OBSERVATIONAL ASTRONOMY – II

Vitaly Neustroev

Practical sessions

- **Location:** YL124

- **Time:** see WebOODI

- **News, Lectures and Problems:**
  http://vitaly.neustroev.net/teach/spring-2019.html

Text Books

- **My course "Observational Astrophysics and Data Analysis"**
  http://vitaly.neustroev.net/teach/autumn-2018/

- *Astrophysical techniques* (5th Edition - 2008) – C.R. Kitchen: Taylor & Francis / CRC Press. ISBN 978-1-4200-8243-2.

- *Observational Astrophysics* (3rd Edition – 2012) – P. Léna, D. Rouan, F. Lebrun, F. Mignard, D. Pelat, Translated by S. Lyle: Springer. ISBN 978-3-642-21815-6.

- An Introduction to Astronomical Photometry Using CCDs (Oct. 22, 2006) – W. Romanishin: the latest version of this book can be downloaded from http://vitaly.neustroev.net/teaching/docs/wrccd22oct06.pdf

- http://vitaly.neustroev.net/teaching/docs/iraf.pdf

- http://vitaly.neustroev.net/teaching/docs/irafmanual.pdf

Methods of Observations

Imaging

Photometry

Spectroscopy

The Primary Tools of Astronomy

Light is the only thing we can work with. What can we do with it?

- Imaging – we can take "pictures" of the things we see. But pictures alone tend to lack the "quantitative" aspect that is needed for most serious scientific studies.

- Photometry – the technique that measures the relative *amounts* of light in different wavelength ranges. But these ranges are too wide to provide detailed information on the light's spectral distribution.

- Spectroscopy (spectrophotometry) – the most informative technique of light analysis, that measures how much light an object produces at various wavelengths of light.

Imaging

- Mapping the distribution of celestial sources on the sky in order to locate the position of source precisely – astrometry.

- Getting information on the source's form and that of its local environment.

Primary reduction and Data Analysis

- **Reduction** is the process of turning raw data into a calibrated product; anything after that is **Data Analysis.**

- Data you obtain from observations must be reduced; data you download from the archives may be partially reduced and calibrated.

Charge Coupled Device detectors

- CCDs – a replacement for photoplates. This was an astronomer's dream for decades;

- Found everywhere in optical and very near infra-red astronomy;

- The detector of choice at wavelengths from 4000 Å to 10000 Å;

- Robust enough to fly on space missions.

For more detail, see "Observational Astronomy – I"

CCDs: readout noise

- CCDs suffer from **readout noise** which has a variety of sources (in total, at least a few electrons).

CCDs: Interference Fringes

- In thinned CCDs there are interference effects caused by multiple reflections within the silicon layer, or within the resin which holds the CCD to a glass plate to flatten it.

- These effects are classical thin film interference (Newton's rings).

- Only visible if there is strong line radiation in the passband, either in the object or in the sky background.

- Visible in the sky at wavelengths > 700nm.

- Corrected by subtracting off a scaled exposure of blank sky.

- Fringing can dominate the noise in the redder photometric bands, or in narrow bands, and can sometimes force us back to using thick CCDs despite the loss in QE.

Image processing

- A CCD image is built up from three signal sources:
  - object: photons imaged onto each pixel of the CCD
  - dark current: thermal electrons collected in each pixel during the exposure
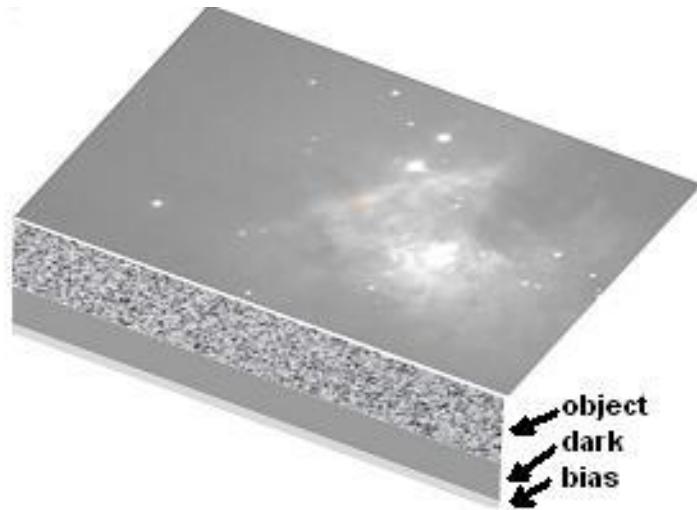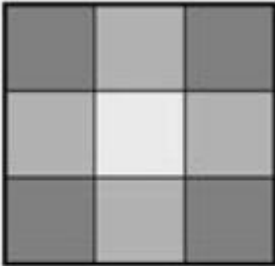 - bias: a low level electrical signal added to each pixel during image readout

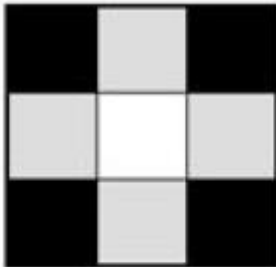# Image processing

□ Most processing steps must be carried out pixel by pixel

A simple operation on digital image data to subtract one frame from another.

Image processing

- **Darks:**

  - In order to remove the accumulated background due to thermal dark current, it is usual to take several "darks" which are images taken with the CCD camera shutter closed. These darks should be of the same exposure time and camera temperature as the object exposure to be dark subtracted.

  - It is best to take a set of dark images and then to combine them to get a "master" dark based on the average of the dark set.
    [Note: it is usual to "median combine"]

Image processing

- **Bias:**
  - In addition to thermal noise, each pixel charge will carry with it a fixed offset voltage value called the bias. Thus even if the output coming from the CCD were exactly zero electrons for every pixel, there would still be a signal that would vary from pixel to pixel in a repeatable fashion. An bias frame is one taken to determine this bias pattern.
  - Again, it is best to take a set of bias images and then to combine them to get a "master" bias based on the average of the bias set.

Image processing

- **Flat Fielding:**
  each pixel on the CCD may have a different sensitivity to incoming photons due to small variations in individual pixel dimensions and quantum efficiency. For precision photometry it is necessary to calibrate such pixel-to-pixel variations and this is the function of "flat fielding". There are several different approaches but the two that are applicable to most observatories are
  - Dome Flats: A uniformly illuminated target is installed in the dome or attached to the front of the telescope
  - Sky Flats: Images are taken of the sky which is assumed to be uniform in brightness over the (usually small) field of view of the CCD

Image processing

- **Flat Fielding:**
  - Take an exposure of a source which will uniformly illuminate each pixel of the CCD
  - Pixel sensitivity (and perhaps other effects) will be a function of wavelength so separate flat fields are needed for each filter
  - Use a long enough exposure time to fill pixels to more than 50% of their full well capacity

Image processing

- **Flat Field** types:
  - Twilight Flat: Exposures of the twilight sky (well away from horizon). Can correct for all of the types of sensitivity variations but the twilight sky is typically much bluer than the typical program object.

  - Dome flat: Exposure of a special target, usually mounted on the dome (such a target is completely out of focus and thus effectively uniform). Does well on Pixel to Pixel variations, poorly on vignetting.

  - Sky Flat: Median combination (to remove stars) of many exposures of the night sky
    Good correction of vignetting, poor correction of Pixel to Pixel variation. Hard to get enough photons on CCD – exposures may be very long.

Image processing

- **Flats:**
    - Take a number of dome or long exposure (5 to 10 seconds) twilight flats
    - Do Dark and Bias corrections for each image
    - Average or median combine to get high S/N image
    - Make a copy and smooth with a large area filter (25 x 25 pixels) to remove pixel to pixel variations
    - Divide high S/N image by smoothed image
    - Normalize to 1.00 at the center
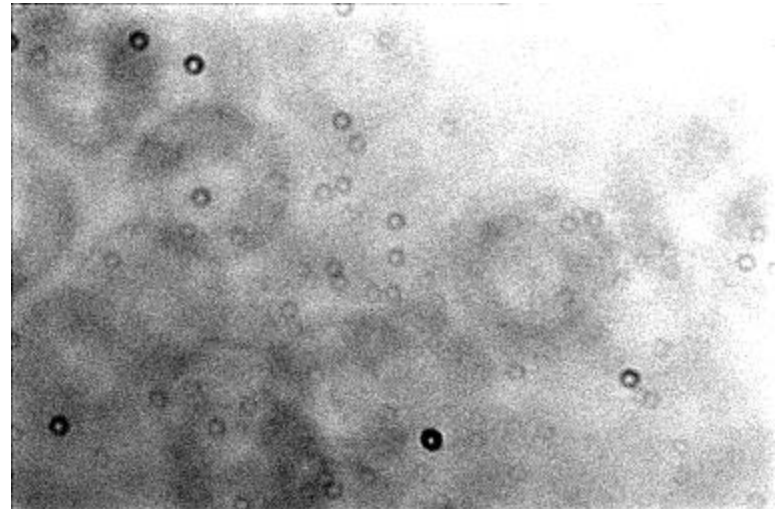   - Save as a 32- bit real image

- The result is your "pixel flat"

Image processing

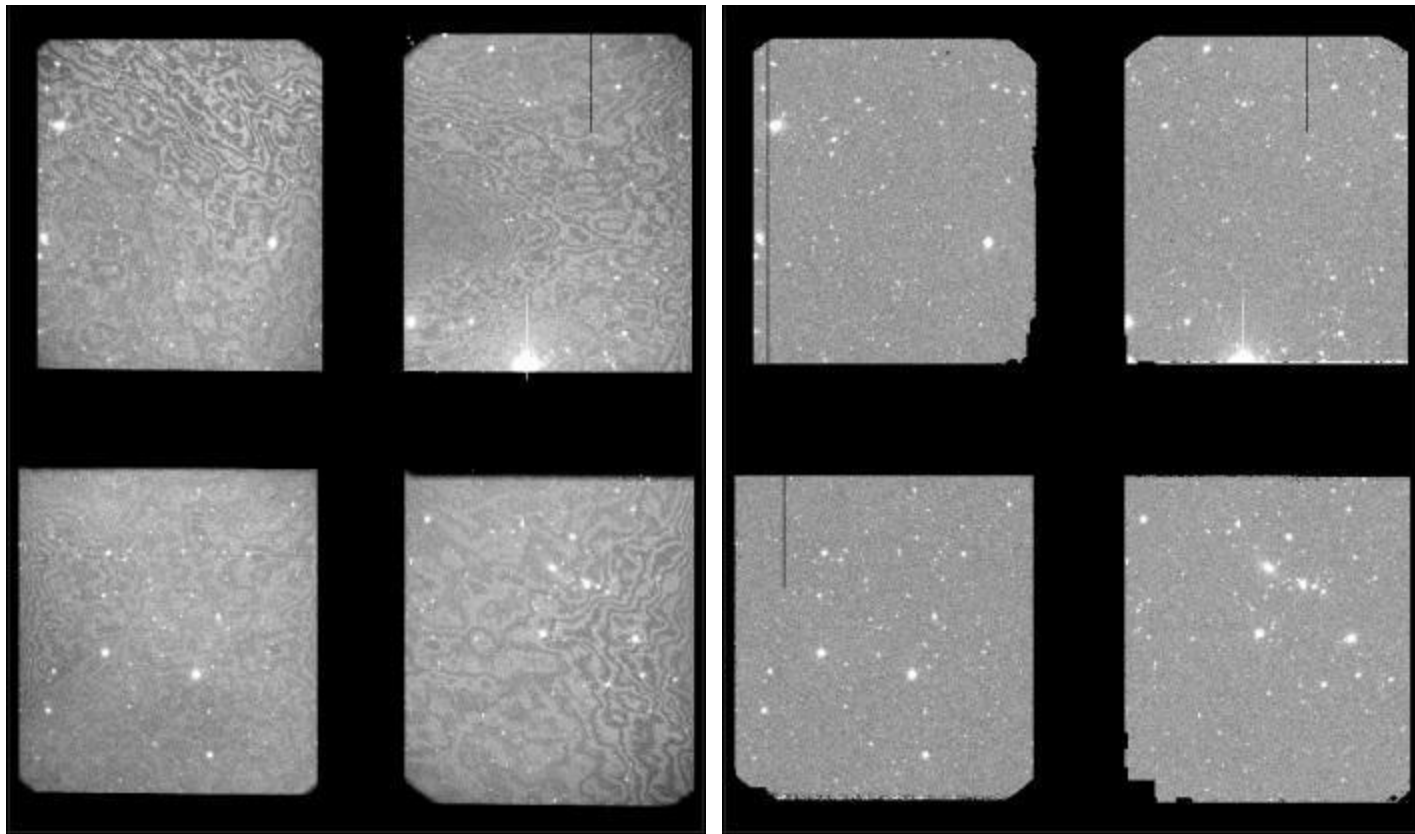- Cleaned image after dark, bias, and flat-field corrections

Image processing

□ **Summary:**

   ▪ Start with raw image

   ▪ Subtract dark and bias images

      ■ use high s/n "master bias" and "master dark" frames for best results

   ▪ Divide by flat field

      ■ use high s/n "master flats" for best results

      ■ flats must have dark and bias removed

Image processing

☐ **Do not forget: Cosmic Ray Events:**

Image processing

- There are several major computer packages:
  - IRAF
  - MIDAS
  - IDL (commercial)
  - Starlink