Mclean seminar sec.9.3-9.6

2024/11/01

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9.3 FLAT-FIELDING STARATEGIES

- **Pixel-to-pixel variations in sensitivity (QE)** arise due to
  - Physical differences between pixels
  - optical attenuation effects

  (e.g. microscopic dust particles on the surface of CCD)

- It is important to reduce pixel-to-pixel differences much further for astronomical observations.
  - Because such variations result in a “noisy” image
  - At a level corresponding to a few % of the sky brightness

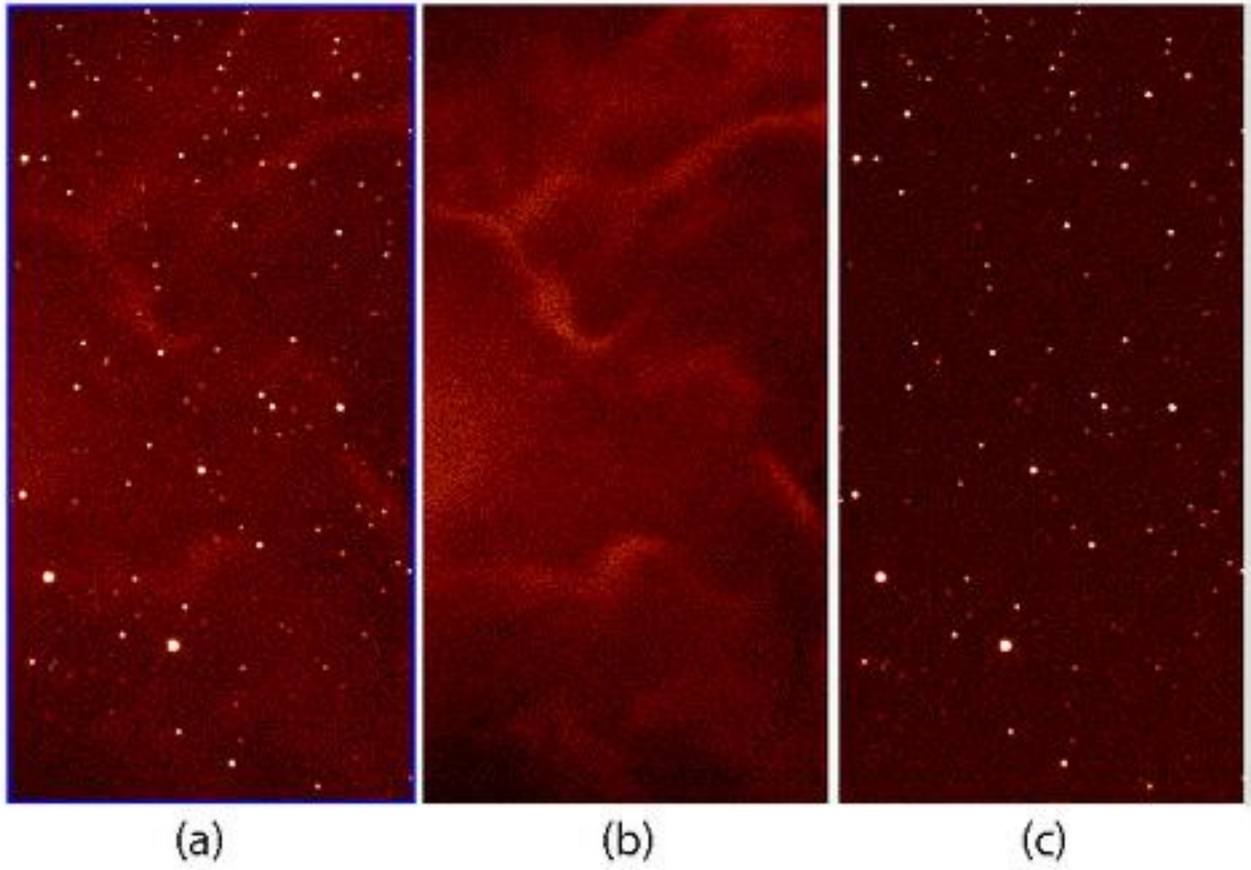
9.3 FLAT-FIELDING STARATEGIES

- a common practice to overcome pix-to-pix variations
  - To observe the inside of the telescope dome
  - To place a huge white card on the dome

- the screens are so close that the telescope is completely out of focus
  - The field is uniformly illuminated (i.e. **flat**)

- Dome illumination is usually done with tungsten lamps.
  - Tungsten lamps do not mimic the spectrum of the night sky.

9.3 FLAT-FIELDING STARATEGIES



https://astro-dic.jp/flat-field-correction/

A) an image before flat process
B) Flat pattern
C) An image after flat processing
(a is divided by b)

9.3 FLAT-FIELDING STARATEGIES

- For faint objects
  - It is the light of the sky that dominates.
  - It is better to try to **use the sky itself as a flat-field**

- For brighter objects
  - It is their own intrinsic color which matters.
    - inappropriate for using dome or sky
  - It is desirable to establish a set of narrow passbands for imaging
    - So as to limit the effect of color-dependent non-uniformity

9.3 FLAT-FIELDING STARATEGIES

- A simple arithmetic division pixel by pixel is required to remove pixel-to-pixel variations in sensitivity.

- I_{FF} : the uniform illumination of **the flat-field source** on a pixel in row i, column j
- η_{ij} : the quantum efficiency
- g : the conversion gain [electrons / DN]

$$\left(X_{ij}\right)_{FF} = \frac{1}{g}\eta_{ij}I_{FF}$$

- $\left(X_{ij}\right)_{FF}$: the observed signal from that pixel in **DN**

9.3 FLAT-FIELDING STARATEGIES

- The mean signal in the flat-field is obtained by averaging X_{ij} over all the rows and columns : S_{FF}

$$S_{FF} = \frac{1}{g}\eta_M I_{FF}$$

- η_M : mean QE

- For **the true image of the sky**

$$X_{ij} = \frac{1}{g}\eta_{ij} I_{ij}$$

- To eliminate the position-dependent QE response, we form the ratio of the image.

$$\frac{X_{ij}}{\left(X_{ij}\right)_{FF}} = \frac{I_{ij}}{I_{FF}}$$

9.3 FLAT-FIELDING STARATEGIES

$$\frac{X_{ij}}{\left(X_{ij}\right)_{FF}} = \frac{I_{ij}}{I_{FF}}$$

$$S_{FF} = \frac{1}{g}\eta_M I_{FF}$$

- Finally, we rescale this ratio to the mean of the flat-field to give

$$\frac{X_{ij}}{\left(X_{ij}\right)_{FF}} S_{FF} = \left(\frac{\eta_M}{g}\right) I_{ij}$$

- The flat-fielded, re-scaled image (left-hand) differs from the true image scene I_{ij}.

9.3 FLAT-FIELDING STARATEGIES

- Many flat-field exposures are averaged
  - to increase the accuracy of the flat-field itself
  - to remove from the flat-field various artifacts such as cosmic-ray events.
- The color of the flat-field should be as good a match as possible to that of the image scene
  - Because QE is a function of wavelength
- To detect the very weakest signals, more complex correction mean is necessary.
  - Obtaining a series of flat-fields at different exposure levels and determining the response of each pixel individually by means of a polynomial-fitting routine.

9.3 FLAT-FIELDING STARATEGIES

- For very high accuracy work or for observations on objects fainter than the night itself, **various systematic errors tend to dominate** over the expected random errors form photon arrival statistics.

- The first advance in counteracting low-level systematic errors
  - Drift scanning
  - Time delay and integration (TDI) (Teledyne page)
    - The CCD charge pattern is transferred slowly along columns, while the image from the telescope is physically scanned along with it **in precise synchronization**.

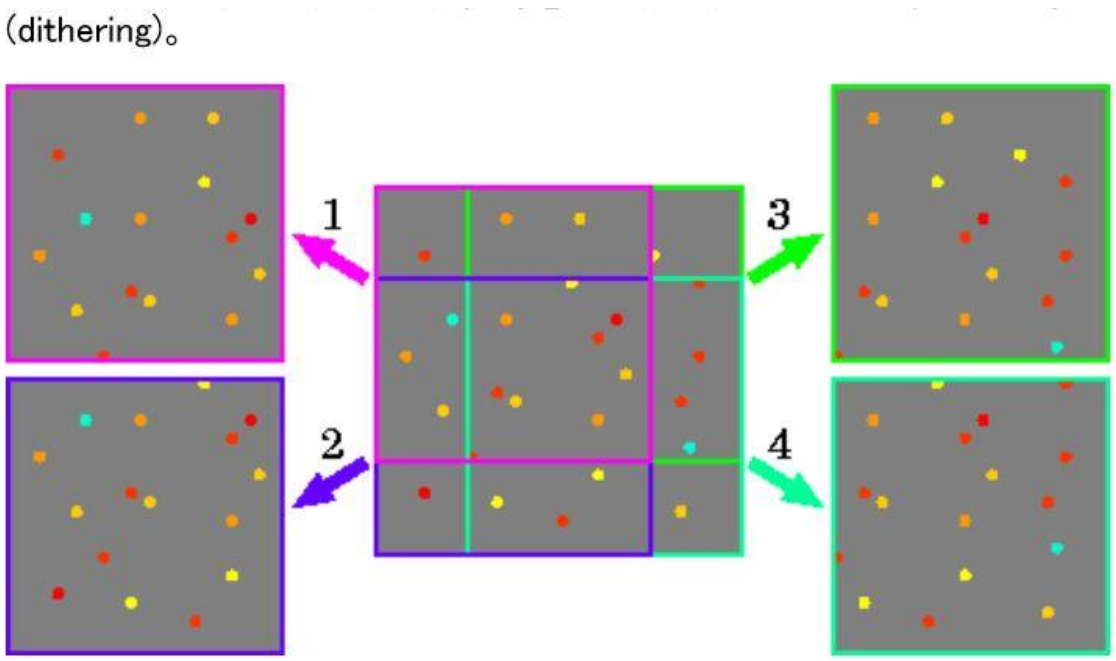
9.3 FLAT-FIELDING STARATEGIES

- The way to reduce systematic errors to a level of 0.1% of the night-sky background
  - Tony Tyson demonstrated
    - Theoretical limiting magnitude of 27^{th} in a 6-hour exposure for a 4m class telescope

- The dominant sources of error
  - The **mismatch in color** between calibration flat-field and actual night-sky background
  - **Interference fringing** due to unblocked night-sky emissions (for thinned CCD)

- Generation of a master flat-field and sky frame from the **object frames themselves** removes systematic effects to better than 0.03% of night sky. (天体画像そのものからフラット画像を生成)

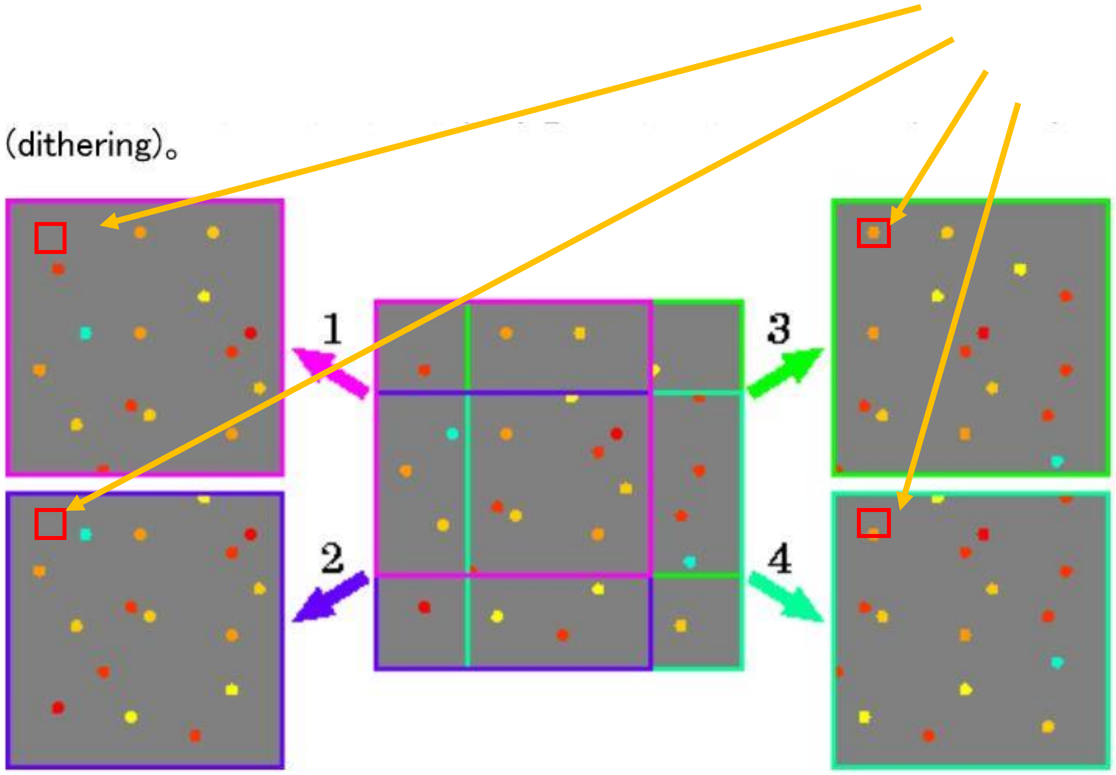
9.3 FLAT-FIELDING STARATEGIES



https://astro-dic.jp/dithering/

- This powerful technique (**dithering**) involves numerous observations of a piece of relatively blank sky with the telescope pointing to a slightly different position on the sky (displaced by 5-10 arcsec) for each exposure.
  - Positions can be chosen randomly or in a simple pattern,
  - But it is best not to repeat the pattern exactly.

9.3 FLAT-FIELDING STARATEGIES



https://astro-dic.jp/dithering/

1. The sequence of dithered exposures is examined
2. The frequency histogram examined
3. One signal value (or a small range) will turn out to **the pure night sky background**

(矢印のpixelに天体が載っていたり、載っていなかったりする。画像枚数だけ、pixelカウントを調べるとカウントの中央値がbackgroundに相当)

9.3 FLAT-FIELDING STARATEGIES

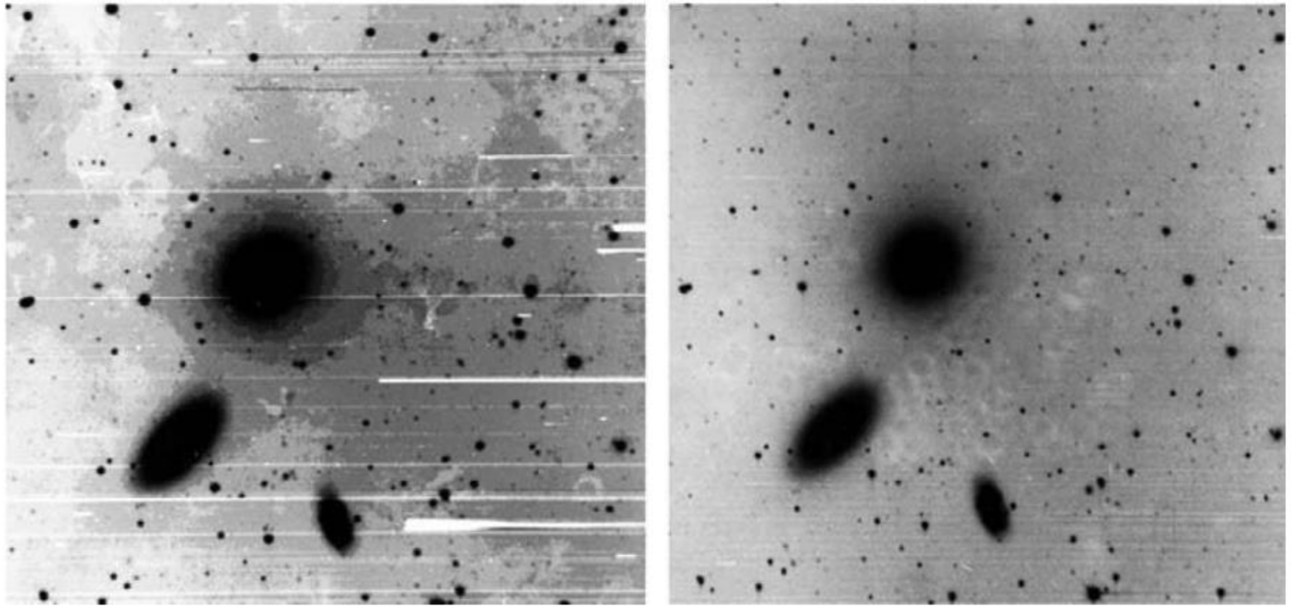


Figure 9.8. (a) A raw CCD image with many defective pixels; (b) same image flattened by using "median sky flats" by shifting the images in a "dither" pattern. Credit: Harold Ables, U.S. Naval Observatory.

- One disadvantage of dithering
  - It will not work on object frames which are too crowded
    - a large galaxy
    - a large nebula
    - A centrally condensed cluster of stars
  - Unless much larger moves are made.
  - →A combination of dome flats and sky flats is often used.

9.3 FLAT-FIELDING STARATEGIES

- It is essential to normalize the various flat-fields **before** applying a median-filtering algorithm.
  - because a drift will affect the calculation of the median value.

- It is very important that any additive effects which do not vary with sky brightness should be removed **before scaling**.

- Additive effects
  - Electronics pattern noise (bias effect)
  - Charge skimming and trapping
  - Interference fringes
  - LED activity

9.3 FLAT-FIELDING STARATEGIES

- Multiplicative effect
  - QE variations across the sky
  - Transmission of optics and coatings
  - Thickness variations of thinned arrays and CCDs

- An appropriate steps for reduction and calibration of raw images
  1. Subtract bias and bias structure (9.2)
  2. Subtract dark (9.2)
  3. Divide by flat-field (9.3)
  4. Subtract fringe frame (sky subtraction) (9.4)
  5. Interpolate(内挿する) over bad pixels ：a bad pixel map is needed.
  6. Remove cosmic-ray events ：identify non-star-like point sources.
  7. Registration of frames and median filtering

9.4 FRINGES AND SKY EMISSION

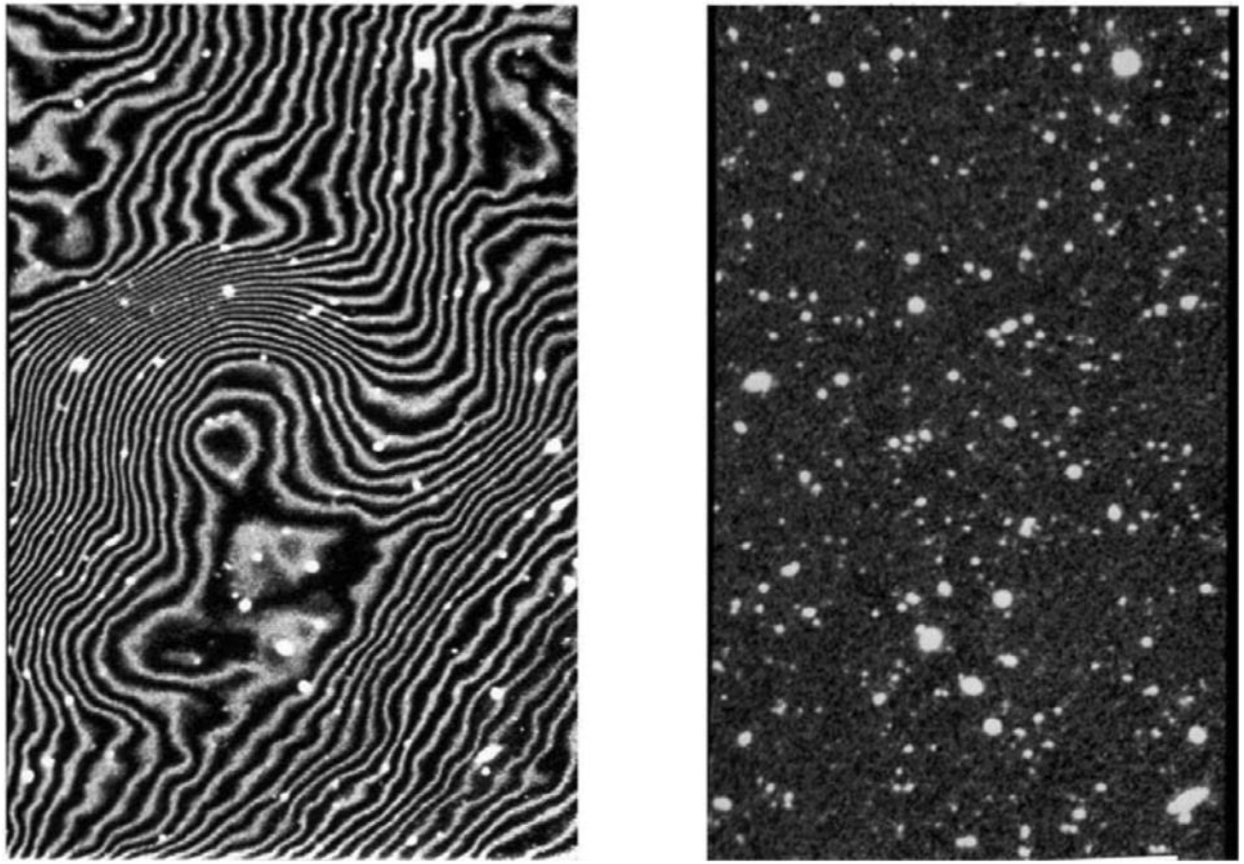


Figure 9.9. (a) A severe fringe pattern due to night-sky emission lines on a deep 4 m telescope exposure with a thinned, back-illuminated CCD. (b) The same field after processing to remove the fringes.

- Near-IR arrays can show significant fringe patterns in narrow-band work in the case of backside-illuminated CCD.
  - caused by OH emission lines
- The left figure shows 500s CCD exposure in a far-red band on a 4m telescope before and after fringe removal.

9.4 FRINGES AND SKY EMISSION

- Fringe removal can be performed by “adaptive modal filtering”
  1. Computes the **absolute difference between the mean and the median** of values associated with a pixel over all images in a set
  2. Rejects deviant values
     - until this difference falls below a certain value

       or
     - until a maximum number of values have been rejected

- This technique fails if large or extended objects are seen.
- The introduction of deep-depletion CCDs and improved anti-reflection coatings has drastically reduced the problems.

9.5 LINEARITY

- It is usual that the **the output voltage** from a CCD **is proportional to the amount of light** falling on the CCD to very high accuracy.

- Linearity curves are usually derived by observing a constant source with various exposure times.

- Non-linear behavior from CCDs can occur if incorrect voltages are applied.
  - The output transistor is operating in its normal linear regime
  - Use the correct clock voltages to ensure the CCD pixel is fully inverted.
  - Use a CCD with MPP build in.

9.6 PHOTOMETRY

- Relative brightness ⇔ absolute amount of radiant energy reaching the Earth
  - A later method is needed if we are to understand the distribution of mass or energy in the Universe.

- Monochromatic flux (W m^{-2} Hz^{-1} / W m^{-2} μm^{-1})
  - Integrating the specific intensity over the angular size of the source
- Magnitude
  - Relative monochromatic flux of a source
  - $m = m_0 - 2.5 logF + 2.5 logF_0$
  - m_0, F_0 : reference
  - There are different magnitude systems for different sets of spectral bands
  - Vega system / AB system

9.6 PHOTOMETRY

$$m = m_0 - 2.5logF + 2.5logF_0$$

- Vega system
  - Vega is assigned 0 magnitudes in every passband.
- AB system
  - F_0 is the same for all wavelengths and passbands.
  - $m_\nu = -2.5logF_\nu - 48.6$ (F is in frequency units)
  - $m_\lambda = -2.5logF_\lambda - 21.1$ (F is in wavelength units)

- Bolometric magnitudes
  - Gives a magnitude corresponding to the total flux integrated over all wavelengths
  - Zero point : $F_b = 2.52 \times 10^8$ W m^{-2}
- Color indices
  - the difference between magnitudes at the two separate wavelengths (e.g. BV , UB)

9.6 PHOTOMETRY

- A UBV system is invented by Johnson and Morgan
- A modified UBVRI system

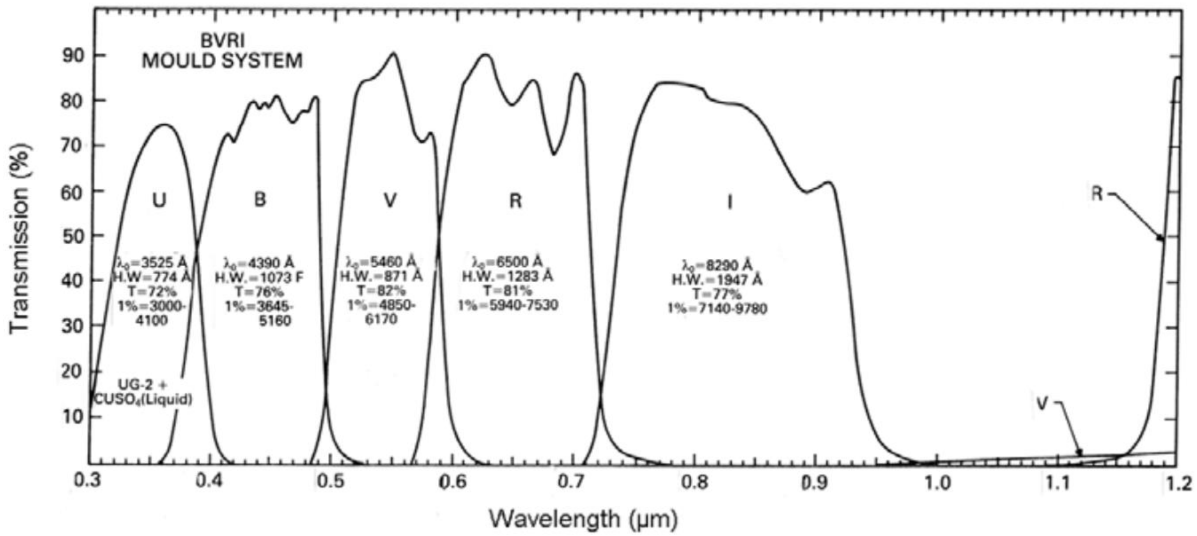


Figure 9.10. Standard filter bandpasses used with CCDs: the Mould system.

Table 9.2. A summary of the major photometric systems.

Kron–Cousins System		*Thuan–Gunn System*	
Wavelength (Å)	*Width* (Å)	*Wavelength* (Å)	*Width* (Å)
U 3,600	700	u 3,530	400
B 4,400	1,000	v 3,980	400
V 5,500	900	g 4,930	700
R 6,500	1,000	r 6,550	900
I 8,000	1,500	i 8,200	1,300

9.6 PHOTOMETRY

- A red leak in the B filter
- The consequences of red leaks depend on the "color" of the illumination and the sensitivity of the detector at longer λ
- Calibration is needed.

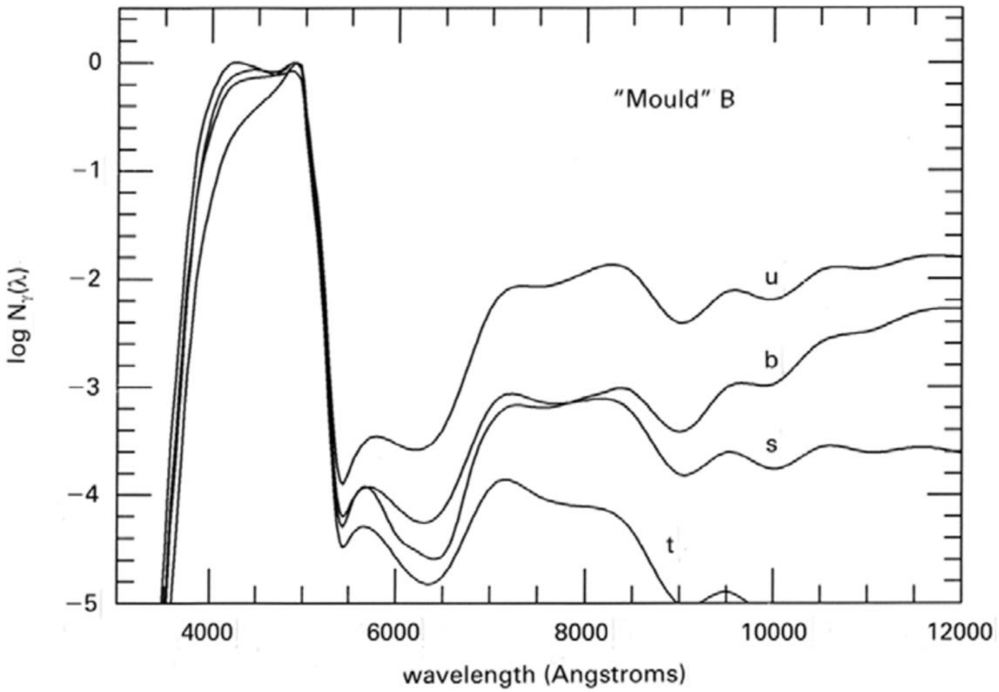


Figure 9.11. The effect of (accidental) imperfect blocking is a "leak" of red photons to which the CCD is very sensitive. The consequence depends on the spectrum or color of the source; *b* and *u* are the balanced (filtered) and unbalanced artificial lamps illuminating the telescope dome, *s* is a typical solar spectrum, and *t* is the twilight sky which is quite blue.

9.6 PHOTOMETRY

- SDSS filters
  - wider bands to ensure high efficiency for faint-object detection
  - Covers the entire range where a CCD is sensitive (0.3-1.1μm)

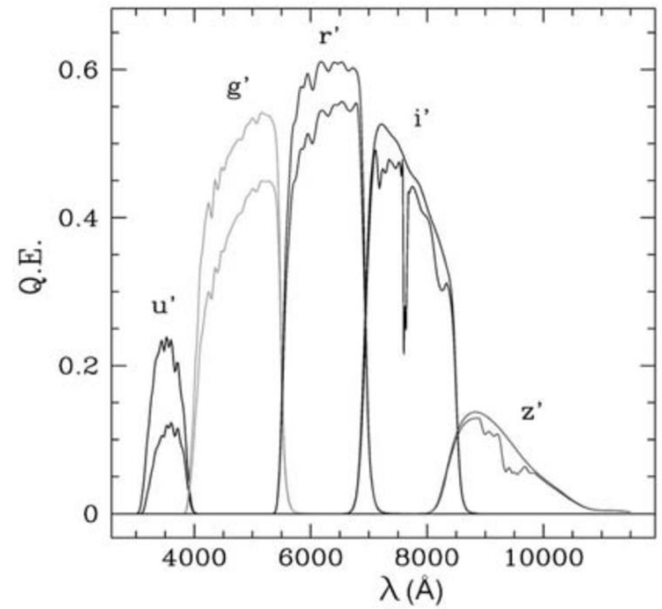


Figure 9.12. The Sloan Digital Sky Survey filter set.

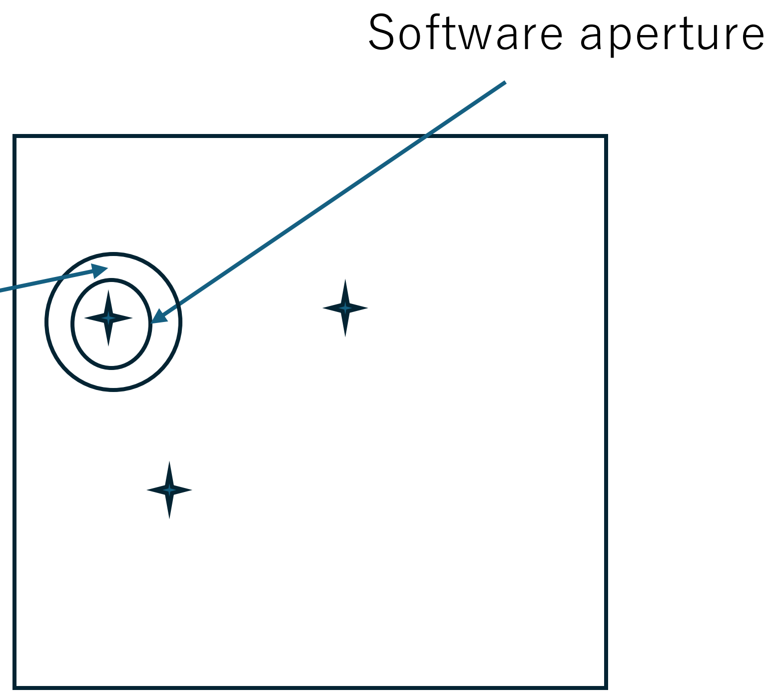
Table 9.3. Sloan Digital Sky Survey passbands and sensitivity limits.

Property	u'	g'	r'	i'	z'
λ_{eff}	355.1 nm	468.6 nm	616.5 nm	748.1 nm	893.1 nm
Width	56.0 nm	137.7 nm	137.1 nm	151.0 nm	94.0 nm
Limits	22.0	22.2	22.2	21.3	20.5

9.6 PHOTOMETRY

- Two procedures for obtaining photometric information from CCD images
  - A) Aperture photometry
  - B) Profile fitting

- <u>Aperture photometry</u>
  - Imaginary aperture (software aperture) is adopted
  - It is difficult to adjust the size and position of the aperture
  - Properties to estimate
    - the background level : within an annulus
    - The center of the optical image
    - The shape of the image



an obtained image

9.6 PHOTOMETRY

- Profile fitting : Point Spread function (PSF) fitting
  - Modeling the image rather than summing over the image.
- Gaussian profile

$$I(r) = I_0 e^{-r^2/2\sigma^2}$$

1. Programs like DAOPHOT (Stetson, 1987) will identify the bright stars.
2. Deduce their Gaussian profiles and subtract those profiles away
3. Thereby revealing fainter stars.

- a convenient term

$$FWHM = 2.35\sigma$$

9.6 PHOTOMETRY

- Four important issues to be considered for fitting
    1. passband mismatch of the filters, including narrow-band filters
    2. Red/infrared "leaks" in the filter which complicate flat-fielding
    3. The finite opening and closing times of electromechanical shutters
    4. Changes in the atmospheric attenuation or "airmass" for long on-chip integrations
- 1 and 2 need to be eliminated by design
- shutter timing (3) errors are mainly relevant for large iris-type shutters that require a finite time (δt) to close,
    - The pixels at the center experience a longer exposure time.
    - For large arrays, the error could be ~0.1s
- Bonn shutter alleviates the problem.
    - https://www.youtube.com/watch?v=d2dZQkqWIOQ

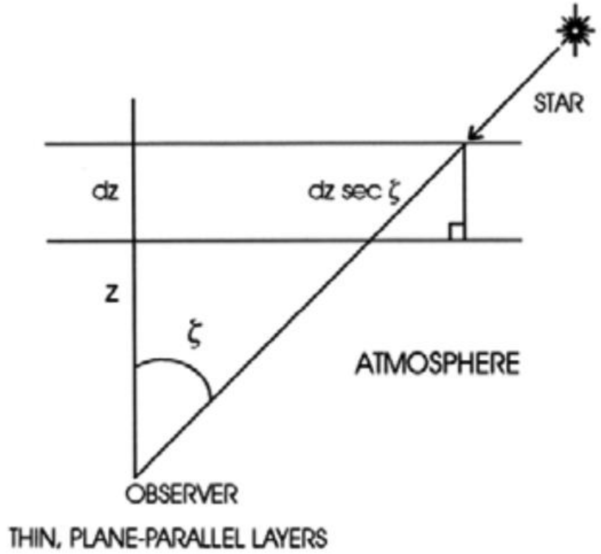
(https://www.printables.com/model/566642-iris-shu

9.6 PHOTOMETRY

- **Photometric values must be compared or calibrated against well-measured "standard" sources.**

- Photometric standard stars must be observed over a wide range of airmass.

$$airmass(X) = \sec(90° - \zeta) = \frac{1}{\cos(90° - \zeta)}$$

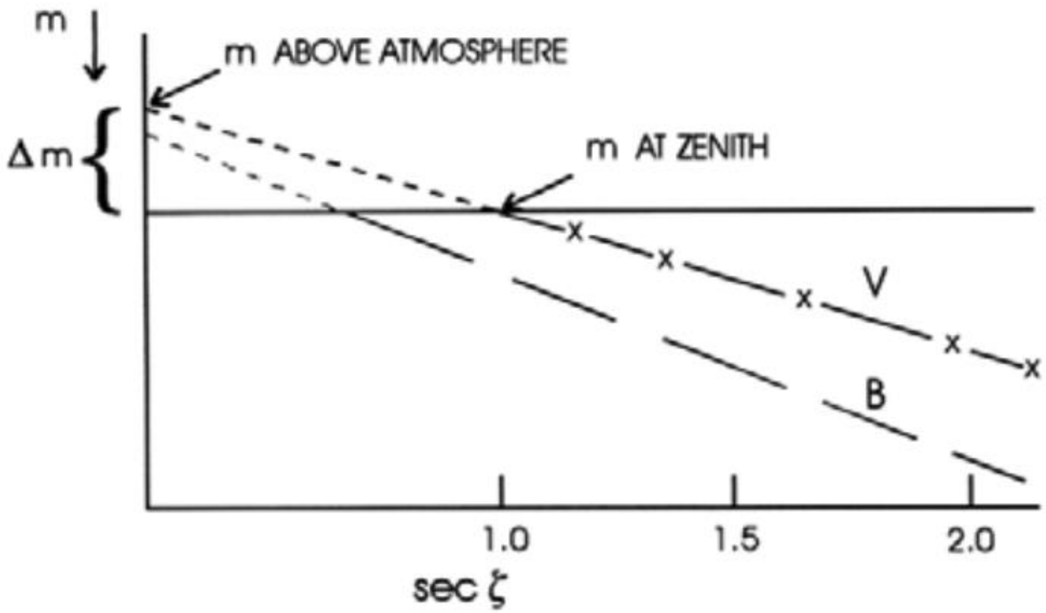


9.6 PHOTOMETRY

- the observed mag at ζ : $m(\zeta)$
- The difference between the true mag and mag which would be observed at ζ : α

$$m = m(\zeta) - \alpha_\lambda \sec(\zeta)$$

- True mag and α_λ can be calculated by plotting the $m(\zeta)$ against airmass (X=$\sec(\zeta)$).



9.6 PHOTOMETRY

- The instrumental magnitudes

$$IM = -2.5\log(counts/s)$$

- The parameters to be determined
  - the “zeropoint”
  - the “color equation” relating the CCD photometric system to the older photoelectric systems
  - the “extinction” factor or light-loss through the Earth’s atmosphere per unit airmass

$$m = -2.5\log(counts/s) - \alpha * (airmass) + \beta * (color) + ZP$$

- X (airmass) is changing for a long exposure.
  - DAOPHOT package

$$\bar{X} = \frac{X_0 + 4X_{1/2} + X_1}{6} + O(e)$$

- At the beginningX_0 , midpoint X_1/2 , the end X_1
- O(e) is a small error of about 1part in 10,000