Astronomical Techniques I

Lecture 10

Yogesh Wadadekar

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Fundamental rule of astronomical error

For discrete number statistics use Poisson, for continuous number statistics or where mean > 30 use Gaussian.

Properties of Variance

If $u = f(x, y)$ is a function of two random variables, x and y, then we can propagate the uncertainty in x and y to u as follows:

$$\sigma_u^2 = \sigma_x^2 \left(\frac{\partial u}{\partial x}\right)^2 + \sigma_y^2 \left(\frac{\partial u}{\partial y}\right)^2 + 2\sigma_{xy}^2 \left(\frac{\partial u}{\partial x}\right)\left(\frac{\partial u}{\partial y}\right)$$

where the *covariance* of x and y is defined as

$$\sigma_{xy}^2 = \frac{1}{M}\sum_{i=1}^{M}[(x - \bar{x})(y - \bar{y})]$$

if x and y are independent variables the $\sigma_{xy} = 0$

Properties of Variance

$$Var(kx) = k^2 Var(x)$$

$$Var(x + y) = Var(x) + Var(y) + 2\sigma_{xy}^2$$

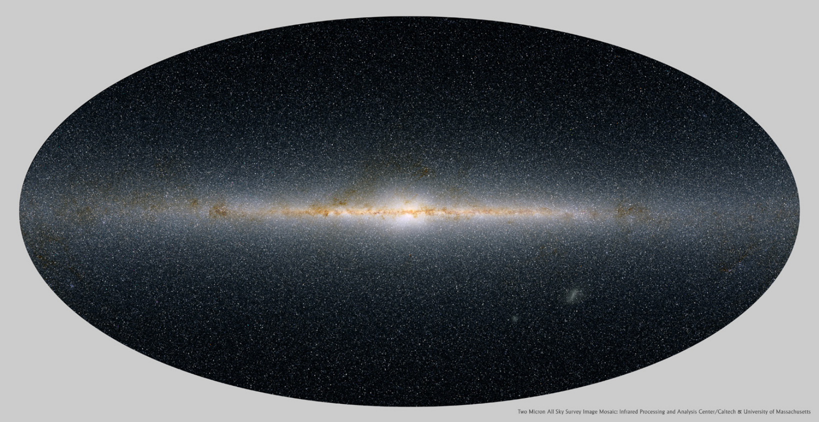
$$Var(xy) = y^2 Var(x) + x^2 Var(y) + 2xy\sigma_{xy}^2$$

to know more....

An Introduction to Error Analysis by *John Taylor*

Signal to noise ratio

In crude terms signal to noise ratio is the ratio of the quantity we are interested in to all the quantities we are not interested in, one person's signal is another person's noise.



Definition of S/N ratio

$$\frac{S}{N} = \frac{\bar{x}}{s_{\bar{x}}}$$

Signal to noise ratio

$$\frac{S}{N} = \frac{N_*}{\sqrt{N_* + n_{\rm pix}(N_S + N_D + N_R^2)}}$$

Why is read noise squared in the above equation?

Three regimes possible

- Source noise dominates
- background noise dominates
- read noise dominates

When source noise dominates

For bright sources, $N_* >> n_{\rm pix}(N_S + N_D + N_R^2)$ so,

$$\frac{S}{N} = \frac{N_*}{\sqrt{N_*}} = \sqrt{N_*}$$

This condition is a good definition of a bright source!

When background noise dominates

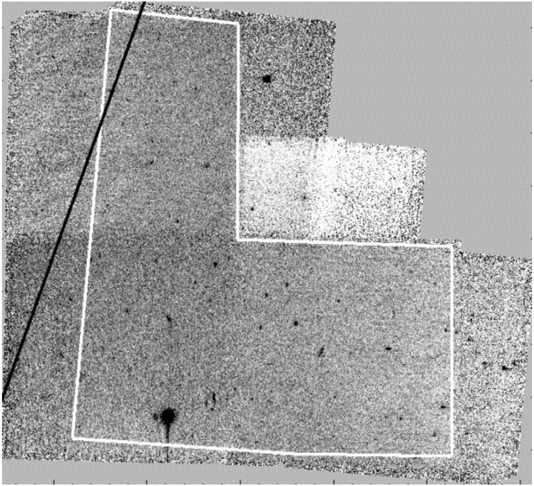
For faint sources, $N_* \sim n_{\rm pix} N_S$ so,

$$\frac{S}{N} = \frac{N_*}{\sqrt{2 n_{\rm pix} N_S}}$$

Why does background variance appear twice?
How to improve S/N?

When read noise dominates

- happens when source is faint and background is low. Solution: increase exposure time



Time dependence

One can write $N_* = n_* t$ and $N_S = n_S t$ and $N_D = n_D t$. In source and background dominated regimes $\frac{S}{N} \propto \sqrt{t}$

Meaning of S/N

SNR measures how well an object is detected and characterized.

- $S/N = 2 - 3$: object barely detected
- $S/N = 5$: object detected, can start to believe what one sees
- $S/N = 10$: can start to do quantitative measurements
- $S/N = 100$: excellent measurements.

As N (noise) is the error on the measurement, 1 / (S/N) is the relative error on the measurement:

- $S/N = 100$: measurement at 1% (0.01 mag)
- $S/N = 10$: measurement at 10% (0.1 mag)
- $S/N = 5$: measurement at 20% (0.2 mag)

Error in magnitudes

$$\sigma_{\text{magnitudes}} = \frac{1.0857\sqrt{N_* + n_{\text{pix}}(N_S + N_D + N_R^2)}}{N_*}$$

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Exposure time calculator for IFOSC and sky background estimation

Pavan Chakraborty[1,2,*], H. K. Das[1], and S. N. Tandon[1]
[1] *Inter University Center for Astronomy and Astrophysics (IUCAA), Post Bag 4, Ganeshkhind, Pune 411 007, India*
[2] *Assam University, Silchar 788 011, Assam, India*

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Photometric night

To correct for the extinction in Earth's atmosphere, we must make observations on nights that are perfectly clear and that have no changes in the basic atmospheric conditions, such as humidity or atmospheric pressure, during the the night.

Sources of extinction in UVOIR

- Rayleigh scattering
- aerosol scattering
- molecular absorption (“telluric bands”) by oxygen, ozone (in UV) and water (in IR).

Air Mass

Earths atmosphere can be approximated as a flat slab of air. That is, initially we ignore the curvature of the atmosphere.
With the atmosphere being treated as a flat slab, we can relate the length of any path through the atmosphere to the minimum distance, which is the path straight up toward the zenith. If we call the minimum path Z, any other path length, L is given by $L = Z/\cos z = Z \sec z$, where z is the zenith angle. The minimum path Z is called 1 Air Mass. The quantity $\sec z$ gives the actual path through the atmosphere in units of Air Mass. But real atmosphere is *curved*.

Extinction

Consider a thin layer of the atmosphere, dl. Because of the extinction that takes place in that layer, the light is diminished going through it. This can be written

$$df = -fkdl$$

where f is the flux of light at the top of the layer, and k is the extinction in the layer.

$$df/f = -kdl$$

Integrating

$$ln(f_g/f_0) = -kL \Rightarrow f_0/f_g = e^{kL}$$

Extinction

$$mag_g - mag_0 = 2.5\log_{10}(f_0/f_g) = 2.5kL\log_{10} e$$

Defining $k' = 2.5k\log_{10} e$ and using $L = \sec z$

$$mag_g = k'\sec z + mag_0$$

Extinction varies with wavelength

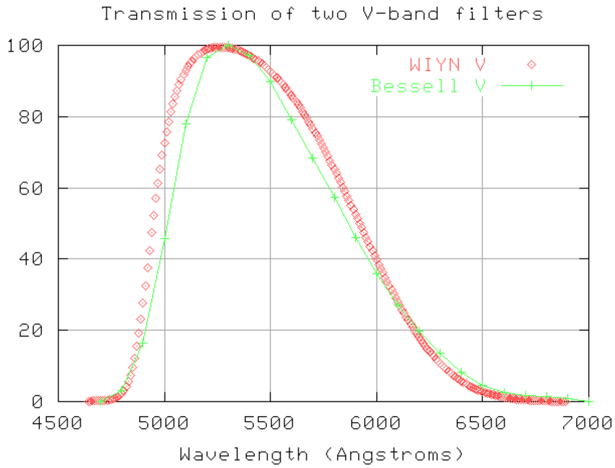
What real life experience tells you this?

- k' must be determined separately for each filter
- $k' \propto 1/\lambda$ use this if extinction is not available in all filters.

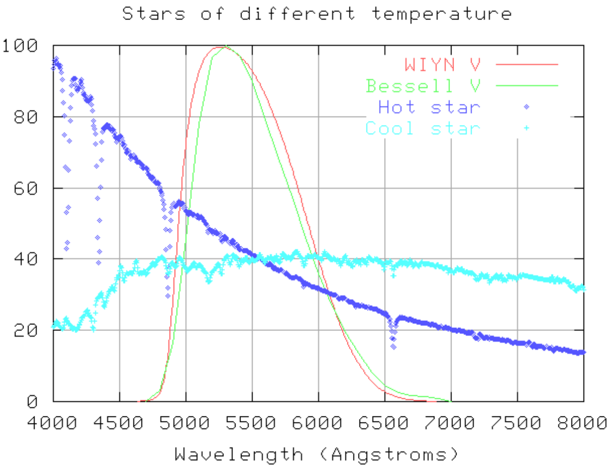
Corrections for galactic extinction

Dust Extinction Service based on Schlegel, Finkbeiner & Davis 1998.
http://irsa.ipac.caltech.edu/applications/DUST/

Ideal versus real filter



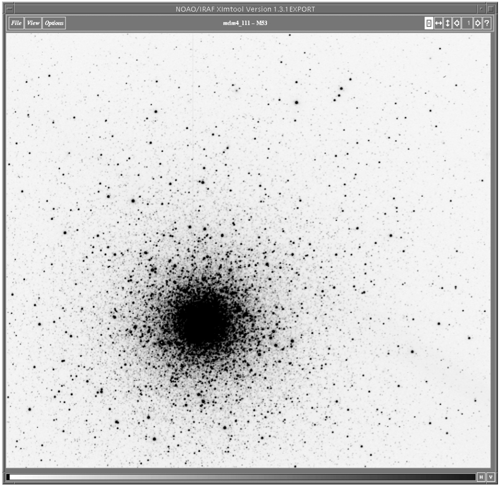
The color term



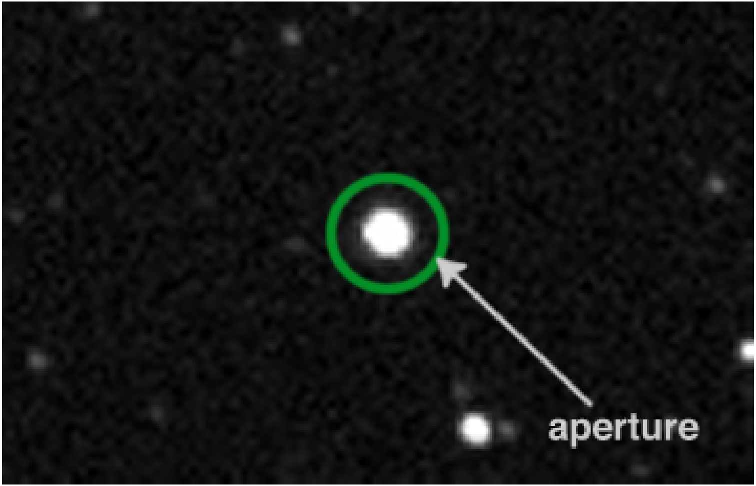
Measuring flux in DN

- PSF/Galaxy profile photometry
- aperture photometry

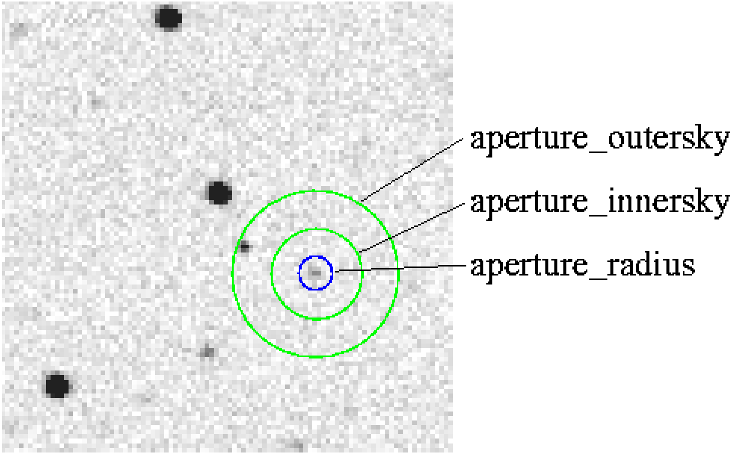
Crowded field photometry



Aperture photometry



Aperture photometry and sky estimation



DN to magnitude conversion - Zero Point

The zero point of an instrument, by definition, is the magnitude of an object that produces one count (or data number, DN) per second. It is the setting of the zeropoint, then, which determines the connection between observed counts and a standard photometric system (such as Gunn *ugriz*), and in turn between counts and astrophysically interesting measurements such as the flux incident on the telescope. The magnitude of an arbitrary distant galaxy producing DN counts in an observation of length EXPTIME is therefore:

$$m = -2.5 \times \log_{10}(\mathrm{DN} \,/\, \mathrm{EXPTIME}) + \mathrm{ZEROPOINT}$$

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$m = -2.5 \times \log_{10}$(DN / EXPTIME) + ZEROPOINT + colorterm + extinction + galactic extinction

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$m = -2.5 \times \log_{10}$(DN / EXPTIME) + ZEROPOINT + colorterm + extinction + galactic extinction + K correction + cosmological dimming + intrinsic dust correction + intergalactic attenuation + aperture correction + bad pixel correction

for more details

Astronomical photometry by Henden & Kaitchuk
Introduction to astronomical photometry by Budding & Demircan