ASTR21200

Observational Techniques in Astrophysics
Lecture 4

Bradford Benson

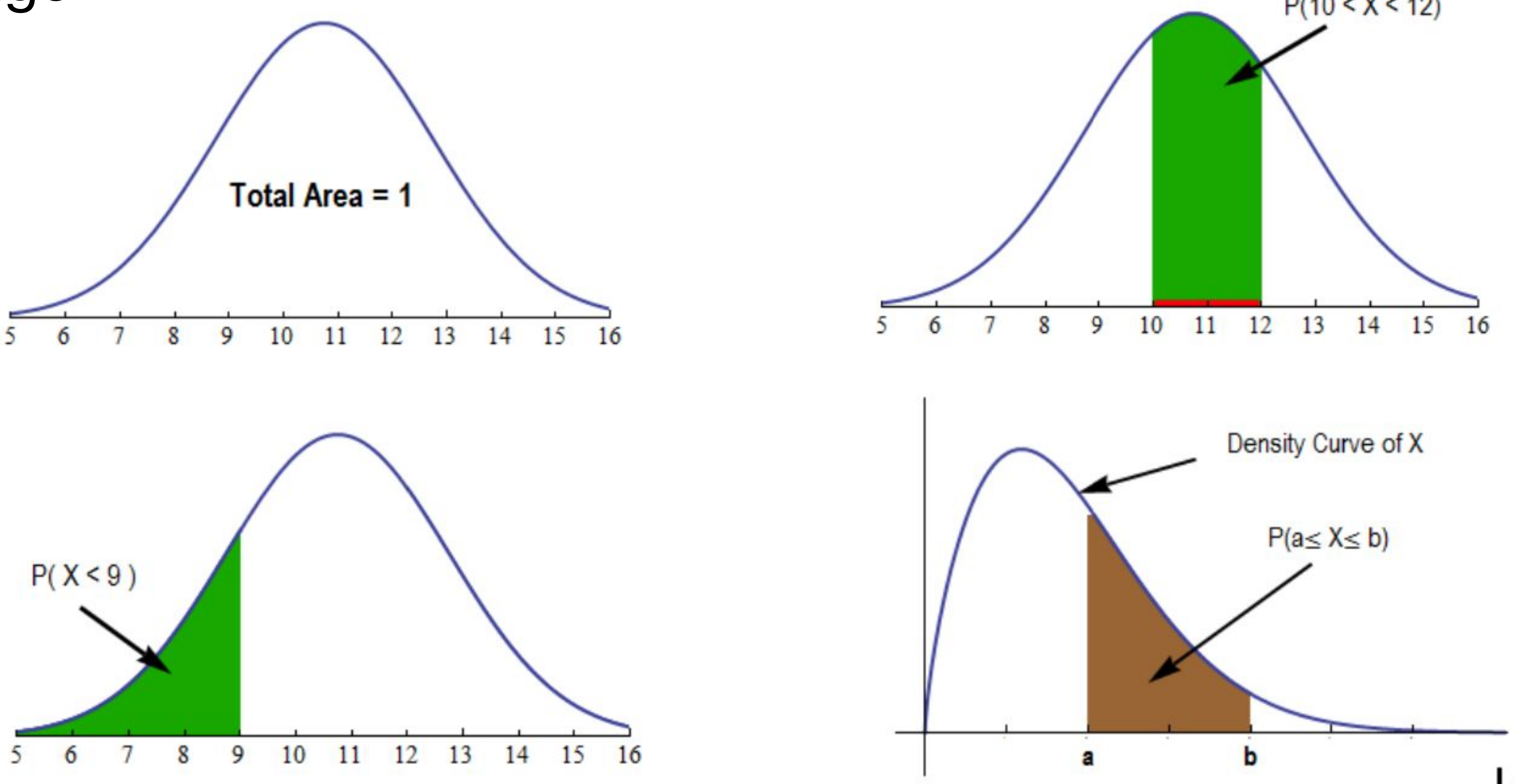
For Next ~Week

- Homework 2 is due on Tues Apr-8 at 5pm, right before class
    1. On class schedule on wiki:
    2. Submit on Canvas
- Office hours:
    1. Logan: Friday 3:30-4:30pm (ERC 583)
    2. Emory: Monday: 3-4pm (KPTC 320)
    3. Brad: Tuesday: 11am-12 (ERC 589)
    4. Marc: Tuesday: 3-4pm (ERC 524)

- Today's Class:
    1. Intro to Statistics useful for Lab-1
    2. Intro to Stone Edge Observatory (SEO), and quick tutorial
- Next Tuesday:
    1. First-half: Lecture providing more detailed intro to SEO, by Marc Berthoud
    2. Second-half: Break into lab-groups and start Lab-1

Probability Distributions

- Probability Distribution: Describes the expected (or measured) distribution of measurements.
- Can integrate a probability distribution over range of values to find a probability to be in that range



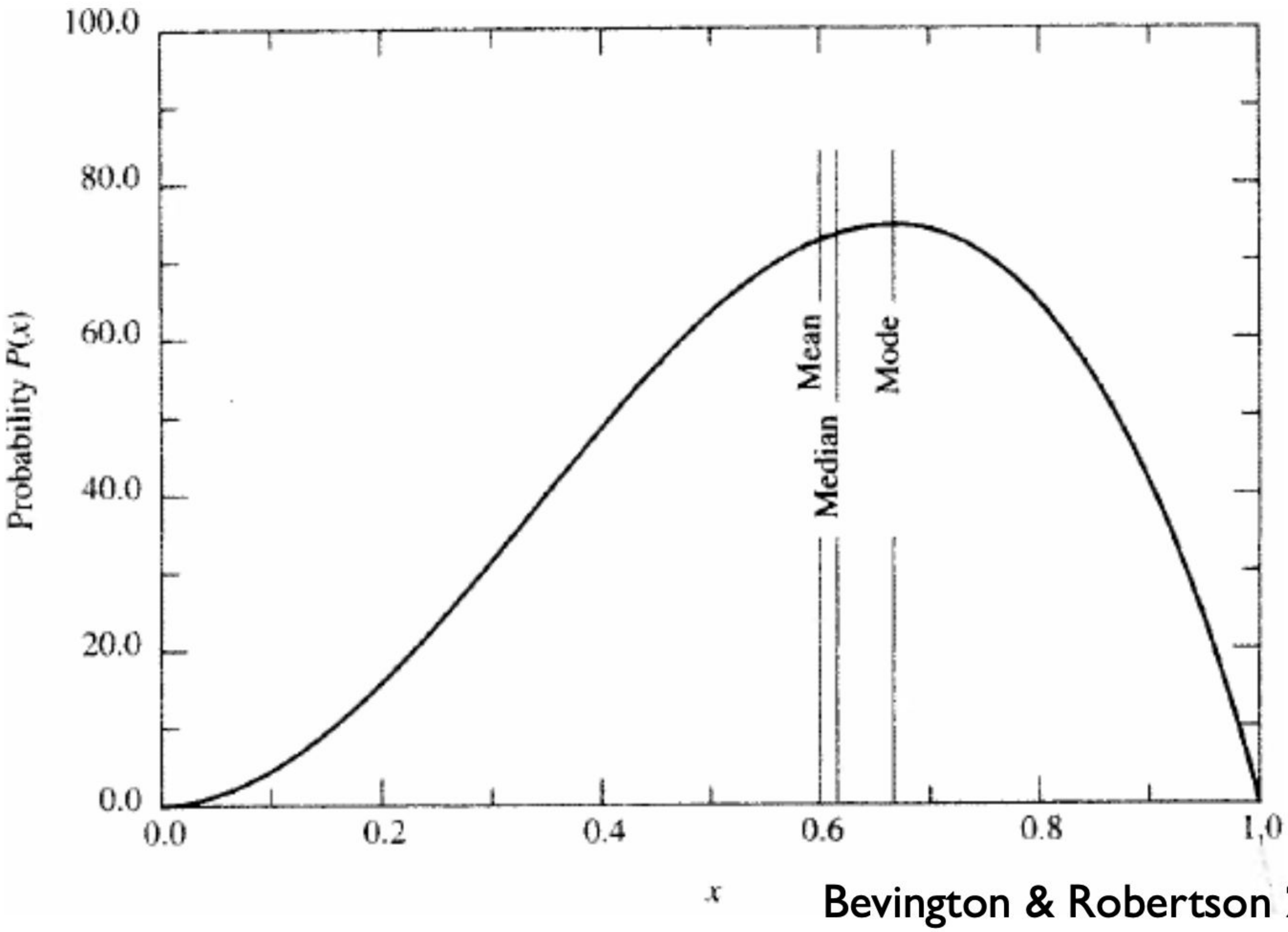
Lumen Learning

Summary Statistics

- **Mean**: The "average"value, in the limit of N measurements:

$$\bar{x} = \frac{1}{N}\sum_i x_i$$

- **Median**: 50th percentile of distribution, i.e., 50% of the measurements are larger (or smaller) than that value
- **Mode**: The most "common", or "likely" measurement value
- All three are useful, but will depend on the problem, and possibly the underlying probability distribution being measured



Bevington & Robertson 2003

Deviation, Variance, Standard Deviation

- **Deviation (d_i)**: of one measurement from the average

$$d_i = x_i - \mu$$

- **Sample variance (σ^2)**: Average of the squares of the deviations.
  - Sample variance can also be estimated from a sample population (i.e., a sample of measurements), using the mean as an estimate of the average.

$$\sigma^2 = \frac{1}{N}\sum_i (x_i - \mu)^2$$

$$= \frac{1}{N-1}\sum_i (x_i - \bar{x})^2$$

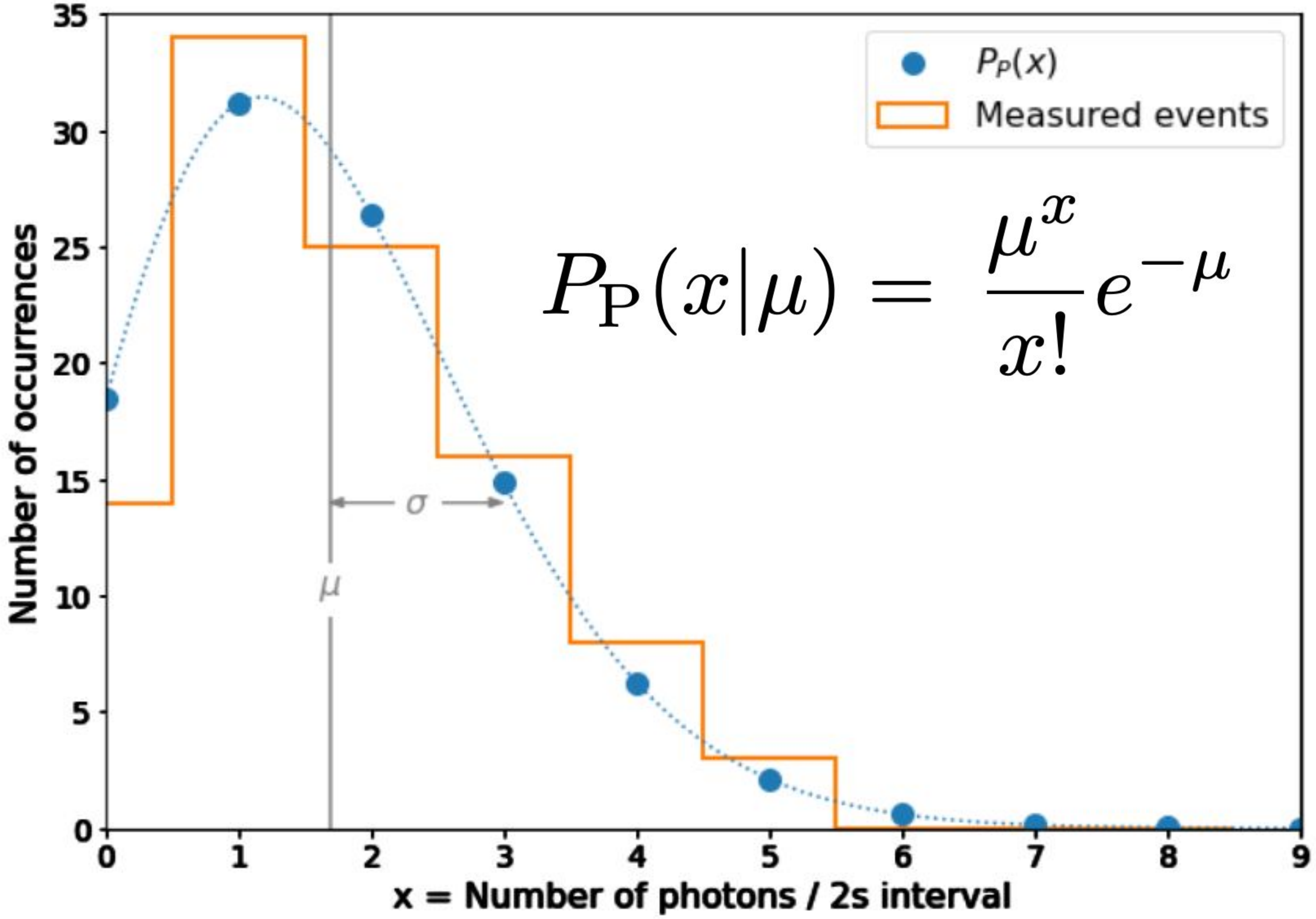
- **Standard Deviation (σ)**: The square root of the variance (i.e., σ), or the "typical" deviation around the mean.

Common Probability Distributions

- Three common probability distributions:
  - **Poisson distribution:** Counting experiments for discrete events (e.g., photon counts, N_{counts})
    - **Standard-Deviation: σ = sqrt(** N_{counts} **)**
  - **Binomial distribution:** For experiments with only a small number of possible final states (e.g., coin tosses)
  - **Gaussian (Normal) distribution:** Limiting case of binomial and poisson distributions, for large number of events / measurements

Poisson Distribution: Example

- A detector measures the number of photons per 2-second interval, repeating 100 measurements. Histogram number of occurrences of photon counts.



$$P_{\mathrm{P}}(x|\mu) = \frac{\mu^x}{x!}e^{-\mu}$$

Measured mean: μ=1.69

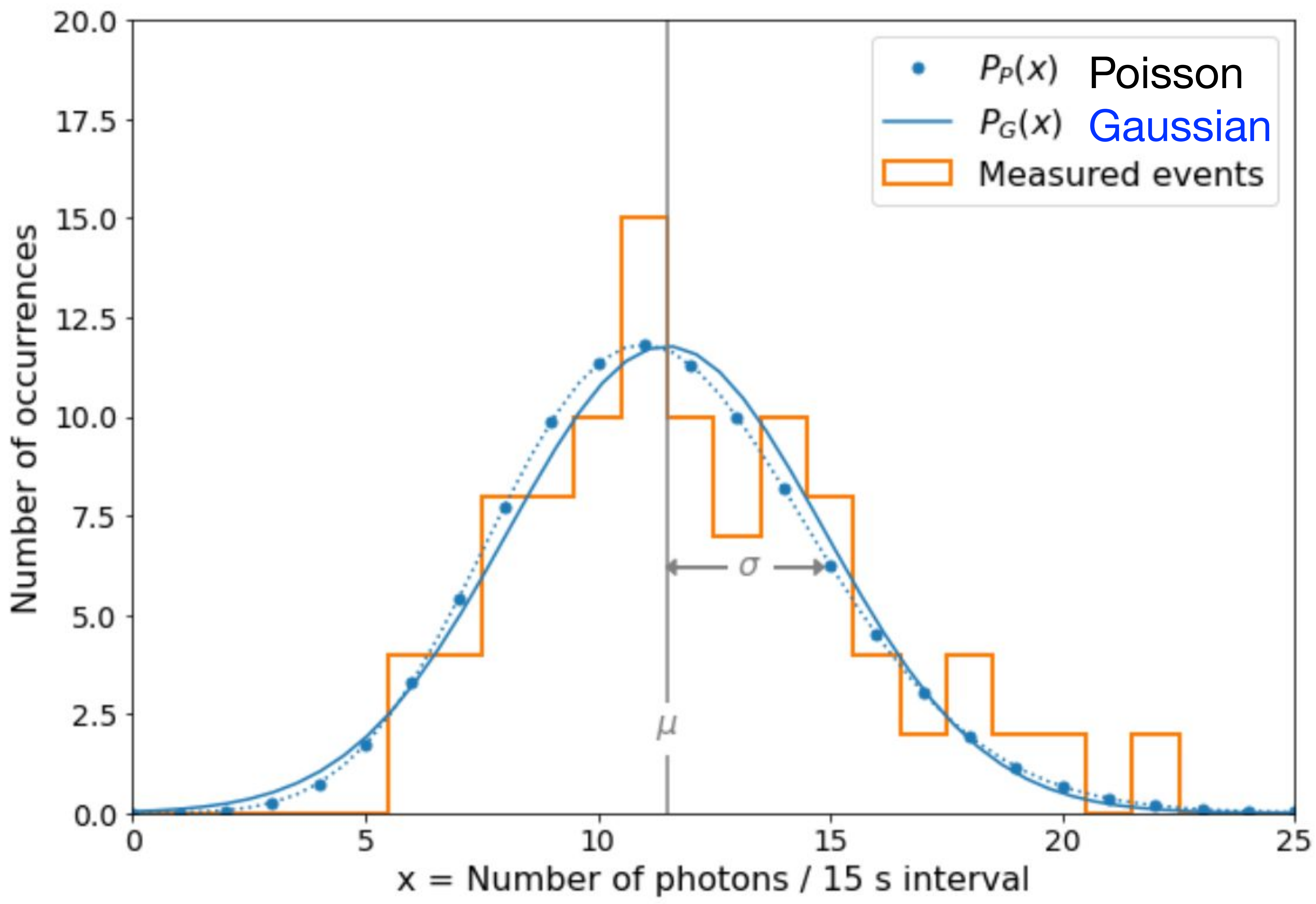
Model for probability, $P_P(x)$, of measuring "x" photons given mean of 1.69 is: $P_{\mathrm{P}}(x|1.69)$

Standard deviation of Poisson distribution is the sqrt of the mean, i.e., σ=sqrt(μ)

This uncertainty for Poisson statistics is often called "**Shot noise**".

Gaussian Distribution: Example

- In the limit of a large numbers, a Poisson distribution is well fit by Gaussian distribution.
- Scaling up previous example, a detector measuring the number of photons per 15-second intervals, making 60 measurements



$$P_{\mathrm{G}}(x|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

measured mean:

$$\bar{x} = 11.48$$

blue points:

$$P_{\mathrm{P}}(x|11.48)$$

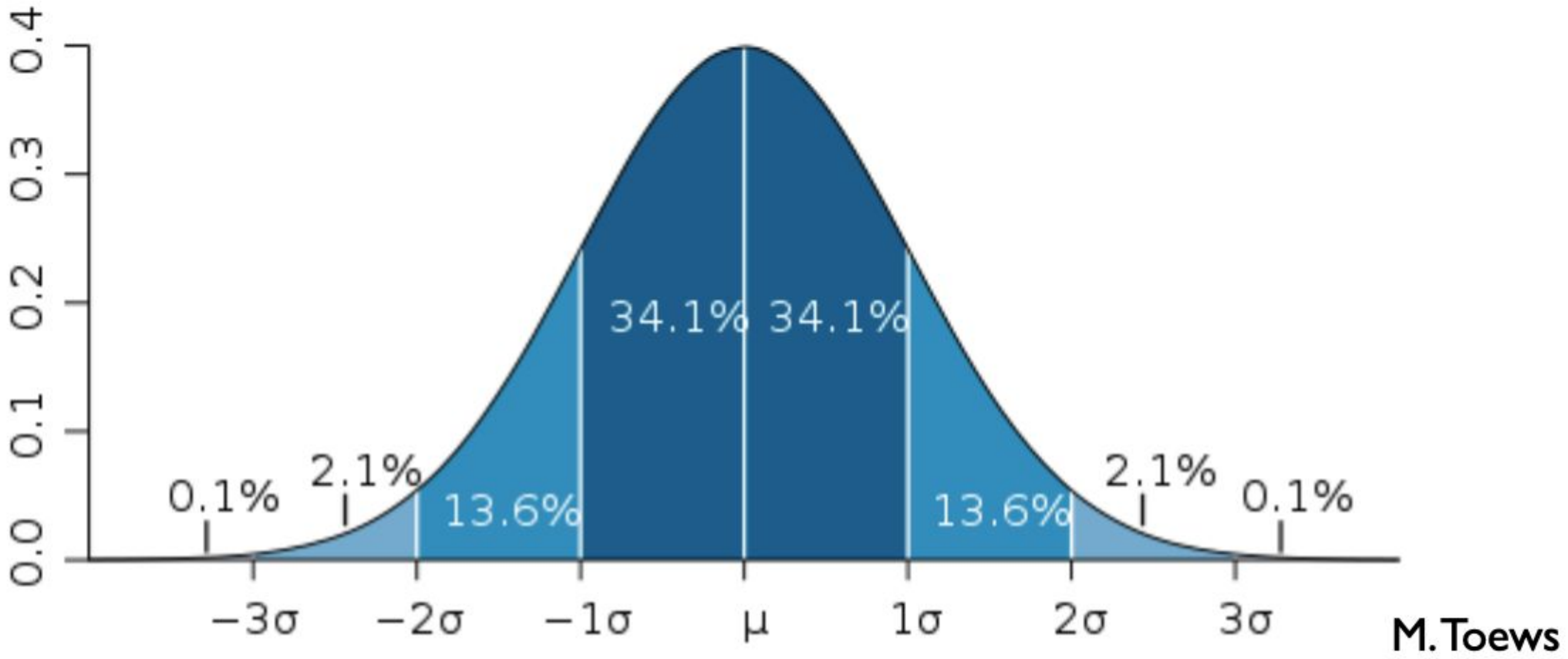
blue curve:

$$P_{\mathrm{G}}(x|\bar{x},\sqrt{\bar{x}})$$

Data is starting to be fit well by a Gaussian distribution

Gaussian Distribution: Example

- Relation between the probability of occurrence and the number of standard deviations away from the mean

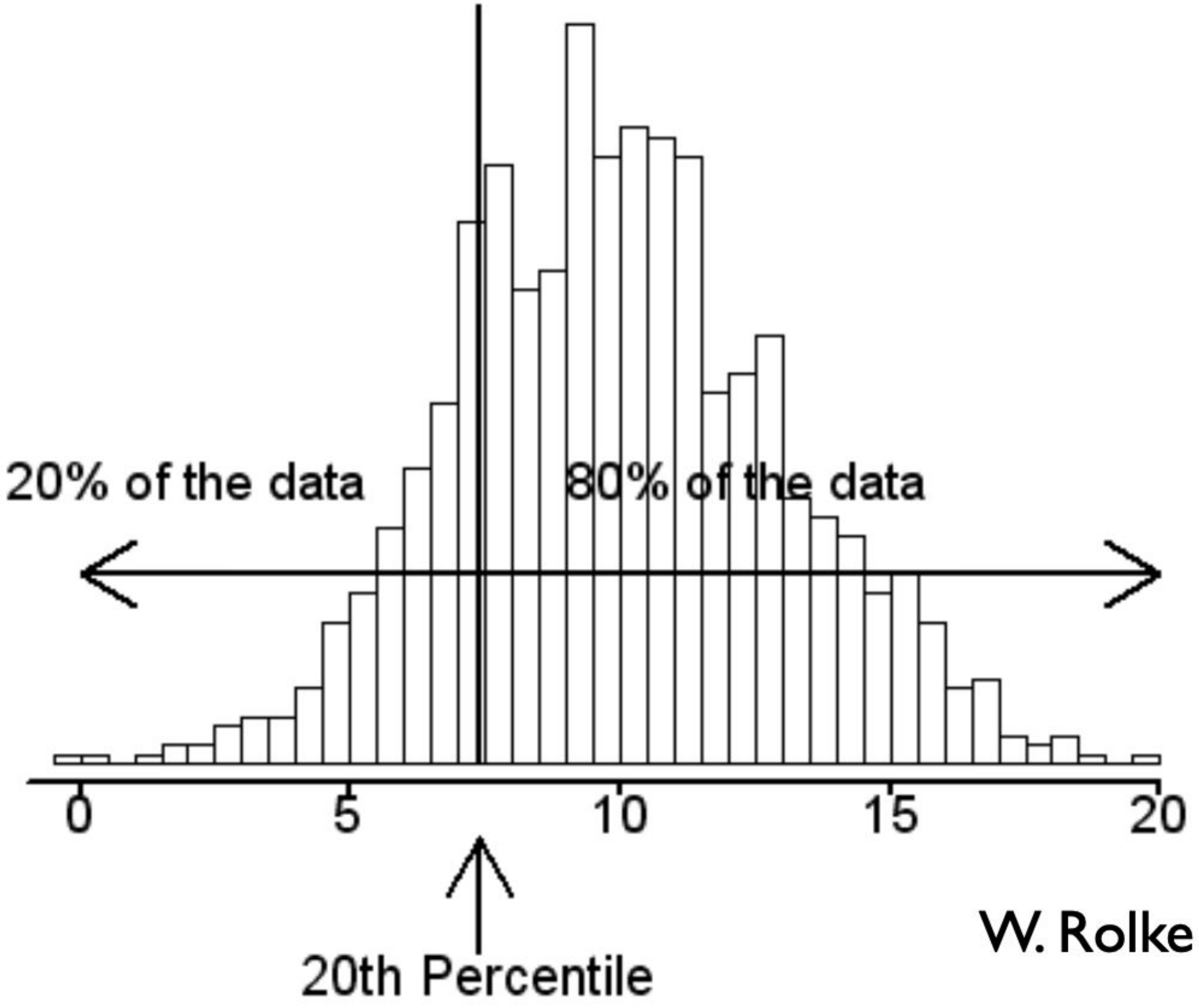


measurements should fall:
- within 1σ of the mean 68.3% of the time
- within 2σ of the mean 95.4% of the time
- within 3σ of the mean 99.73% of the time

Non-Gaussian Distributions

- What if your distribution is non-Gaussian?
- Have to decide on a case-by-case basis
- Percentiles can always sort your data, quote values that are above a certain percentage of the population, e.g.,
    - **Median** = 50th percentile
- Can quote measurement and uncertainty with percentiles, e.g.,
    - The 68 or 95% confidence region, corresponds to the region within 1 or 2-σ of the mean.
    - Results often quote a mean, and 68% (1-σ) confidence region:

$$99.123^{+0.005}_{-0.004}$$



Significant Digits

The accuracy / uncertainty of your measurement informs you how many significant digits to quote. For example:

Mean
Uncertainty

- **Quoting too many digits**, relative to your uncertainty

$$99.123456789$$
$$\pm 0.004556789$$

- Your uncertainty has uncertainty, so typically more appropriate to round to something with 1-2 digits of accuracy

$$0.00455679 \rightarrow 0.005$$

- The uncertainty also tells you how many digits you should quote in your result

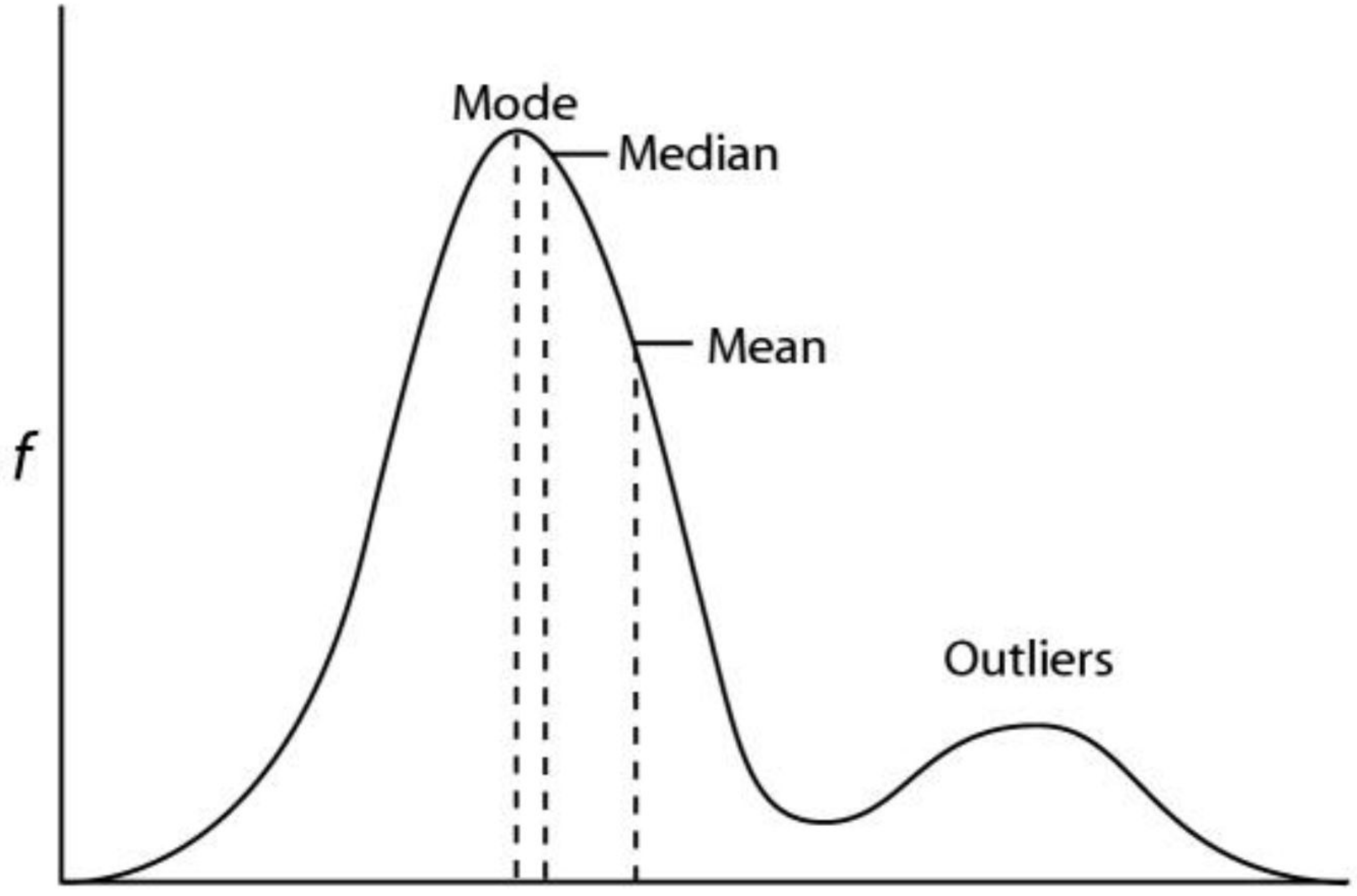
$$99.123$$
$$\pm 0.005$$

- **A better way to quote your result**: A sensible amount of significant digits on your best-fit mean and its uncertainty

$$99.123 \pm 0.005$$

Outliers

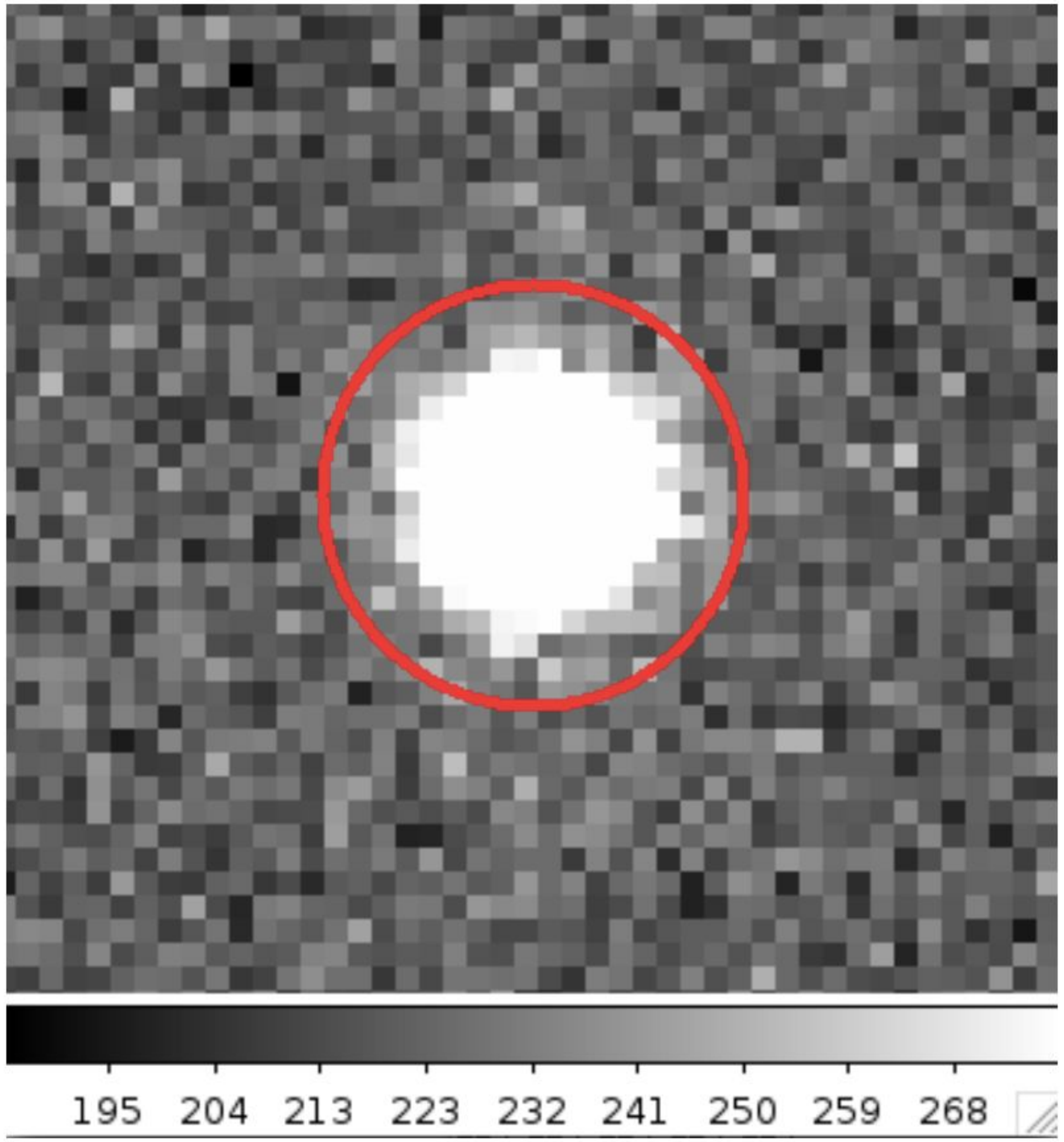
- For Gaussian distribution: Median = Mean
- What if distribution is "almost" normal, but has outliers? (e.g., cosmic rays, hot/dark pixels on a CCD)
    - **Mean**: Significantly affected by outliers
    - **Median**: More robust to (a small number of) outliers
- Sometimes its ok to remove gross outliers, to make sure to not bias your results.
    - "Sigma-clipping": Cut data outside some unlikely range defined by standard deviation.
    - e.g., 10-σ is ~1-in-1-trillion probability, so with 5-million pixels about 1:200,000 odds to have a 10-σ outlier.



Hedges & Shah 2003

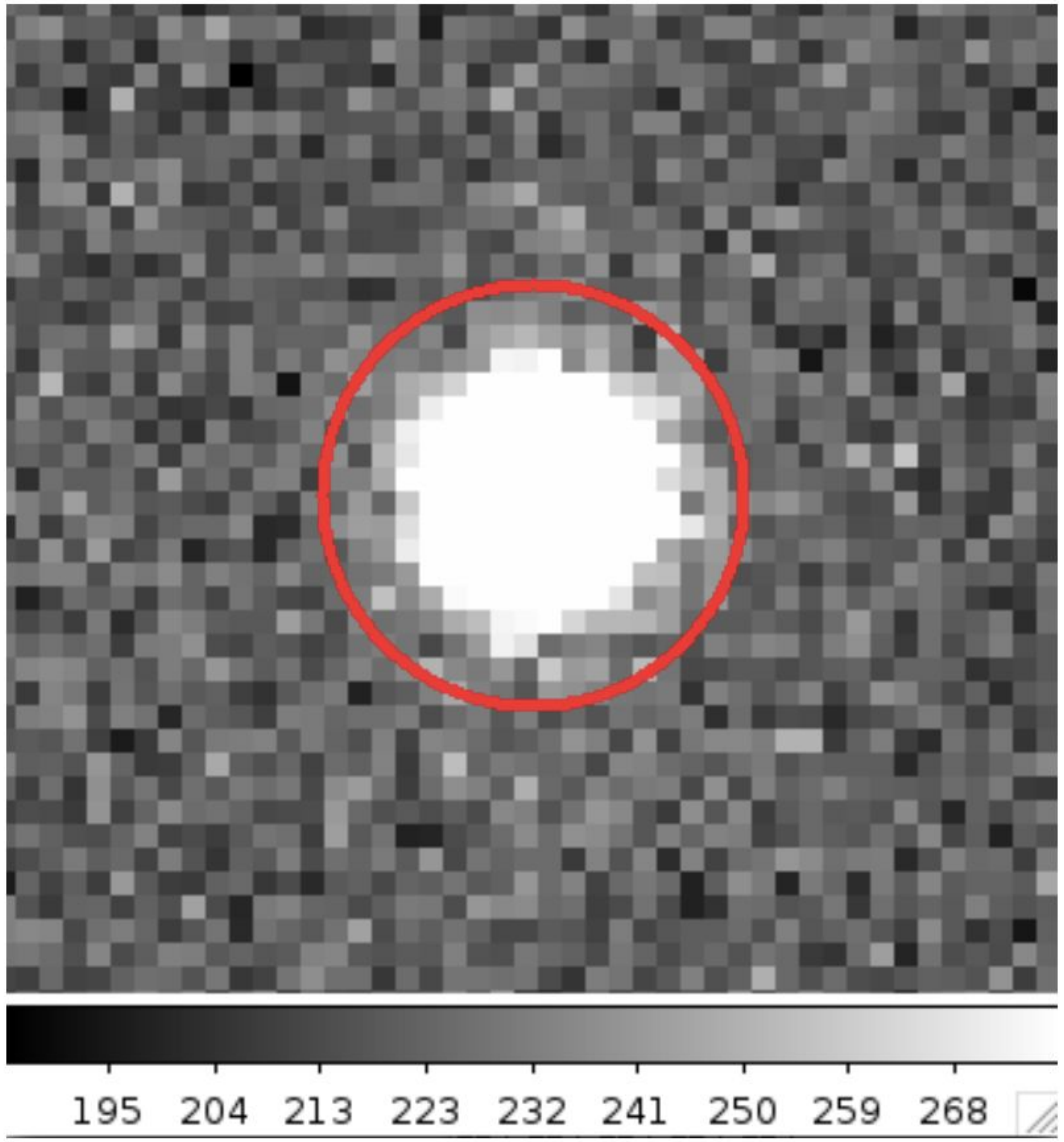
Signal: Flux from an Object

- Flux measured in an aperture:
  - **Total electrons from the object**
    - Need to integrate over each pixel that contains “flux” (or photons) from the object.
  - **Total electrons from any backgrounds**
    - Things like atmosphere emission, dark current, etc., can all contribute electrons in the image
  - $N_{\text{Aperture}} = N_{\text{Object}} + N_{\text{Background}}$
- **Note:** From the image alone, we can’t really tell which electrons are from the “object” (aka, signal), and which are from backgrounds (aka, noise).
  - The signal-to-noise ratio (SNR) is the estimated ratio of the signal to the noise in this aperture.



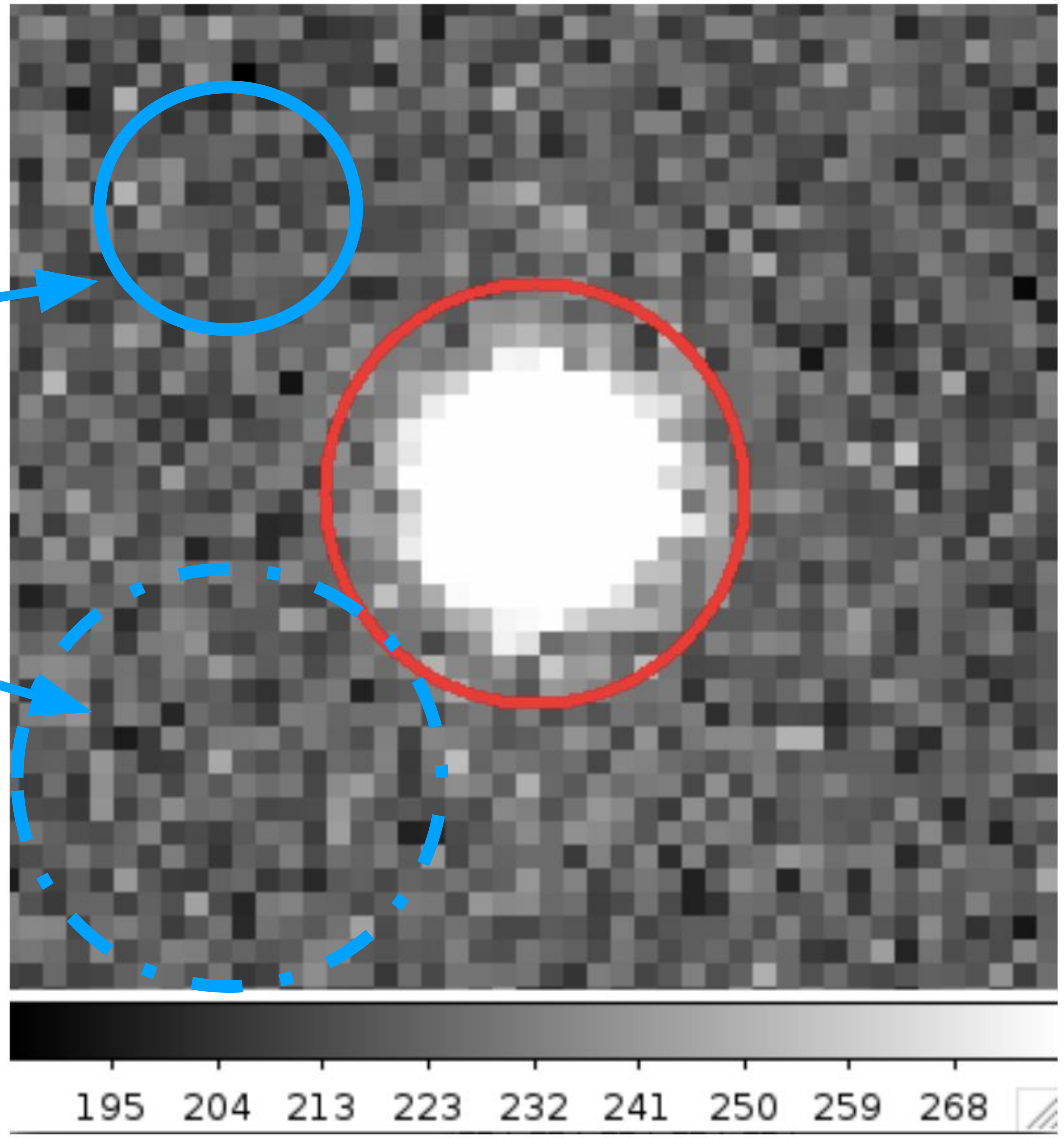
Signal: Flux from an Object

- There is always “noise” in a CCD image
- For each pixel, we can imagine that the measurement is drawn from a distribution of **mean (*N*)** and **width (σ)**
  - So talking histograms of pixel values, is a useful way to characterize noise statistics of the data/pixels
- Even our estimates of the “background electrons” will have some uncertainty, so total uncertainty in source flux will be due to some combination in variance of signal, noise, background, etc.



Signal: Flux from an Object

- For example:
    - In "**empty**" regions of the image, we can measure the noise as the standard deviation of the pixel values.
    - The accuracy with which we measure that standard deviation will improve, the more "background" regions we can average over.
- $N_{\text{Aperture}} = N_{\text{Object}} + N_{\text{background}}$



How big is the noise? What dominates?

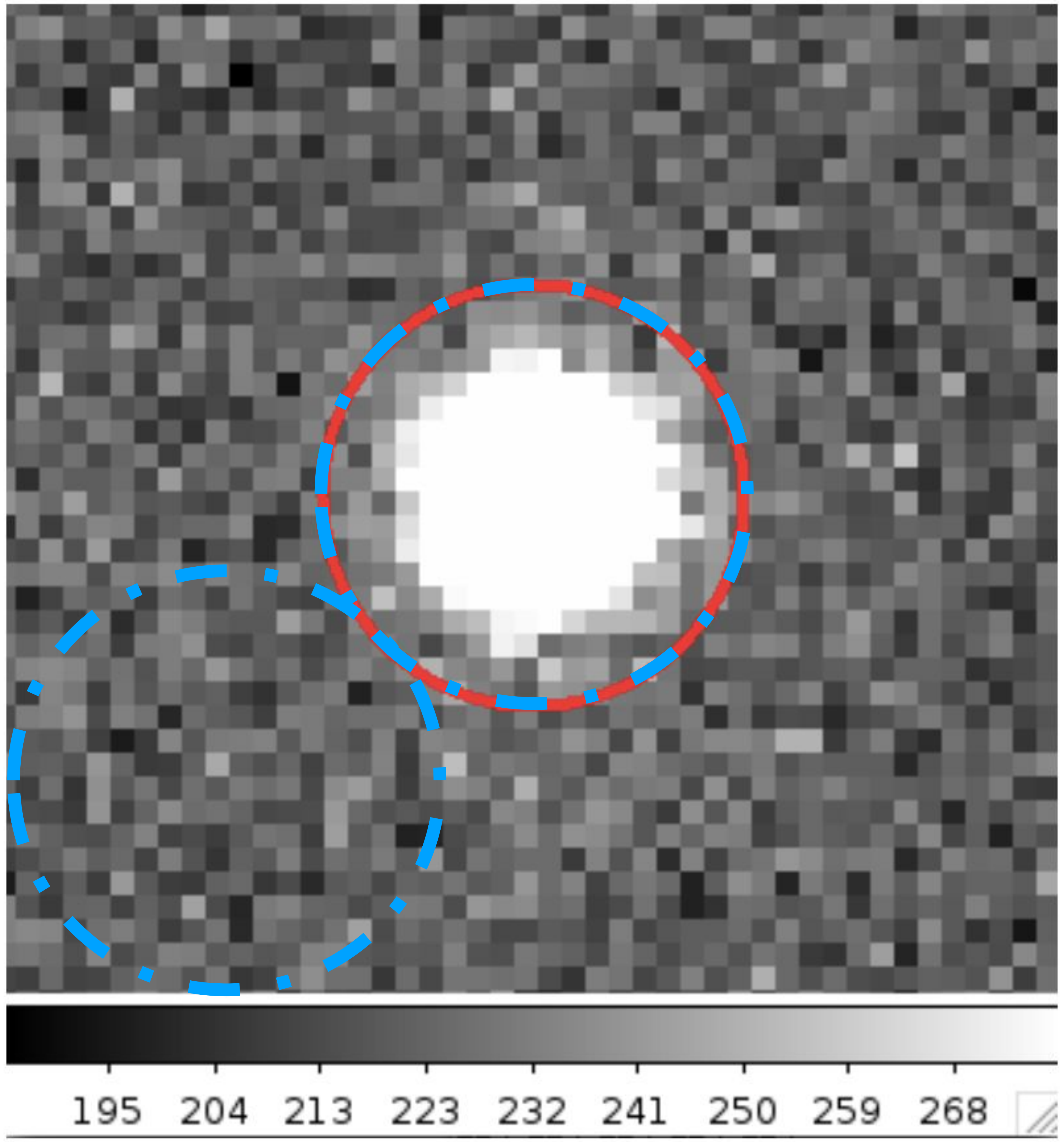
$$N_{\text{Object}} = N_{\text{Aperture}} - N_{\text{Sky}}$$

Sources of noise:

- Shot noise from the source
- Shot noise from sky / atmospheric emission
- Dark current noise
- Readout noise

$$\sigma_{\text{object}} = \sqrt{N_{\text{object}}} = \sqrt{S_{\text{object}} \times t}$$

$$\sigma_{\text{sky}} = \sqrt{N_{\text{sky}}} = \sqrt{s_{\text{sky}} \times n_{\text{pix}} \times t}$$



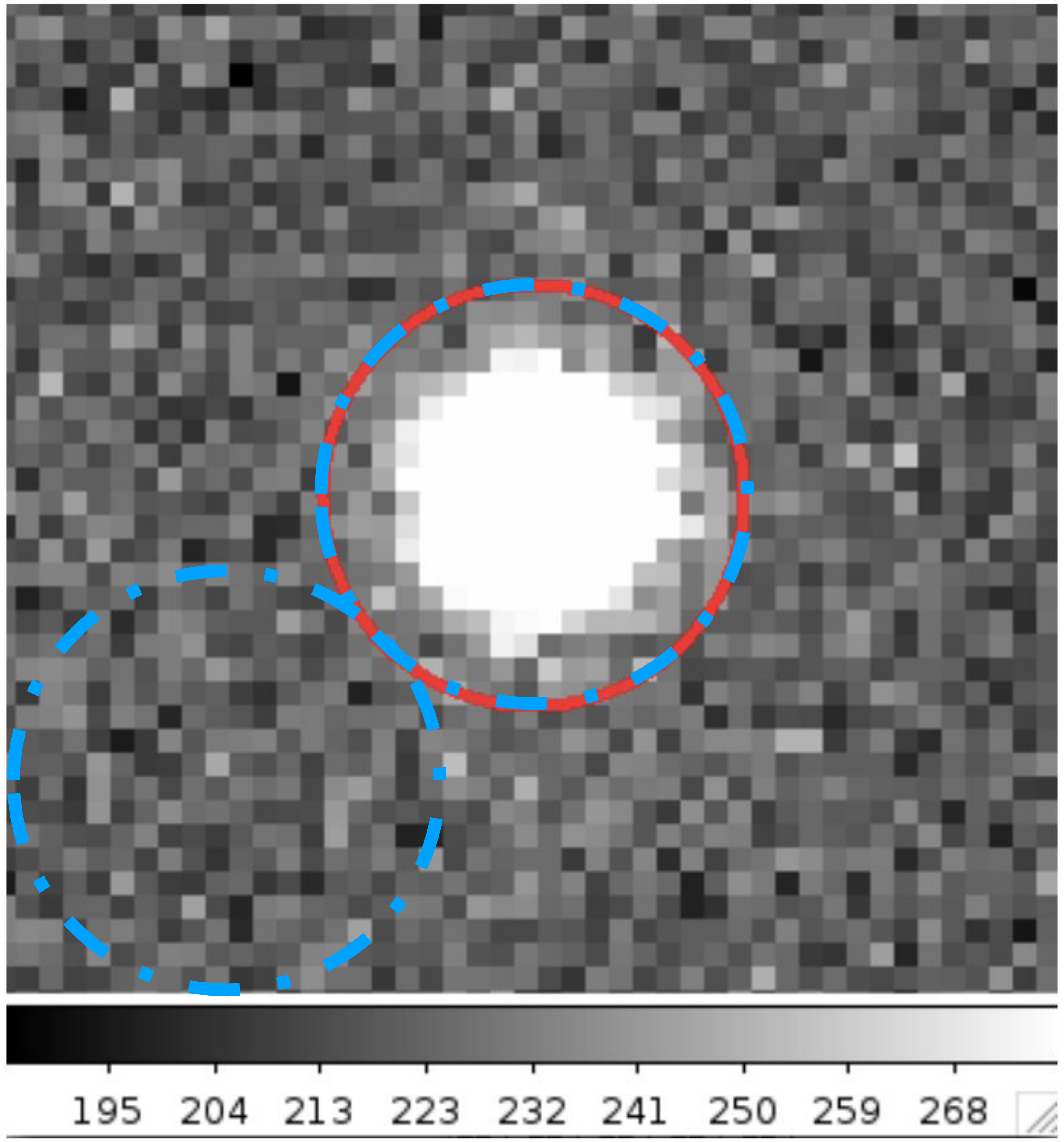
Quadrature Sum, and Signal-to-Noise

- If noise contributions are independent of each other, the variance adds quadratically:

$$\sigma_{\text{total}} = \sqrt{\sum_{i \in \text{noise terms}} \sigma_i^2}$$

- From "empty" image region, the total noise will be sum of background contributions

$$\sigma_{\text{bkg}} = \sqrt{\sigma_{\text{sky}}^2 + \sigma_{\text{dk}}^2 + \sigma_{\text{ro}}^2}$$



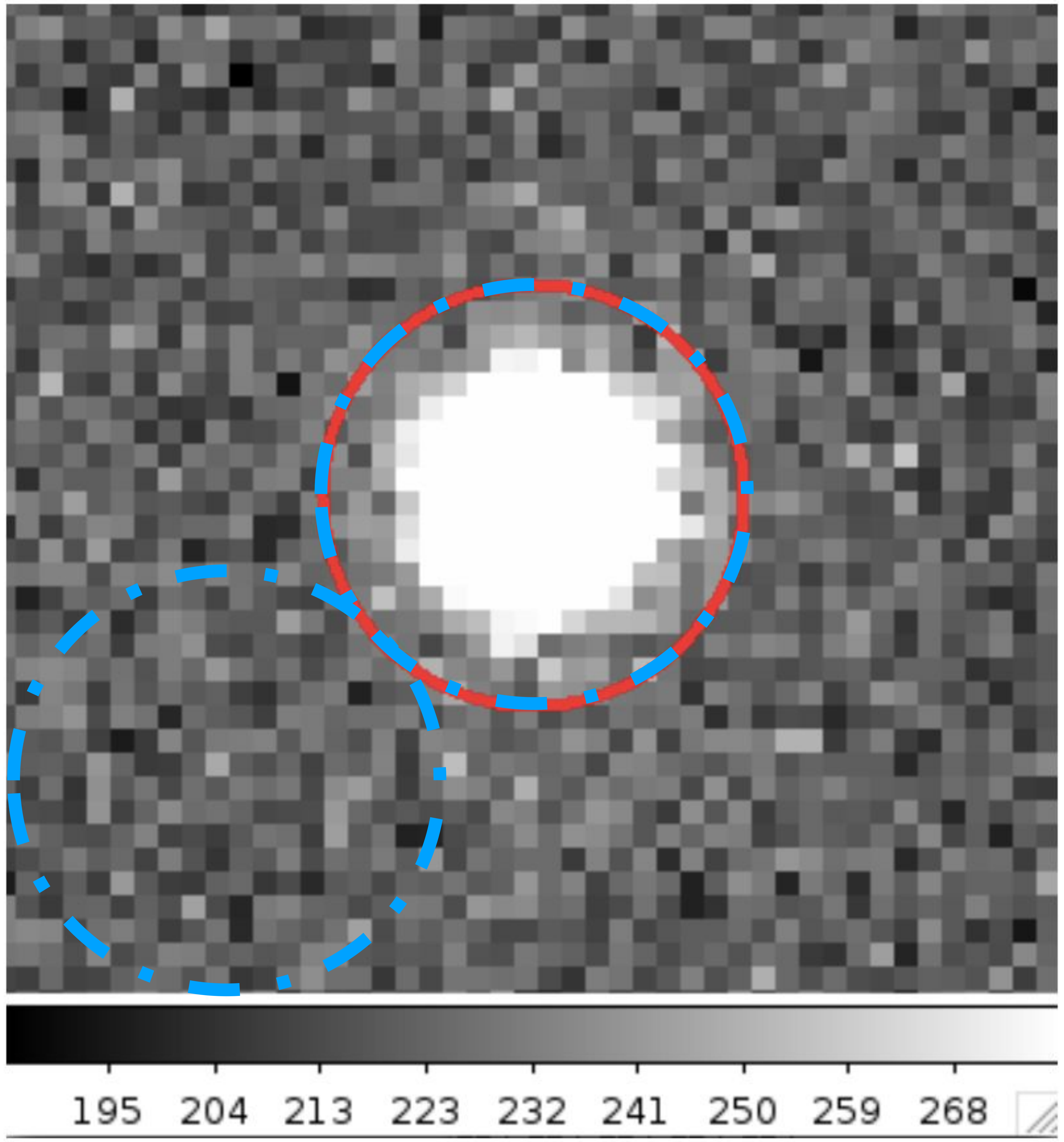
Quadrature Sum, and Signal-to-Noise

- However, for an object, the measurement uncertainty on the flux comes from the background + the shot noise of the object

$$\sigma_{\text{total}} = \sqrt{\sigma^2_{\text{object}} + \sigma^2_{\text{bkg}}}$$
$$= \sqrt{N_{\text{object}} + \sigma^2_{\text{bkg}}}$$

- Given knowledge of a system, we can predict/define a signal-to-noise ratio (SNR) as:

$$SNR = \frac{N_{\text{object}}}{\sqrt{\sum_{\text{noise}} \sigma_i^2}}$$



CCD Equation: Total Counts

- Read noise follows a Gaussian distribution
- Shot noise (from source, sky, etc.) follows a Poisson distribution (i.e., we are measuring some number of photons in a unit of time)

$$\underbrace{N}_{\text{Total counts per pixel, electrons}} = \sqrt{\underbrace{S_\star}_{\text{Astronomical Source}} + \underbrace{S_S}_{\text{Sky background}} + \underbrace{t \cdot dc}_{\text{Dark current}} + \underbrace{\mathcal{R}^2}_{\text{Read noise}}}$$

CCD Equation: Signal-to-Noise Ratio (SNR)

- In general, we do not want to be limited by dark current or readout noise.
- Two limiting cases for the SNR:
  - **1) Very bright object: N_{object} >> N_{other}**

$$SNR = \frac{N_{\mathrm{object}}}{\sqrt{N_{\mathrm{object}}}} = \frac{s_{\mathrm{object}} \times t}{\sqrt{s_{\mathrm{object}} \times t}}$$

$$\propto \sqrt{t}$$

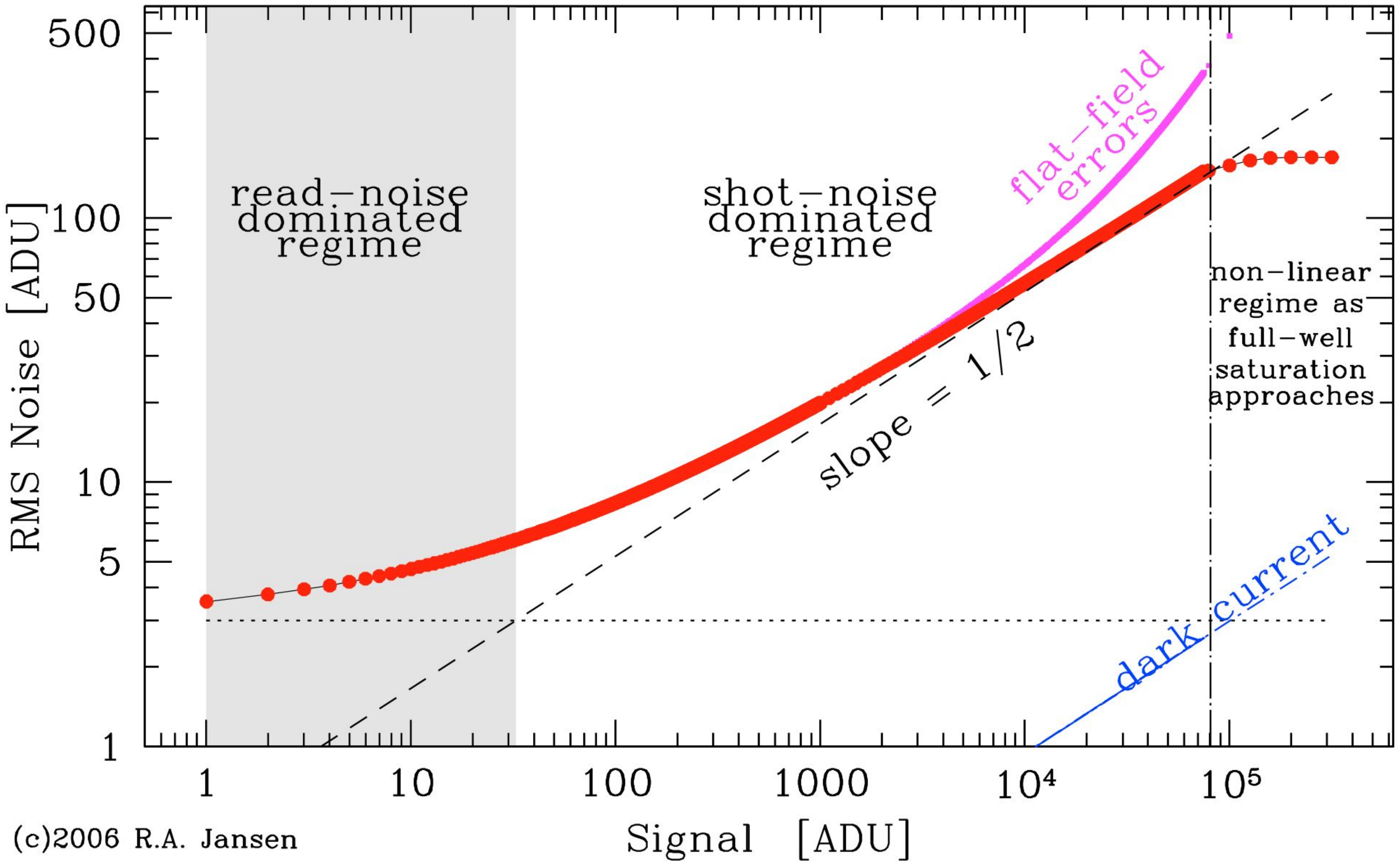
  - **2) Very faint object: N_{sky} >> N_{other}**

$$SNR = \frac{N_{\mathrm{object}}}{\sqrt{N_{\mathrm{sky}}}} = \frac{s_{\mathrm{object}} \times t}{\sqrt{s_{\mathrm{sky}} \times n_{\mathrm{pix}} \times t}}$$

$$\propto \sqrt{t}$$

CCD Equation: Signal-to-Noise (S/N)

$$\frac{S}{N} = \frac{S_\star}{\sqrt{S_\star + n_{\text{pix}} \cdot \left(1 + \frac{n_{\text{pix}}}{n_{\text{sky}}}\right) \cdot \left(S_S + t \cdot dc + \mathcal{R}^2 + \mathcal{G}^2 \sigma_f^2\right)}}$$



Any questions before SEO intro?

Stone Edge Observatory

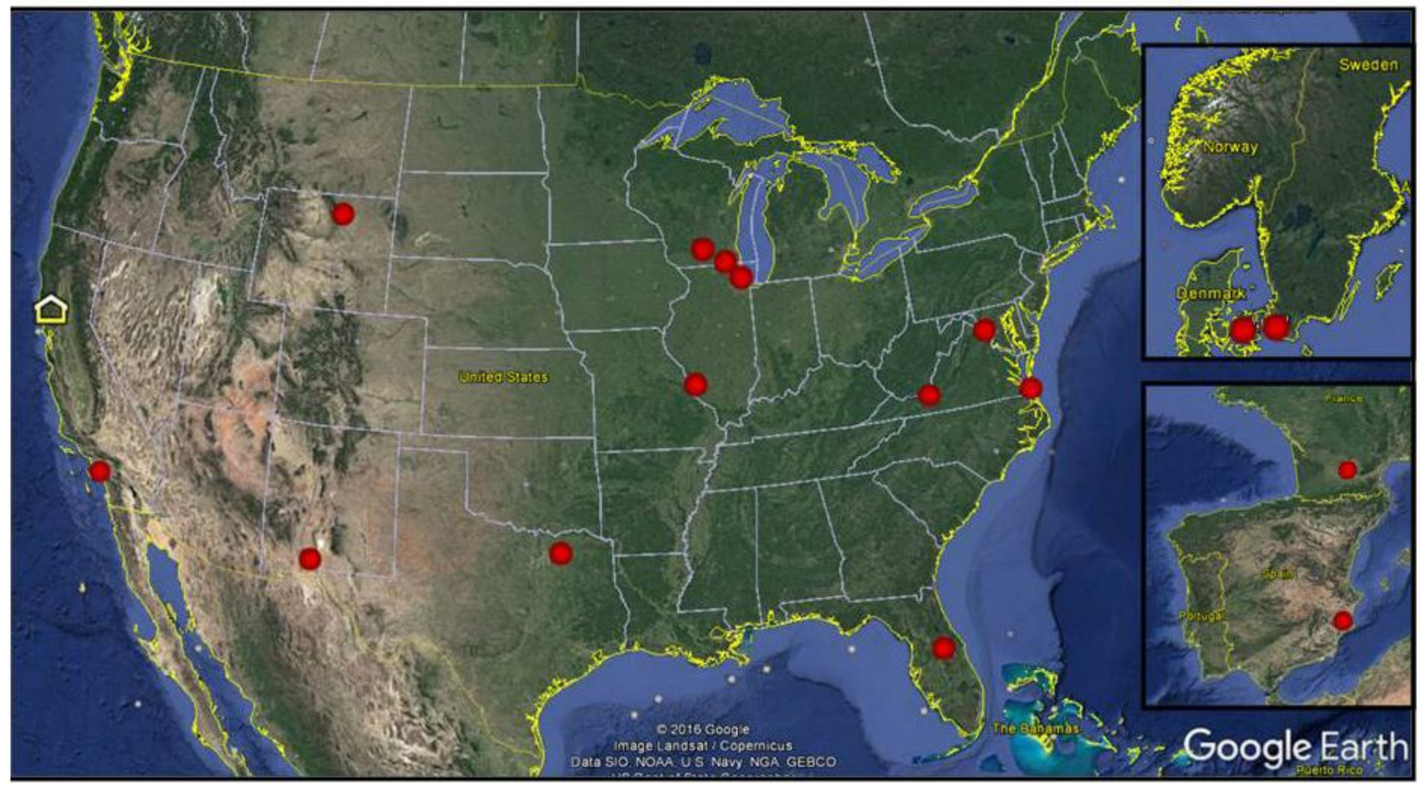
Authors: Amanda Pagul, Marc Berthoud


M8 by Lindsay


M42 by Emil

About

- **SEO**: located on Stone Edge Farm vineyards and winery in Sonoma, CA.
- University of Chicago is operating the telescope making it available to students and researchers.
- SEO is used by astronomers and students worldwide.



- **SEO science examples**: asteroid lightcurves, supernovae and comet observations and high precision photometry.

Who's Who

- John McQuown: Owner of Stone Edge Farm
- Rich Kron: Faculty advisor
- Al Harper: Scientific advisor
- Richard Treffers: Telescope Engineer
- Amanda Pagul: Facility Astronomer
- Matt Nowinski: Observation software engineer and student advisor
- Rohan Gupta: System integrator
- Seth Knights: Software engineer
- Caleb Krueger: Observation specialist
- Marc Berthoud: Data software engineer and database curator.

Rich, Al, Amanda and Marc are available for support anytime.

Your gateway to SEO: UChicago server at
https://stars.uchicago.edu

More about the Stone Edge Observatory

Some technical details:

- **Optical design:** Ritchey-Chretien telescope with an **aperture of 0.5m** (20”)
- **Field of view** is 26’x26’ (2048 x 2048 pixels)
- **Filters:** Currently SDSS g’, r’, i’, H-alpha, SII, OIII, and clear filters (will soon include SDSS u’, z’)
- **Current Camera**: FLI Proline PL230 camera with an e2v CCD 230-42 chip
- Spare Camera: SBIG Aluma AC4040 CMOS

For general information, tutorials, and to request observing time, visit https://voices.uchicago.edu/stoneedgeobservatory.com/

Student Teacher
Astronomy Resource

STAR Server

stars.uchicago.edu

Website Tabs:

- **Education** → Class Wiki
- **Stone Edge** → Queue, SEO Main page
- **FITS Data** → Fits View, Folders

Itzamna on Slack

Itzamna: Mayan sky god

Itzamna: Slack robot interacting with the SEO telescope. Takes commands on a Slack channel. Written by Matt Nowinski

To use Itzamna:

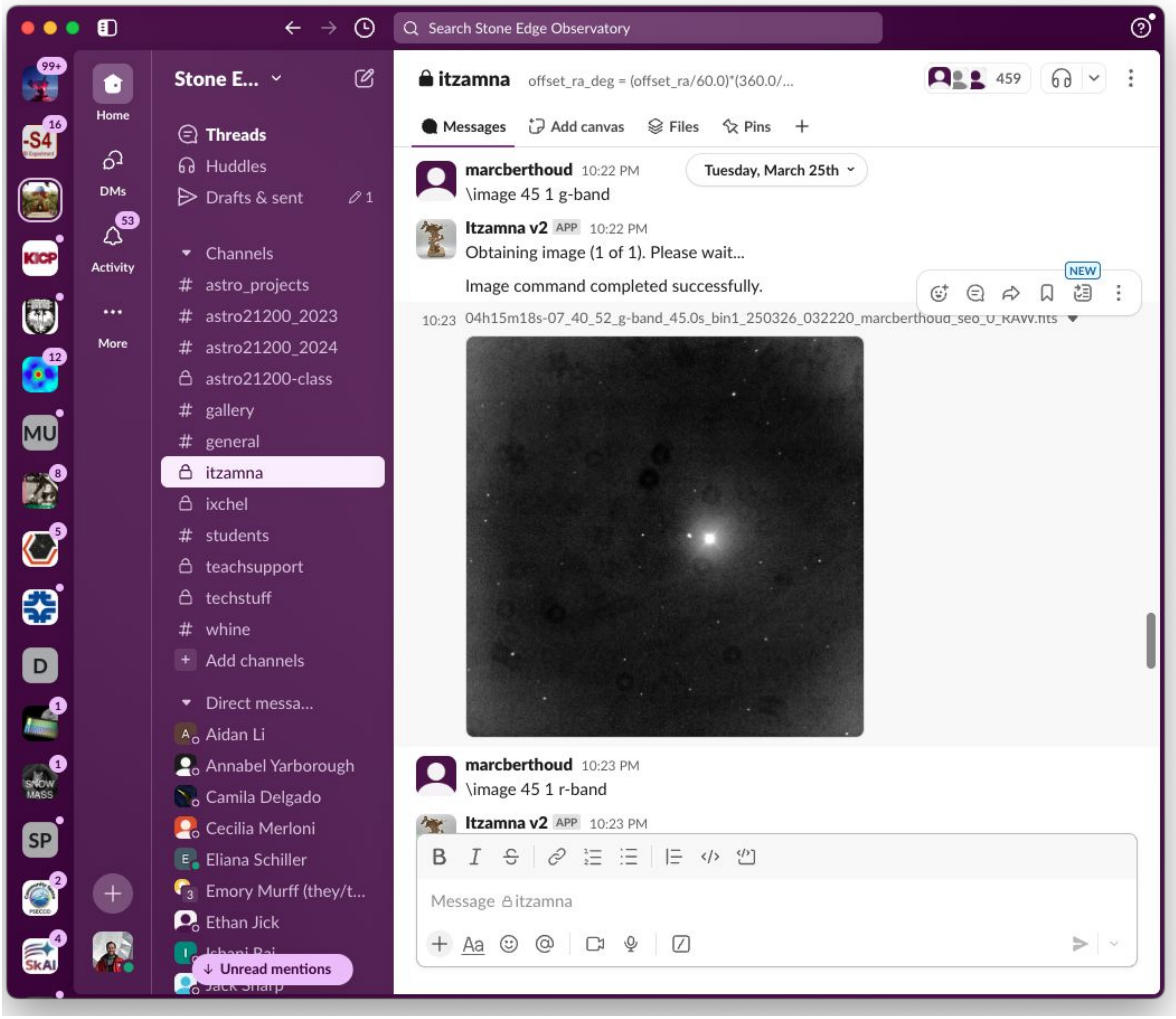
- Go to stars.uchicago.edu → Stone Edge → Slack
- Use your personal login or class account.

- Use the “itzamna” channel:
  - \help - to get command list
  - \clearsky - gives weather information
  - \lock - to lock the telescope so you can use it.
  - \crack - open the dome
  - \track on - start tracking
  - \find “object“- search the database
  - \pinpoint - point telescope to found object
  - \image “seconds” “bin” “filter” - take an image with given settings
  - \tostars - copies images to stars server
  - \squeeze - close the telescope dome
  - \unlock - release your lock on the telescope.
- Make sure the skies are clear, check at:
  - NOAA Sonoma Weather
  - Airport reports for KAPC KDVO KO69
  - **No Observing if** Humidity > 90%, chance of rain > 10% or sky cover > 25% at any of these

Observing with SEO:

Use Itzamna Channel on Slack

[SEO Cheat Sheet on GitHub]



SEO Itzamna Cheat Sheet

1 "Typical" SEO Sequence of Observing Commands

This would be a somewhat typical set of commands that you would use to do an observation on SEO:

1. **Make sure there is no rain in the near future.** You should do this a couple different ways: a) Check the NOAA Sonoma weather page [1], and b) Check one of the nearby airport weather reports, e.g., KPAC[2], KDVO[3], KO69[4].

   If: humidity > 90%, or chance of rain > 5%, or cloud sky cover > 25%, then don't observe!

2. # List all the commands available in itzamna

   \help

3. # check the forecast for next couple days, looking to see that there is no rain or bad cloud cover in the forecast, for when you are planning to observe

   \forecast

4. # confirm the current weather is ok, i.e., no rain, etc (assuming you are trying to observe in the next couple hours)

   \weather

5. # make sure there are no clouds visible in the sky via a webcam image of the sky

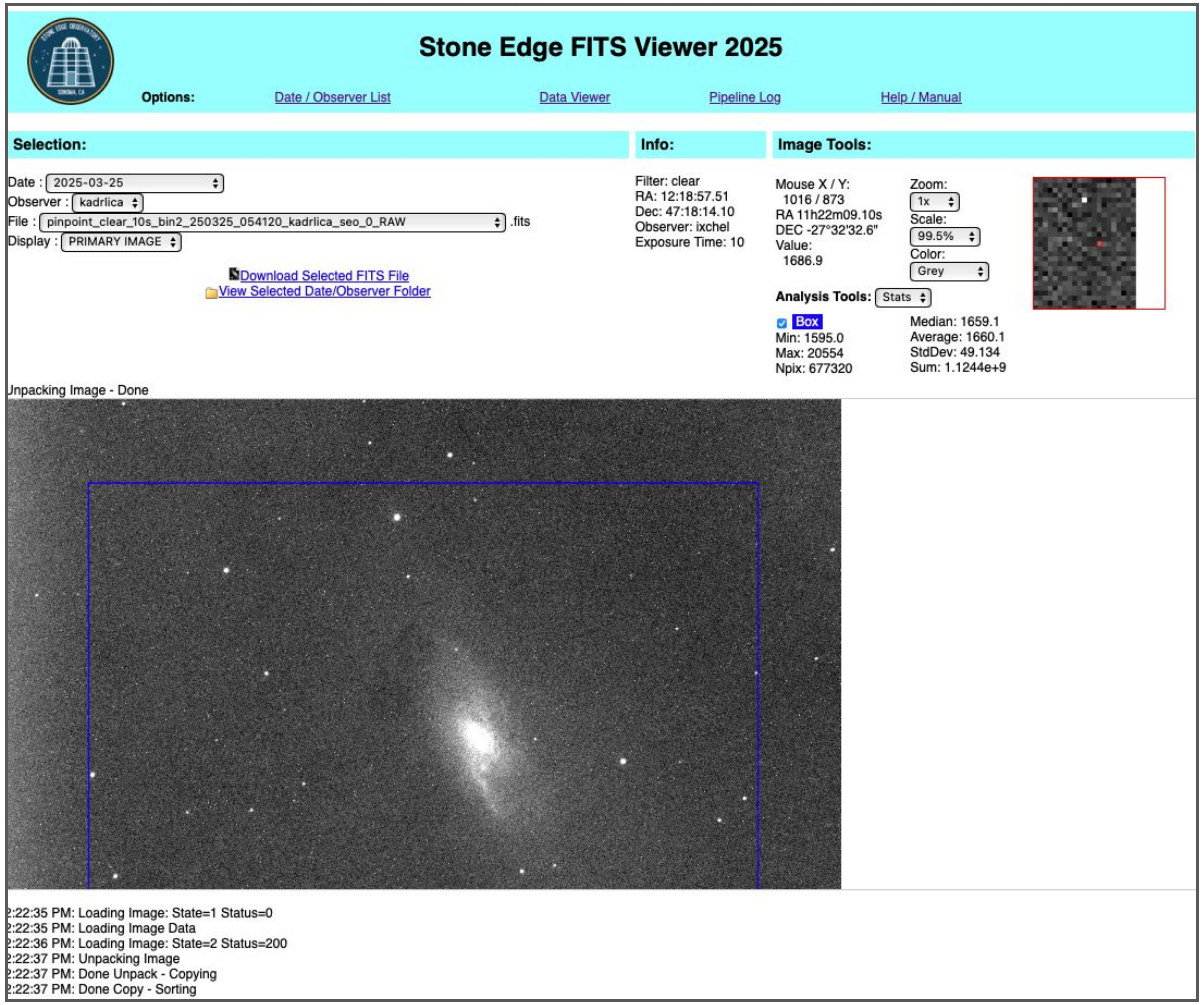
   \skycam

6. # Double check that no-one is using the telescope.

Getting SEO Images

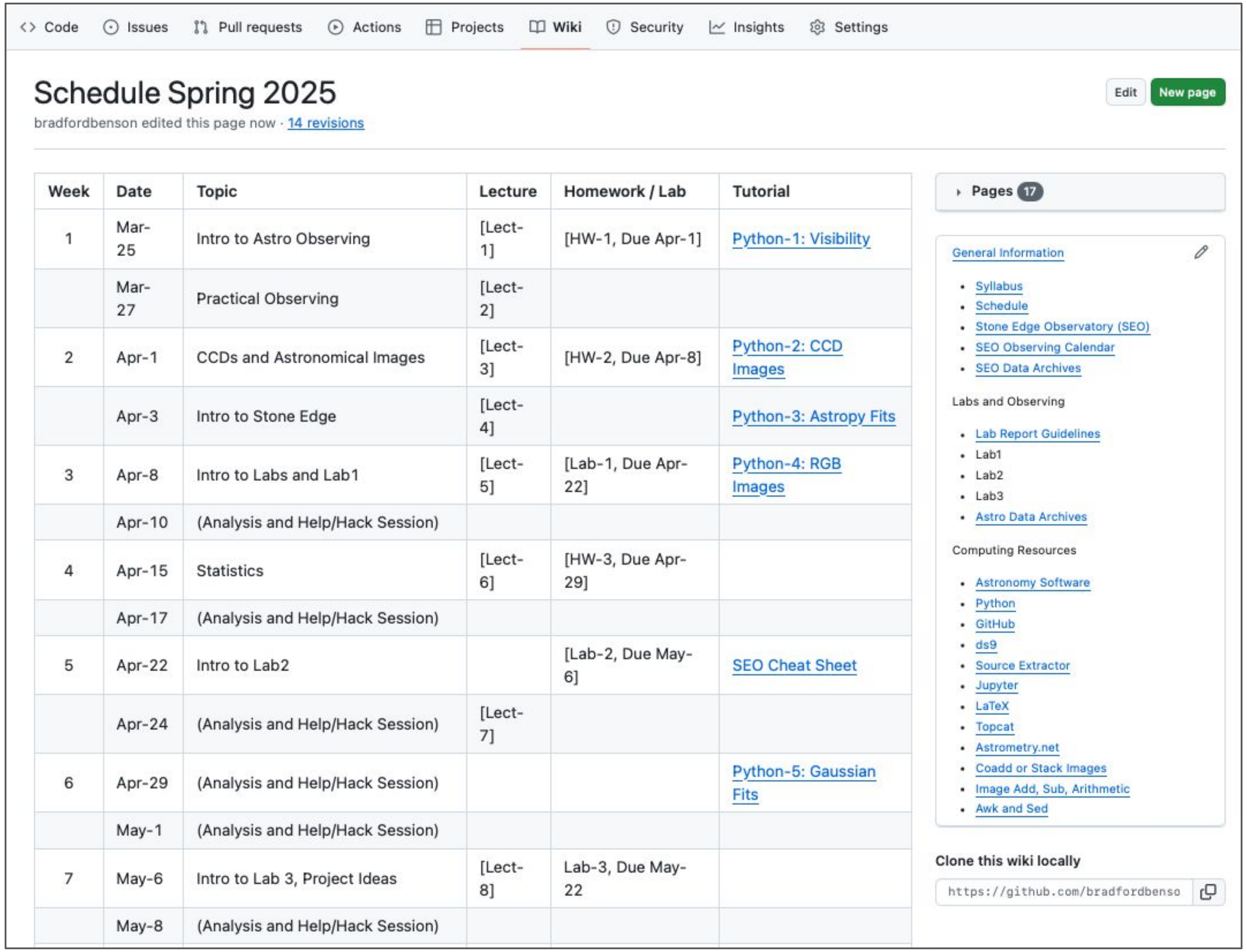
Use Data Viewer on STARS to view and analyze data and to download images.

- Several viewers on stars:
  - stars.uchicago.edu/fitsview25 for 2025 data
  - stars.uchicago.edu/queue for queue and class support data
- Several views:
  - List view: allows you to select observations
  - Data view: to look at and analyze data.
  - Pipeline log: current log of reduction pipeline
- Details on data access on the class wiki at github.com/bradfordbenson/ASTR21200_2025/wiki/Stone-Edge-Observatory



Lab-1: CCDs and Astronomical Images

- Brief intro for context for the lab!
- Lab is posted on the GitHub and Canvas
  - Last years lab is posted, but I will update it ahead of next week's class
- Two phases to the lab:
  1) Analyzing "archival" SEO data
  2) Scheduling and analyzing SEO data of your own



Code · Issues · Pull requests · Actions · Projects · Wiki · Security · Insights · Settings

Schedule Spring 2025

bradfordbenson edited this page now · 14 revisions

Edit · New page

Week	Date	Topic	Lecture	Homework / Lab	Tutorial
1	Mar-25	Intro to Astro Observing	[Lect-1]	[HW-1, Due Apr-1]	Python-1: Visibility
	Mar-27	Practical Observing	[Lect-2]		
2	Apr-1	CCDs and Astronomical Images	[Lect-3]	[HW-2, Due Apr-8]	Python-2: CCD Images
	Apr-3	Intro to Stone Edge	[Lect-4]		Python-3: Astropy Fits
3	Apr-8	Intro to Labs and Lab1	[Lect-5]	[Lab-1, Due Apr-22]	Python-4: RGB Images
	Apr-10	(Analysis and Help/Hack Session)			
4	Apr-15	Statistics	[Lect-6]	[HW-3, Due Apr-29]	
	Apr-17	(Analysis and Help/Hack Session)			
5	Apr-22	Intro to Lab2		[Lab-2, Due May-6]	SEO Cheat Sheet
	Apr-24	(Analysis and Help/Hack Session)	[Lect-7]		
6	Apr-29	(Analysis and Help/Hack Session)			Python-5: Gaussian Fits
	May-1	(Analysis and Help/Hack Session)			
7	May-6	Intro to Lab 3, Project Ideas	[Lect-8]	Lab-3, Due May-22	
	May-8	(Analysis and Help/Hack Session)			

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General Information
- Syllabus
- Schedule
- Stone Edge Observatory (SEO)
- SEO Observing Calendar
- SEO Data Archives

Labs and Observing
- Lab Report Guidelines
- Lab1
- Lab2
- Lab3
- Astro Data Archives

Computing Resources
- Astronomy Software
- Python
- GitHub
- ds9
- Source Extractor
- Jupyter
- LaTeX
- Topcat
- Astrometry.net
- Coadd or Stack Images
- Image Add, Sub, Arithmetic
- Awk and Sed

Clone this wiki locally

https://github.com/bradfordbenso

Lab-1: Lab Groups

- You will do the labs in “groups”
  - We have ~30 people in the course, so next week, we will need to break into 6-7x groups of 4-5 people per group at next week’s class
  - ***Next week*: During the first half of class, we will break into lab groups, so attendance is critical.**
  - Feel free to choose your group, and we will help match anyone needing a group.
- Everyone will submit their own **Lab Report**
  - In your Lab report, put your name first, but note which people were also in your Lab group at the top of your report (see example)
- Any questions?

5 Lab Report

Prepare a *jupyter* notebook that documents your entire analysis for the lab. Make sure to explain your steps and conclusions; imagine writing a tutorial for another astronomy student, who is not taking the class. Use *markdown* boxes (which can also parse LaTeX). Note that you can also include figures (i.e., in png, jpg, etc. form) that are produced outside of the notebook (e.g. with ds9).

The explanations in the *jupyter* notebook will be what we read, but we might look at your code if we think you did something wrong. Make sure that the report is logical; each section should have a short introduction, then code with results and plots, then a conclusion. Make sure the section numbering follows this manual (e.g., Introduction, Data, Data Analysis, Conclusions). Once your notebook is finished, make sure to restart it and re-run all cells. Then save the notebook in pdf format, e.g., through the print menu.

1 Lab Report 2

1.0.0.1 Jason Wu, with Elena Jochum, Dillion Bass, and Joseph Yeung

In the 1929, Edwin Hubble laid the groundwork for modern cosmology by observationally confirm the notion of an expanding universe, a theory implicitly suggested by Einstein's theory of General Reletivity. This discovery was an

Extras