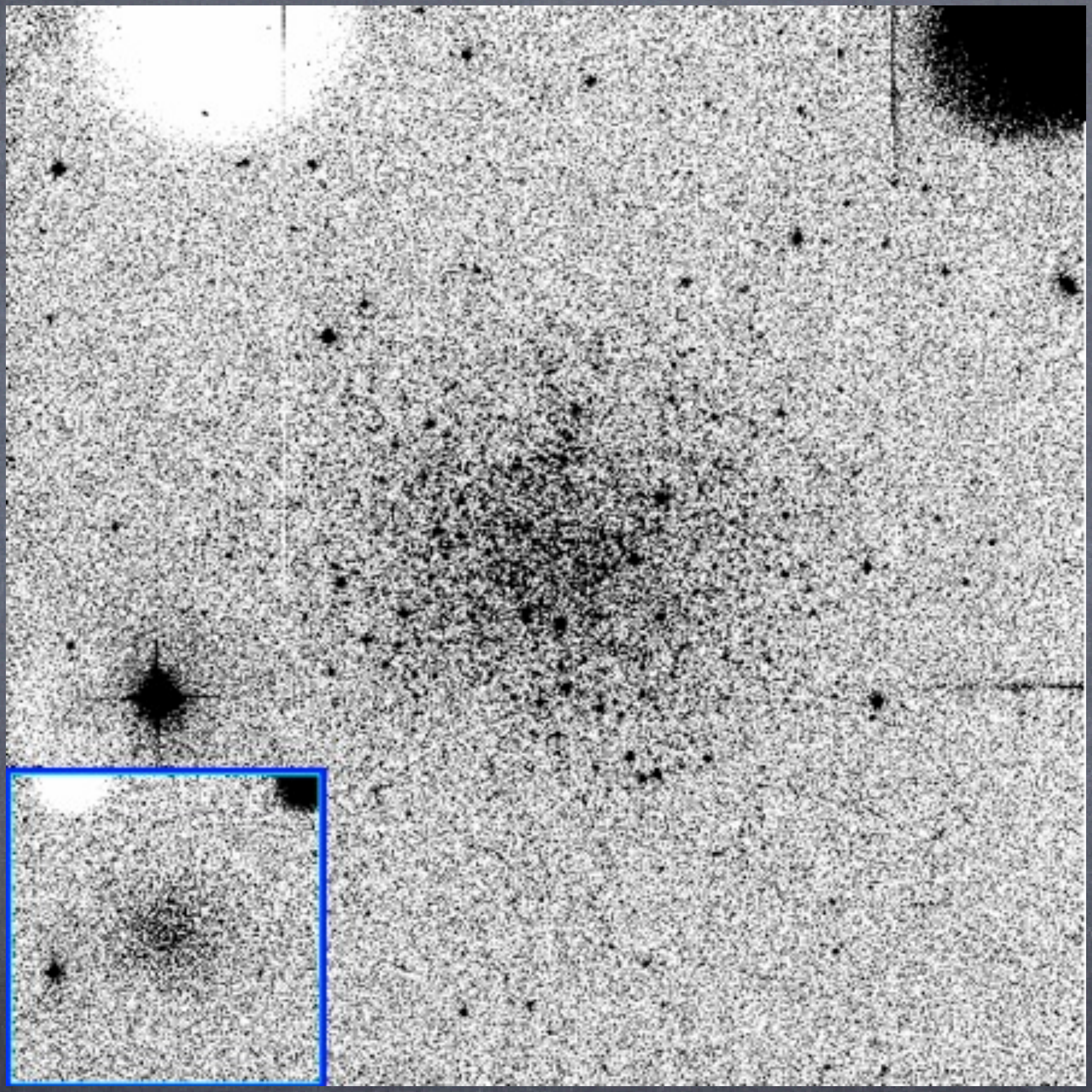
Coma

Uncommon Problems



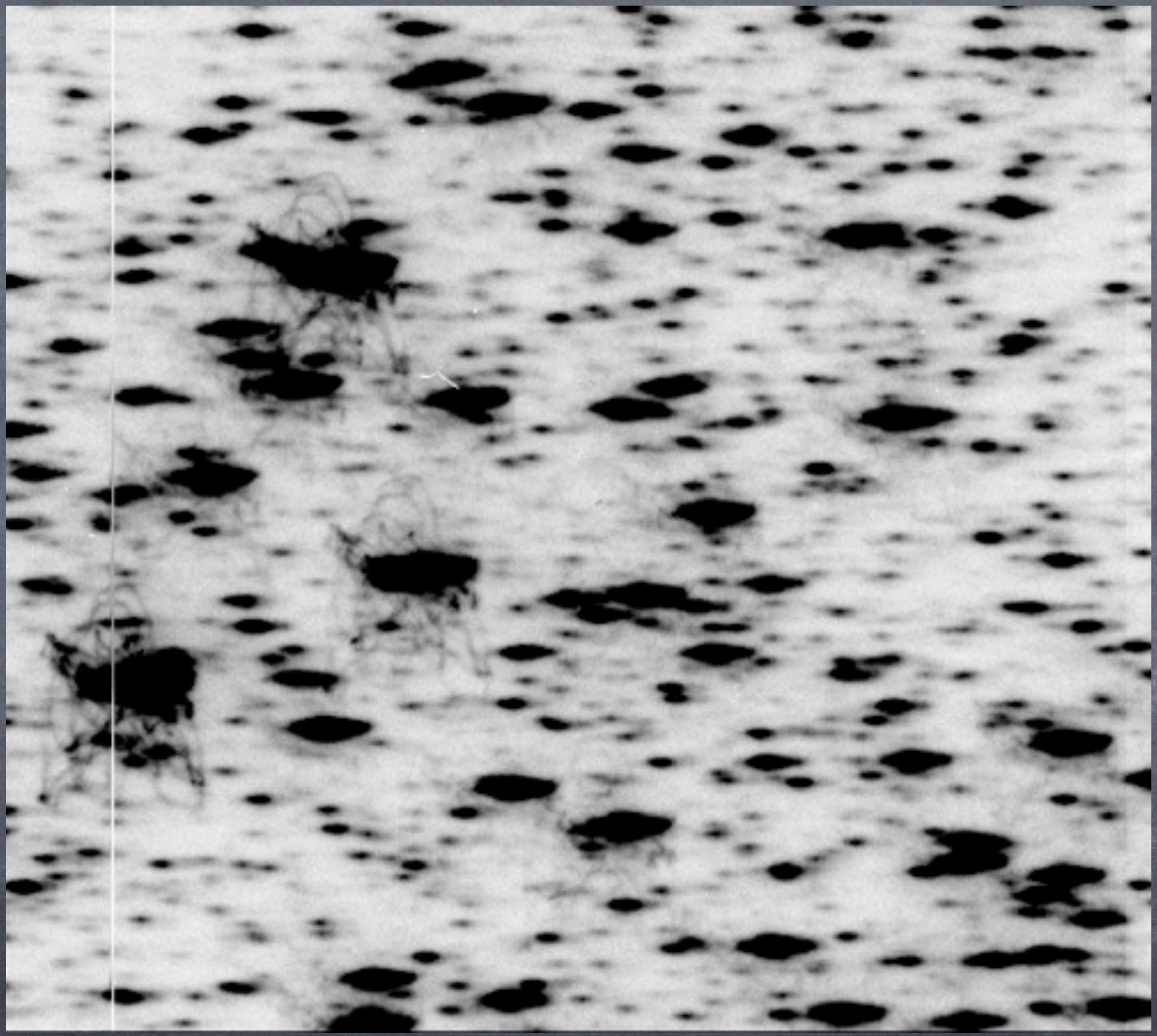
Airplane flew overhead

Uncommon Problems



Dead ladybug on the filter

Uncommon Problems

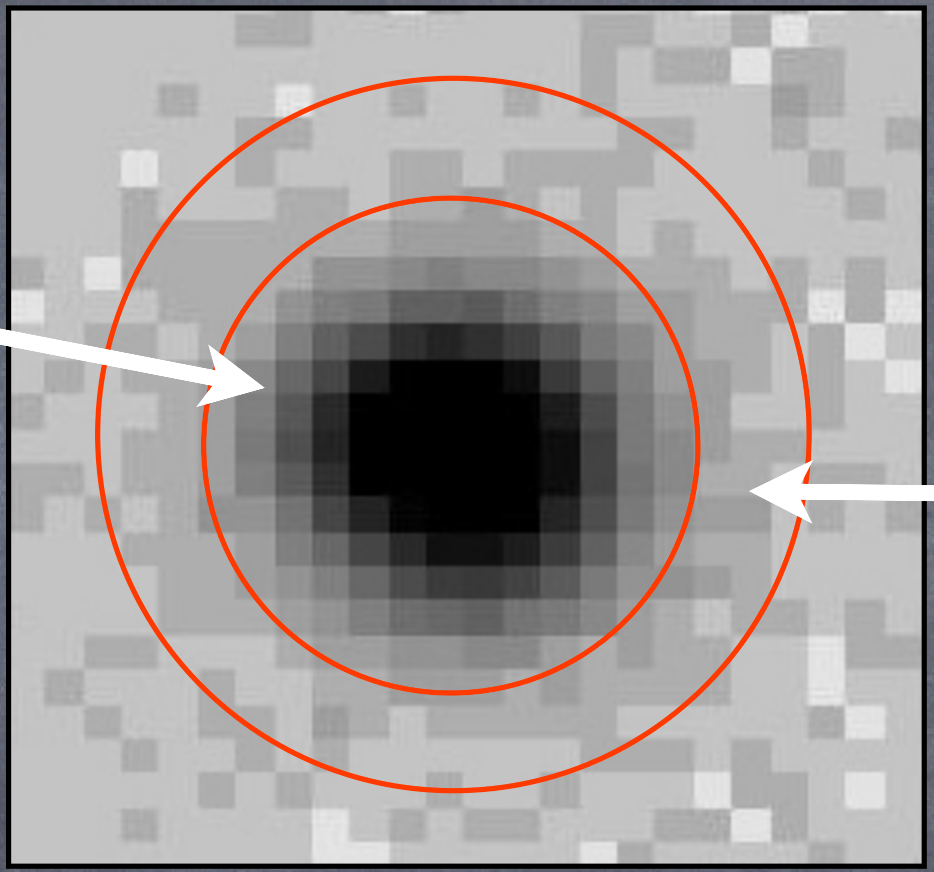


Earthquake!

Photometry

Aperture Photometry

Sum up counts in aperture

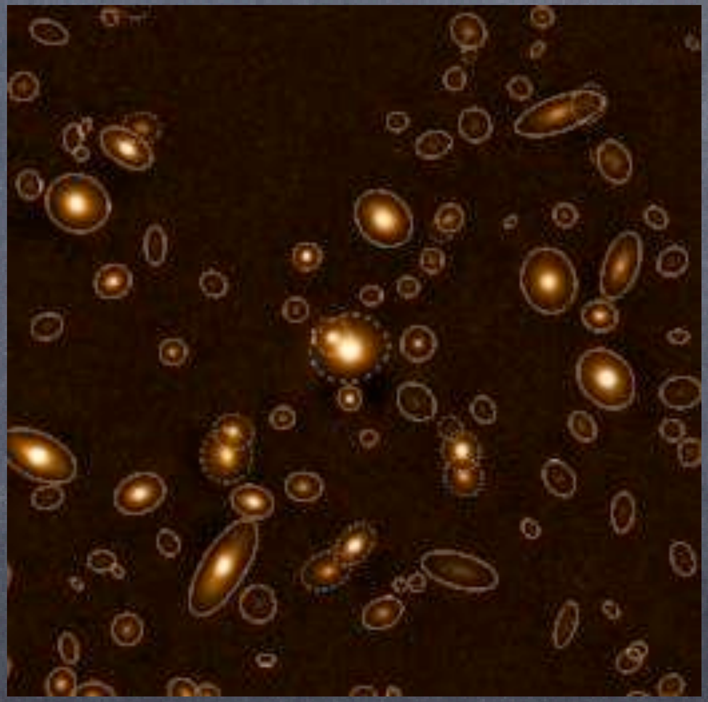


Find average counts per pixel in background region and subtract

A simple idea which is harder in practice. One needs to determine object center and make intelligent choices for the size of the source and background apertures. Need to employ "aperture correction". What might be important to consider?

SExtractor

An astronomical source extractor which creates a catalog of objects from an image. Used for example by SDSS. A bit of a black box, but very useful software.



Author: Emmanuel Bertin

More Elaborate Photometry

from "Source Extractor for Dummies"
Benne Holwerda

ISO	Photometry derived from the counts above the threshold minus the background (see also section 7.4.1).
ISOCOR	ISO photometry, corrected for loss as a Gaussian profile (see also section 7.4.2).
AUTO	Photometry from the Kron flexible elliptical aperture. ? (see also section 7.4.3)
BEST	Choice between AUTO and ISOCOR. AUTO, except when influence from neighbors is more than 10%. (see also section 7.4.4)
APER	Photometry from circular, user specified (PHOT_APERTURES in the config file), apertures.

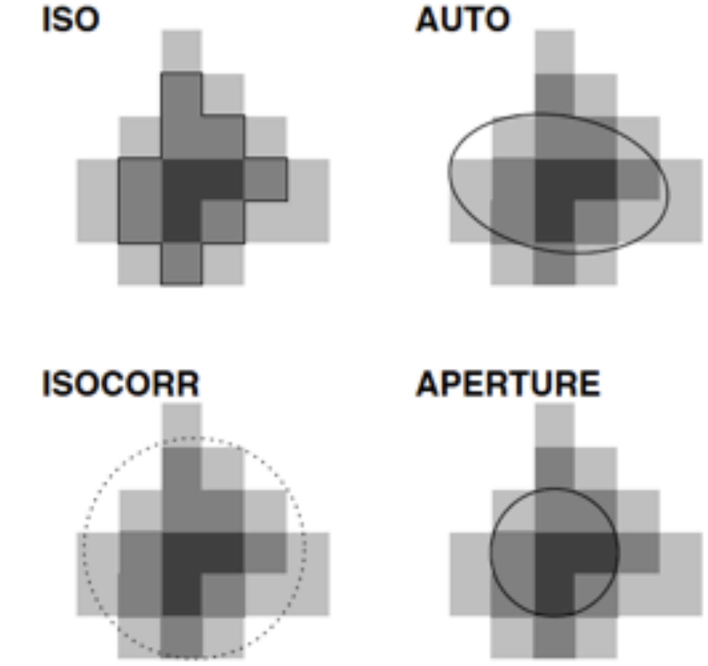


Figure 8.1: Illustration of the different apertures possible; ISO, ISOCOR, AUTO and APER (user specified in PHOT_APERTURES)

NOTE: oh and I'll say it again...the "BEST" photometry is a misnomer. Rather use something that is consistent across your image.

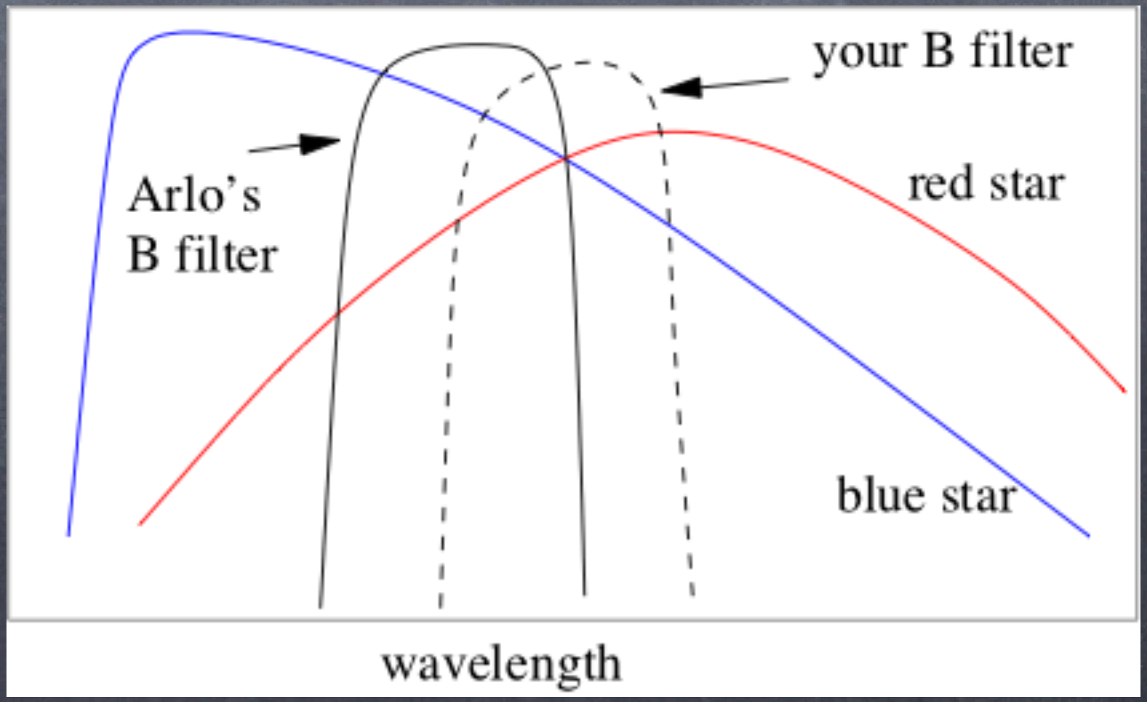
NOTE: For a color (Great Brittain and Canada: colour) measurement, the ISO and APER options are good, especially when run in dual mode since you'll know the apertures are the same. The other apertures may be too inclusive in crowded fields.

Absolute Photometry

Done by observing standard stars.

Need to correct for factors like:

- extinction/air mass
- color: the bandpass of your filter may not be the same as the standard system and the offset this creates depends on the spectrum of the source.

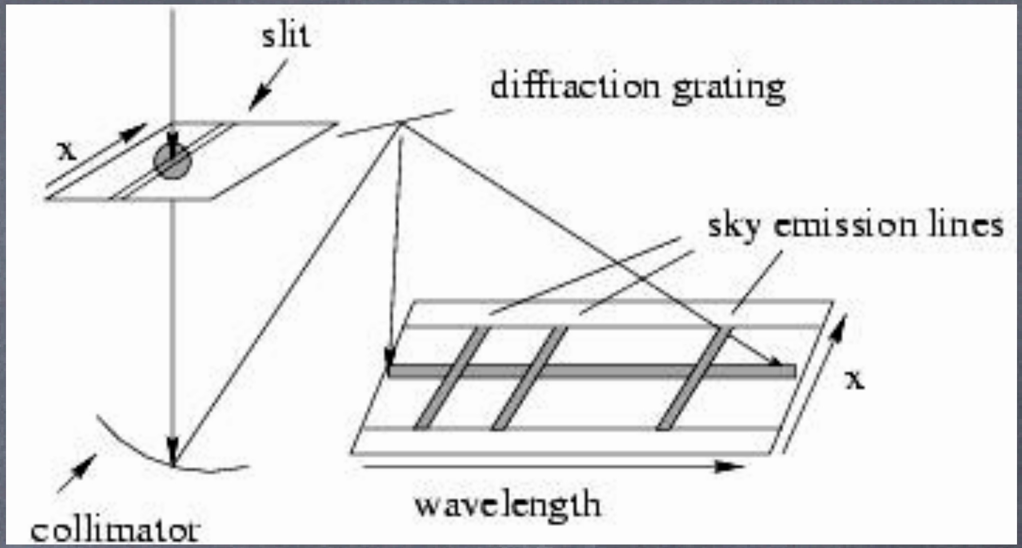


Spectroscopy

Spectroscopic Data

- Long Slit

one dispersive and one spatial dimension



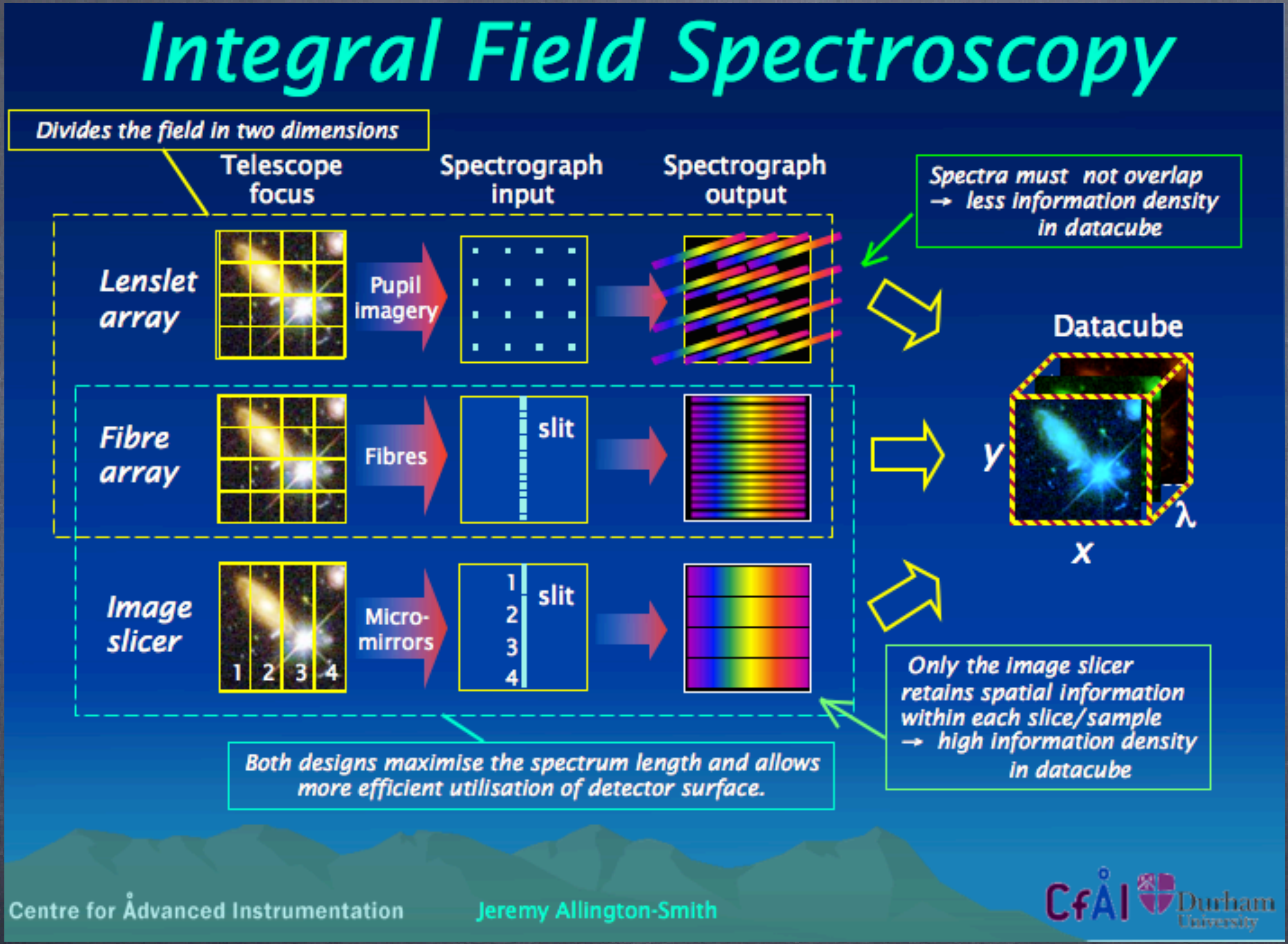
- Multi-object Spectrograph

(slit mask, fiber-fed)
used to get spectra for many object at the same time

for slits, width and length can vary depending on goals (e.g. object size, background sampling, spectral resolution)

- Integral Field Spectrograph

spatially resolved spectroscopy, spectra of extended objects as a function of position


Integral Field Spectroscopy
Divides the field in two dimensions
Telescope focus
Spectrograph input
Spectrograph output
Spectra must not overlap → less information density in datacube
Lenslet array
Pupil imagery
Datacube
Fibre array
Fibres
slit
y
λ
x
Image slicer
1 2 3 4
Micro-mirrors
1 2 3 4
slit
Only the image slicer retains spatial information within each slice/sample → high information density in datacube
Both designs maximise the spectrum length and allows more efficient utilisation of detector surface.
Centre for Ådvanced Instrumentation
Jeremy Allington-Smith
CfAI
Durham University

Spectral Resolution

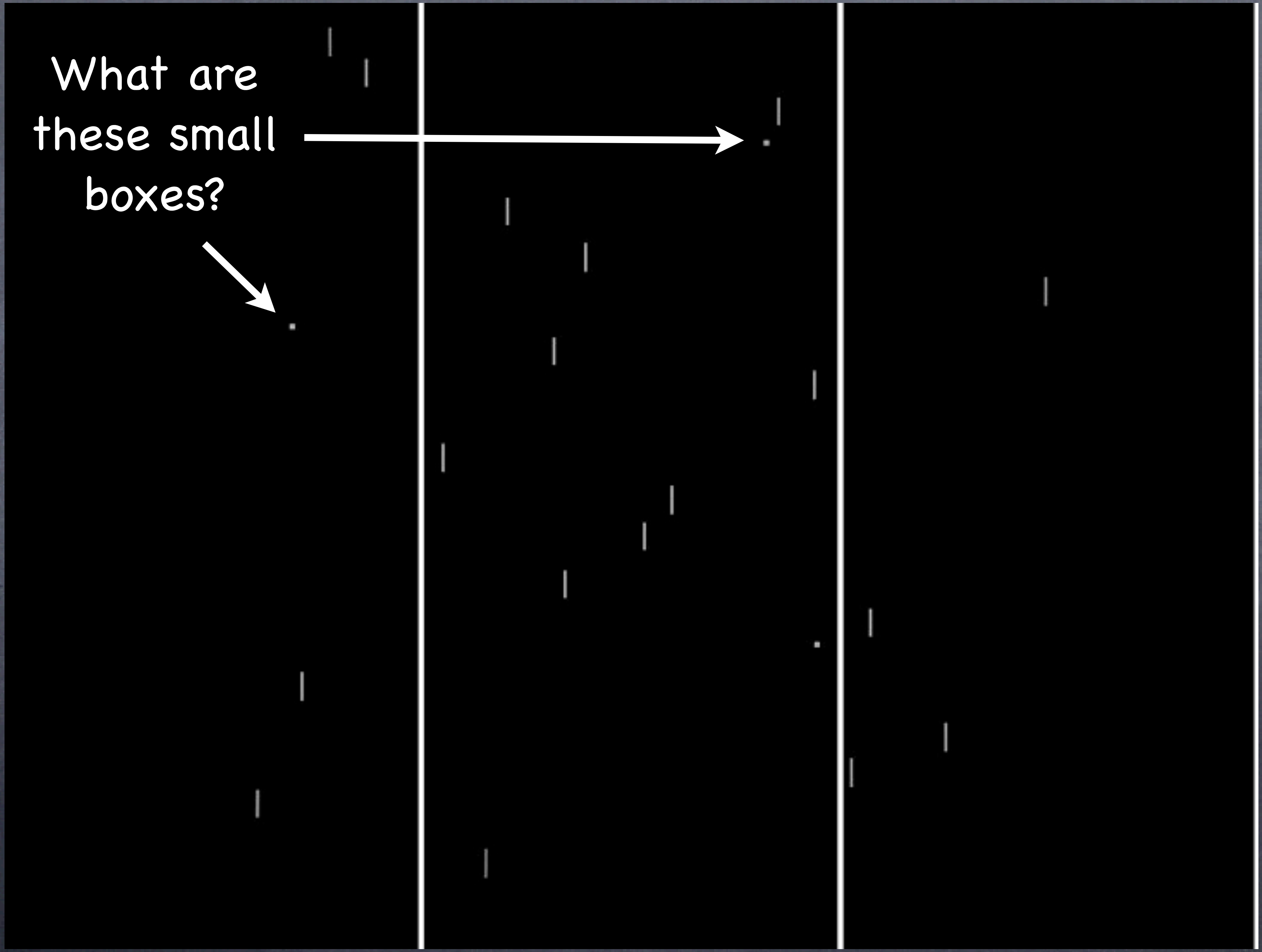
$$R = \lambda/\Delta\lambda$$

Resolution depends on slit width and grating choice. For example, using LRIS with a 1″ slit width (~4 pixels) and 600 l/mm grating the resolution at 6500 Å is R = 6500/(4∗1.28) = 1270.

Keck LRIS gratings

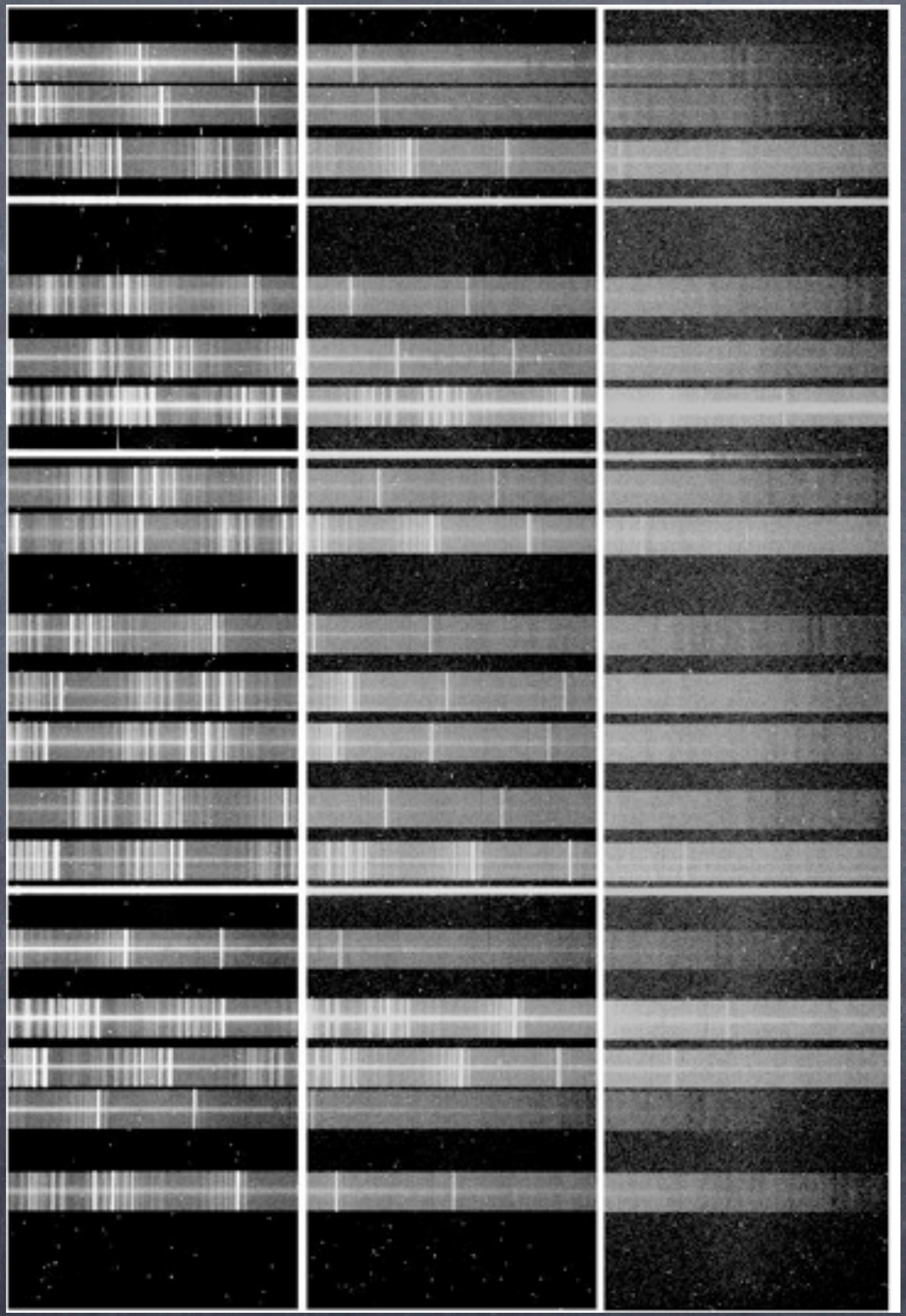
Grating Name	Grooves (l/mm)	Blaze Wave (Å)	Dispersion (Å/pix)	Spectral coverage (Å/2048 pix)
150/7500	150	7500	4.8	9830
300/5000	300	5000	2.55	5220
400/8500	400	8500	1.86	3810
600/5000	600	5000	1.28	2620
600/7500	600	7500	1.28	2620
600/10000	600	10000	1.28	2620
831/8200	831	8200	0.93	1900
900/5500	900	5500	0.85	1740
1200/7500	1200	7500	0.64	1310

Example MOS Mask



Example Spectral Image

Why are the night sky lines not all in the same place?



Spectroscopic Data Calibration

Additional data needed compared to imaging observations:

- Arcs: spectrum of lamps featuring a number of spectral lines of known wavelength. These are used to wavelength calibrate the spectrum and allow you to derive a mapping between pixel position and wavelength (need not be linear)
- Flux standard: spectrum of a spectrophotometric standard star to flux calibrate

Spectroscopic Data Calibration

1. Combine biases to create average bias frame
2. Create normalized flat field
3. Identify spectrum and sky regions, extract spectrum, fit sky and subtract
4. Wavelength calibrate: extract arc spectrum, identify lines, derive pixel to wavelength calibration
5. Flux calibrate with spectrophotometric standard

Some Important Spectral Lines

Emission lines:

- Hα: star formation (use [OII] at high-z)
- [OII], [OIII], Hβ: star formation, AGN

Absorption lines:

- 4000Å break, metals: older cooler stars, older stellar population
- Balmer series: young stars

"Baldwin, Phillips & Terlevich"
BPT diagram