ASTR 535

Observational Techniques

Fall 2023

Uncertainties and Error Propagation

Topics 8/31

- APO trip : 10/29-10/31, rough schedule
- Questions
- Probability distribution functions
- Application to observational uncertainties

- Exposure time calculator: signal equation

Questions

Probability distribution functions

- What is a PDF, esp in the context of observational techniques?
  - What are some statistics that are often used to characterize a PDF?
- Population statistic vs sample statistics
  - Robustness and efficiency

Poisson distribution

- What is it a function of? What is the analytical form?
- What does it look like?
- What is the mean?
- Standard deviation?
- What is the application in observational techniques?

Poisson statistics

- You collect 10000 photons with an instrument on the 3.5m. What's the uncertainty (standard deviation)?
- You collect 10000 photons with an instrument on the 0.6m. What's the uncertainty (standard deviation)?
- You collect 100000 photons with an instrument. What's the uncertainty? Is the better or worse than the 10000 photon case?
- What fractional uncertainties (uncertainty / signal) do these correspond to?
- You collect 100 photons/second with some instrument. How long to you have to expose to reach the same fractional uncertainty as the first two above?

Gaussian (normal) distribution

- What does it look like?

- What is the mean?

- What is the standard deviation?

- What is the application in observational techniques?

Importance of uncertainties: applications

- Exposure time calculation
- Probability of single measurements
  - Gaussian: error function and typical values
- Probability of a series of measurements
  - Chi^2 and reduced chi^2
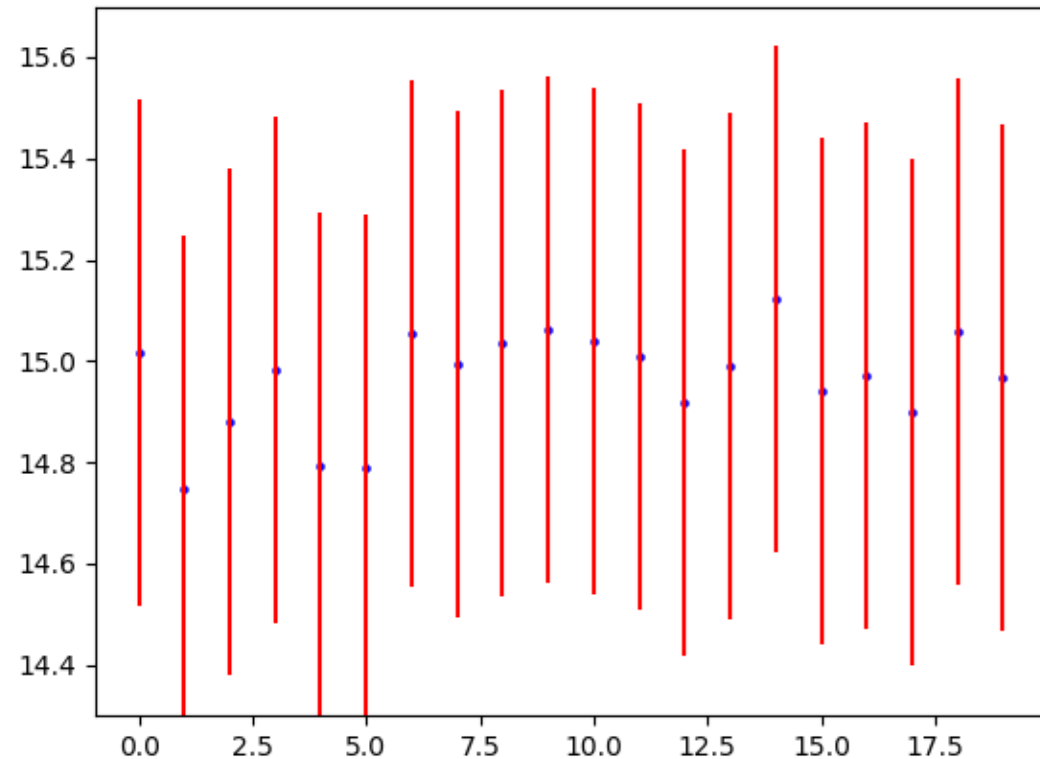
Exposure time calculator

- Given information about source (magnitude and SED) and observational setup (telescope, instrument, etc.), how long do you have to observe to achieve a desired fractional uncertainty?
  - What photon flux does the source produce?
  - How long to achieve desired fractional uncertainty? Depends not only on source photon flux, but also on:
    - Sky flux
    - Instrumental noise

- Start with first piece: what photon flux does the source produce?
  - Spectroscopic and photometric applications

Examples

- Class problem notebook
- https://github.com/APOExposureTimeCalculator/APOExptime) (compiles many data files relevant for APO)

Topics 9/5

- Questions
- Noise equation
- Propagation of uncertainties

Noise equation

- Without looking it up, what is the "noise equation" that allows you to calculate the S/N of some data?

$$\frac{S}{N} = \frac{S}{\sqrt{S + AB + Npix \ \sigma_{rn}^2}}$$

How would you factor out the exposure time, if readout noise is negligible?

$$\frac{S}{N} = \frac{S'T}{\sqrt{S'T + AB'T}}\sqrt{t}$$

How would you use this for your exposure time calculator?

What would you need to do to include readout noise?

Astronomical measurements

- Uncertainty, noise, fractional uncertainty, and S/N
- Standard noise sources
  - Source
  - Background : note area term, and importance of dark skies AND good image quality
  - Readout noise
- Noise equation, assuming perfect background subtraction
- What is typical area over which we need to integrate source (and background)?
- Where do we encounter different limiting cases?
  - Broad band imaging (optical and near-IR), narrow-band imaging, spectroscopy
- Limiting cases
  - Signal-limited, background-limited, readout noise-limited
  - Behavior with signal, exposure time and telescope aperture

Error propagation

- Without looking it up, what is the general equation for error propagation?

Problems: noise equation

See Canvas assignment

Problems: error propagation

See Canvas assignment

Topics 9/7

- Questions
- Averaging and splitting
- Random and systematic uncertainties
- Digital photometry
- Exposure time calculator

Exposure time calculator

- Code comments
- Code organization
  - Group subdirectories
  - Code subdirectory
    - using import
    - Using PYTHONPATH
    - Example:
      - code in XXX/a535/holtz/exptime/
        - Say your code is in expcalc.py
      - setenv PYTHONPATH = XXX/a535/holtz (csh) or export PYTHONPATH=XXX/a535/holtz (bash)
      - From exptime import expcalc
- Code development
  - Generalize to reading throughput files with named columns
  - Add routine to calculate noise (or S/N) given exptime
  - Add routine to calculate exptime given S/N
- Code testing and validations

Splitting and averaging measurements

See canvas assignment

Exposure time calculator II

See Canvas assignment