ASTR 2401

Photometry

Observational Astronomy

Labs This Week

- Observing Labs Start at 7:00 - **PROJECTS**
  - **Bring your observing plan and finder charts**
- Observatory Status (should be online)
- Labs due Friday or Monday? (Class Decides)
  - Alt Lab 2, Lab 4, Lab 5, Obs Lab 3, Obs Lab 4
  - **Bring data on a thumb drive during Thursday Lab**
- Thursday Lab - Photometry with your data.
- All nighter and weekend nights?

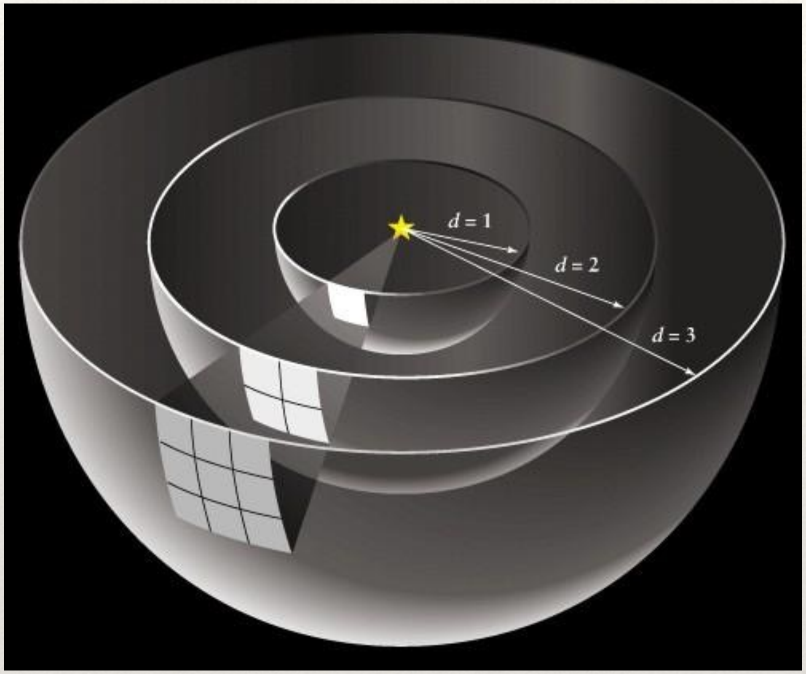
Lab Books

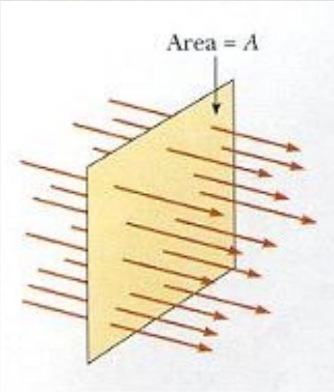
- Paragraphs not bullet points.
- Each section should be at a minimum one paragraph, but can and should go longer.
- Take notes during the lab, and include them. Denote them clearly.
- Label all sections.
- **Sections**
  - Purpose and Background
  - Procedure and Data Collection
    - In lab notes go here as a subsection
  - *Data Analysis**
  - Results and Discussion
  - Conclusion
  - *Error Analysis**
  - *Data Access**

Final Lab book due Tuesday Nov 29th, 5:00pm

**Only some labs need these, I'll tell you in advance.*

Observational Astronomy is all about the Flux





$$F = \frac{L}{4\pi d^2}$$

Where L is the total Luminosity, and d is the distance to the observer

energy per second per unit area
Units:
  [W m^{-2}] (physics)
  [ergs s^{-1} cm^{-2}] (astronomy)

Magnitudes

The magnitude is the standard unit for measuring the apparent brightness of astronomical objects

If m_1 and m_2 = magnitudes of stars with fluxes f_1 and f_2, then,

$$m_1 - m_2 = -2.5 \log(f_1/f_2)$$

Alternatively,

$$f_1/f_2 = 10^{-0.4(m_1 - m_2)}$$

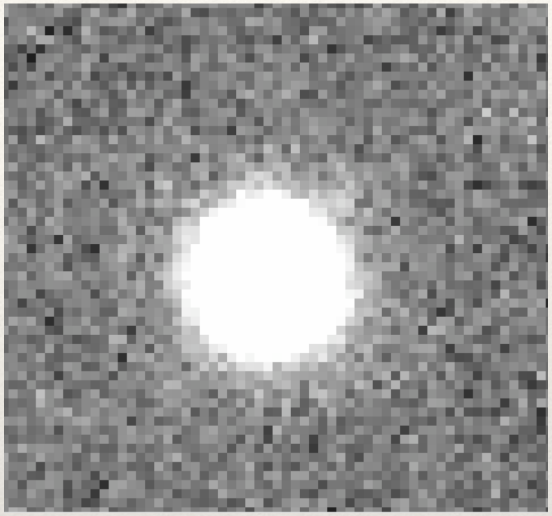
Note that 1 mag corresponds to a flux ratio of 2.5

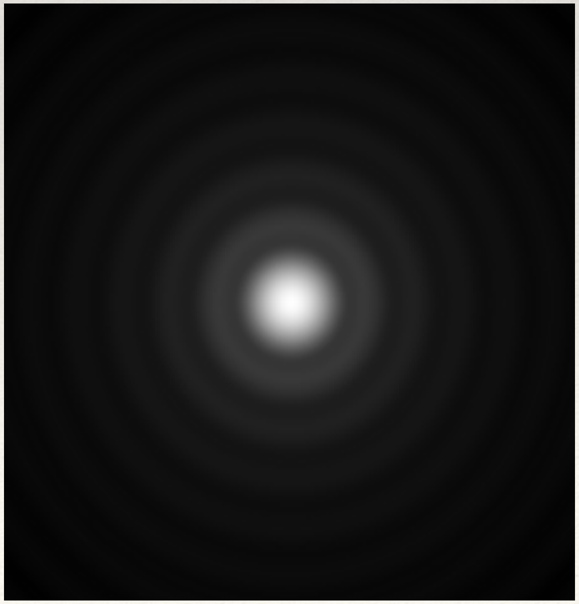
Note that 5 mag corresponds to a flux ratio of 100

The lower the value of the magnitude, the brighter the object

Photometry: Basic Questions

- How do you identify objects in your image?
- How do you measure the flux from an object?
- What are the potential challenges?
- Does it matter what type of object you're studying?





Topics

1. General Considerations
2. Stellar Photometry
3. Extended Source Photometry

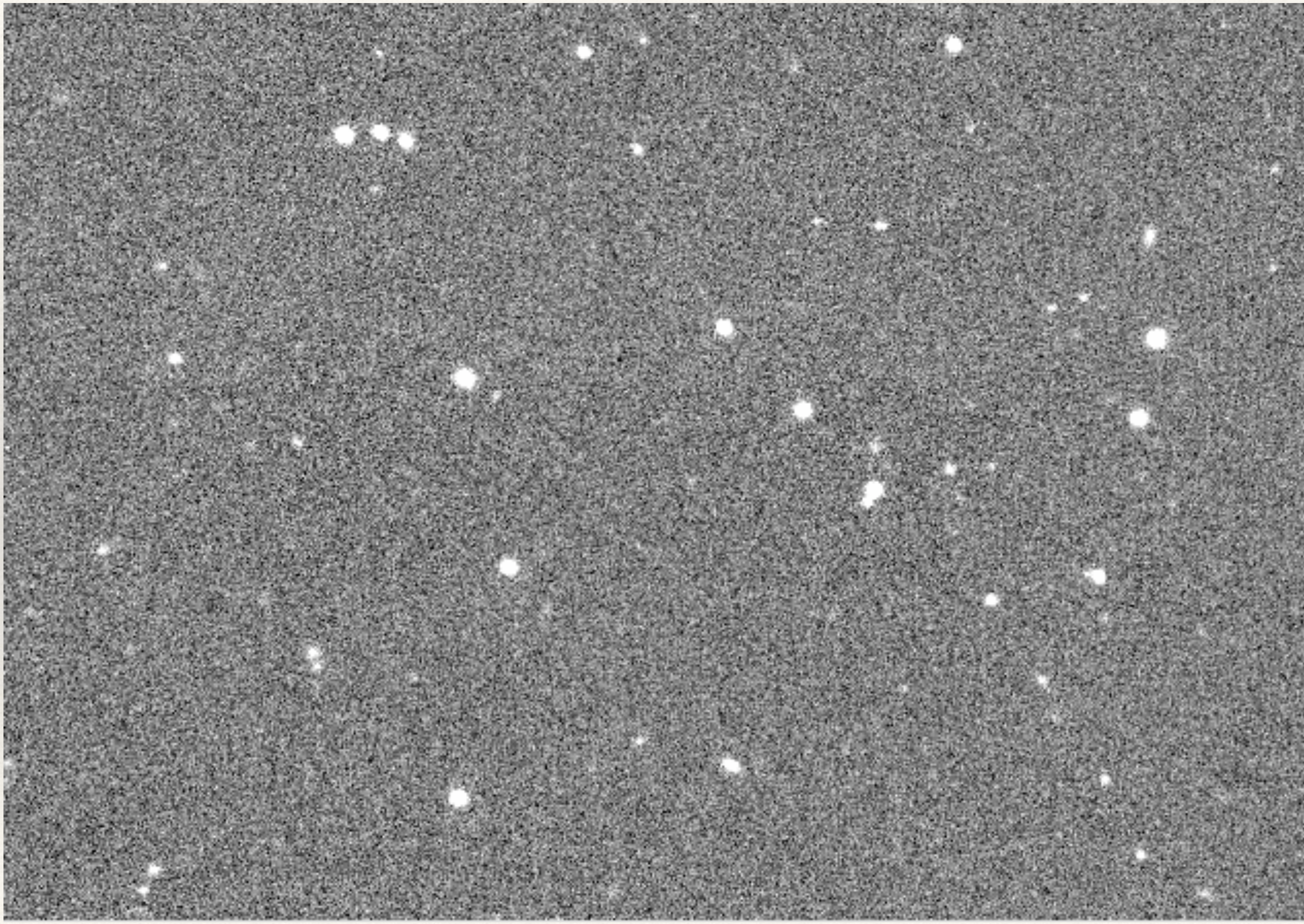
I: General Considerations

1. Garbage in, garbage out...
2. Object Detection
3. Centroiding
4. Measuring Flux
5. Background Flux
6. Computing the noise and correlated pixel statistics

Object Detection

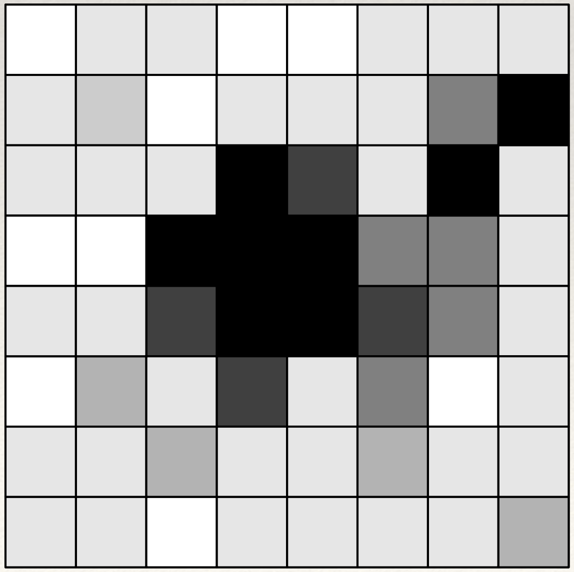
- Object Detection

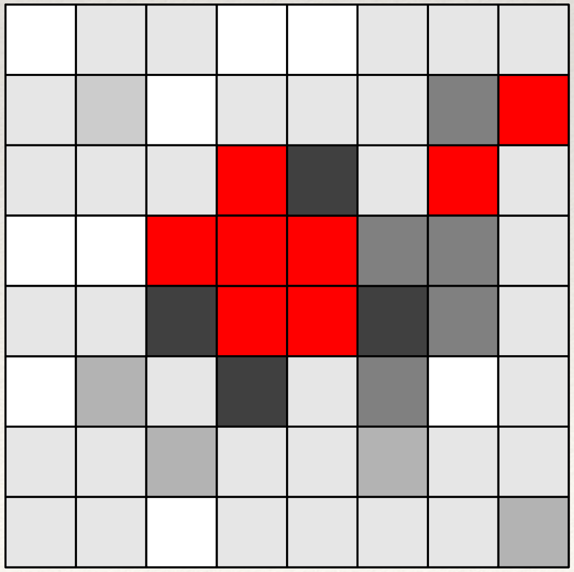
How do you mathematically define where there's an object?



Object Detection

- Object Detection
  - Define a *detection threshold* and *detection area*. An object is only detected if it has N pixels above the threshold level.
  - One simple example of a detection algorithm:
    - Generate a *segmentation image* that includes only pixels above the threshold.
    - Identify each group of contiguous pixels, and call it an object if there are more than N contiguous pixels





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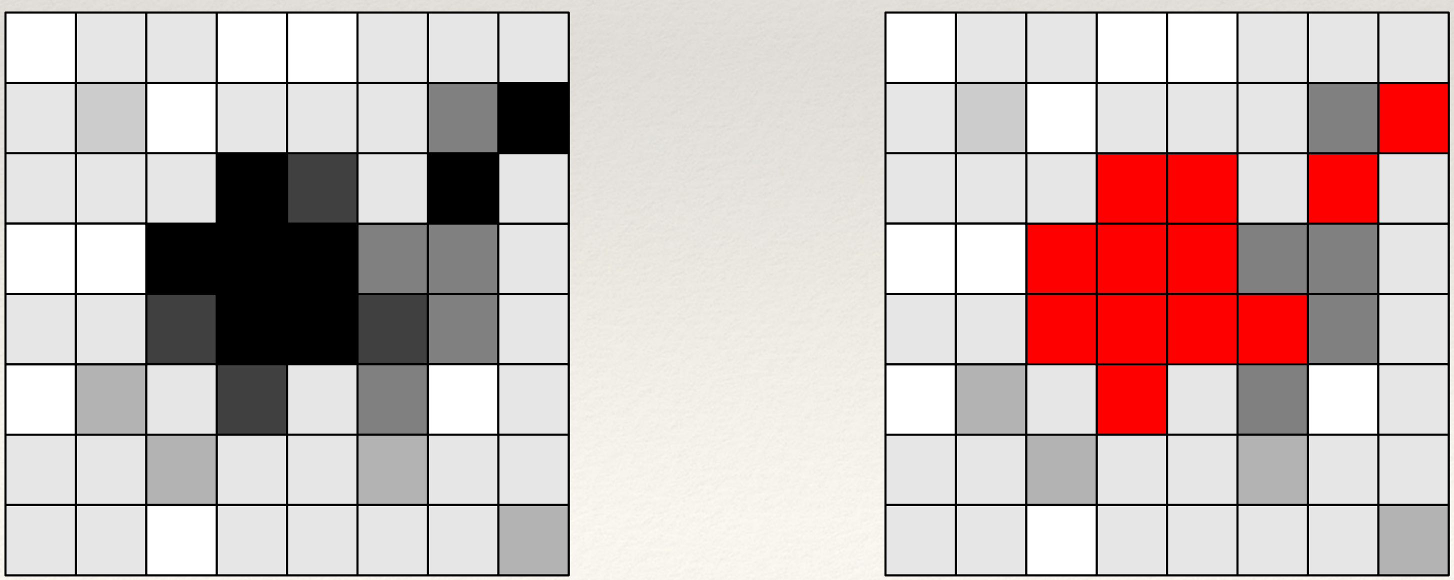

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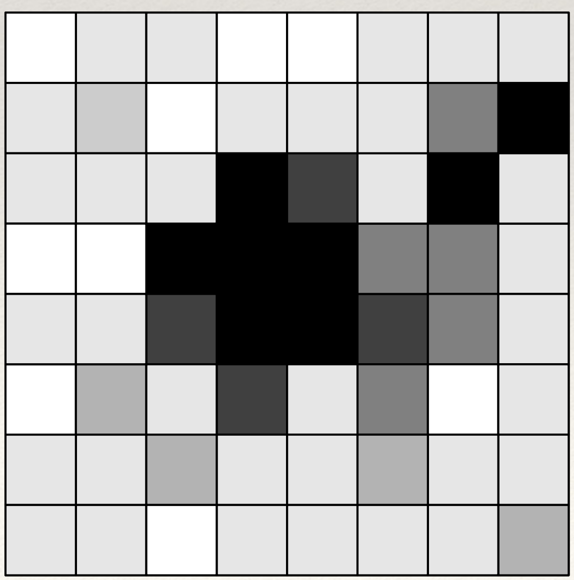
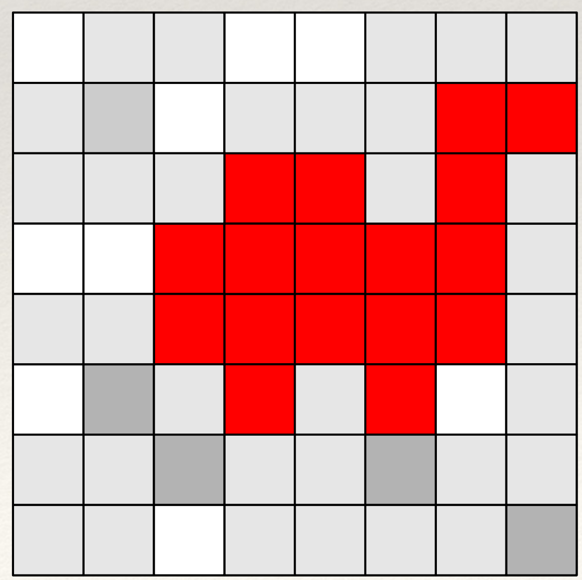
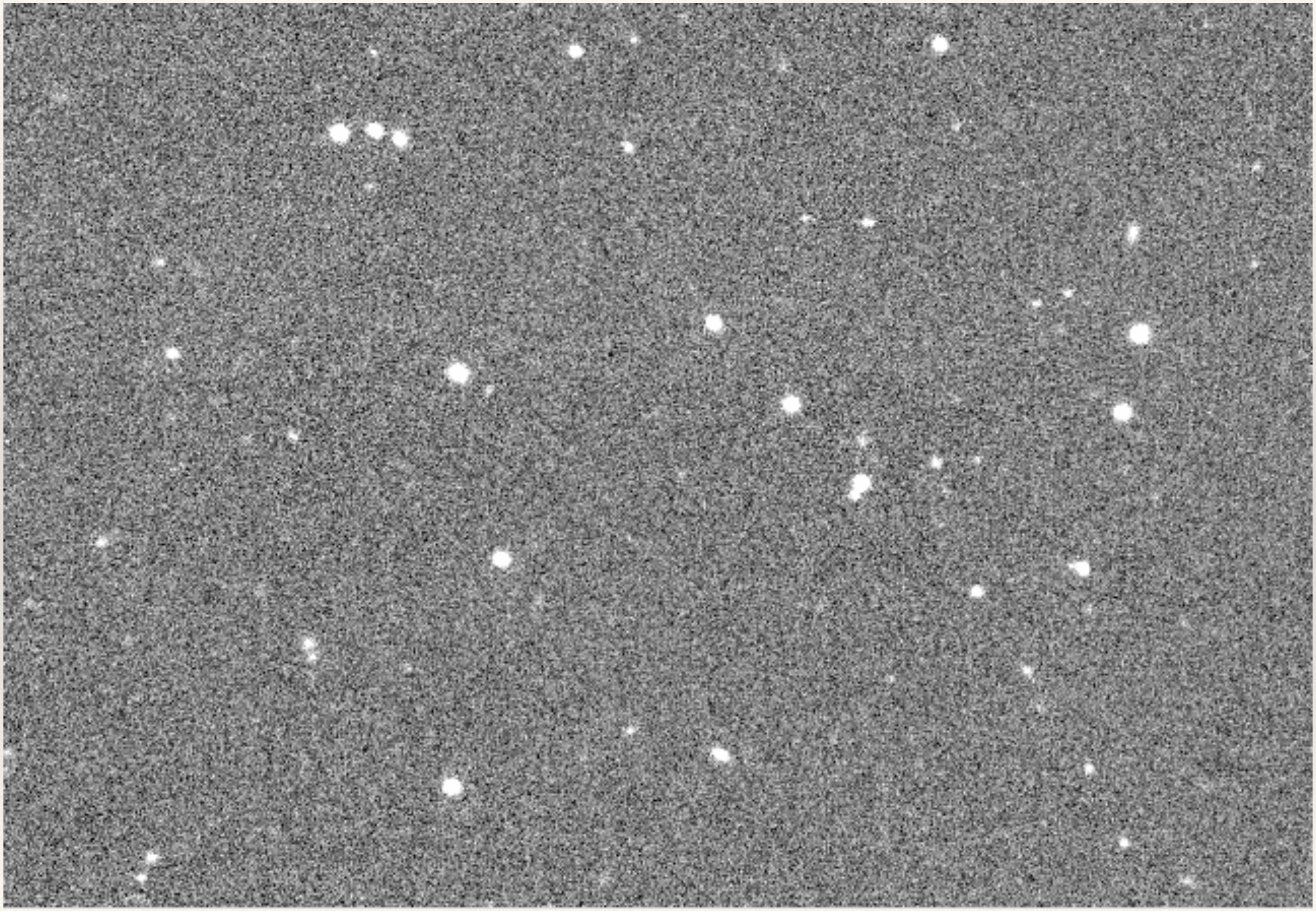
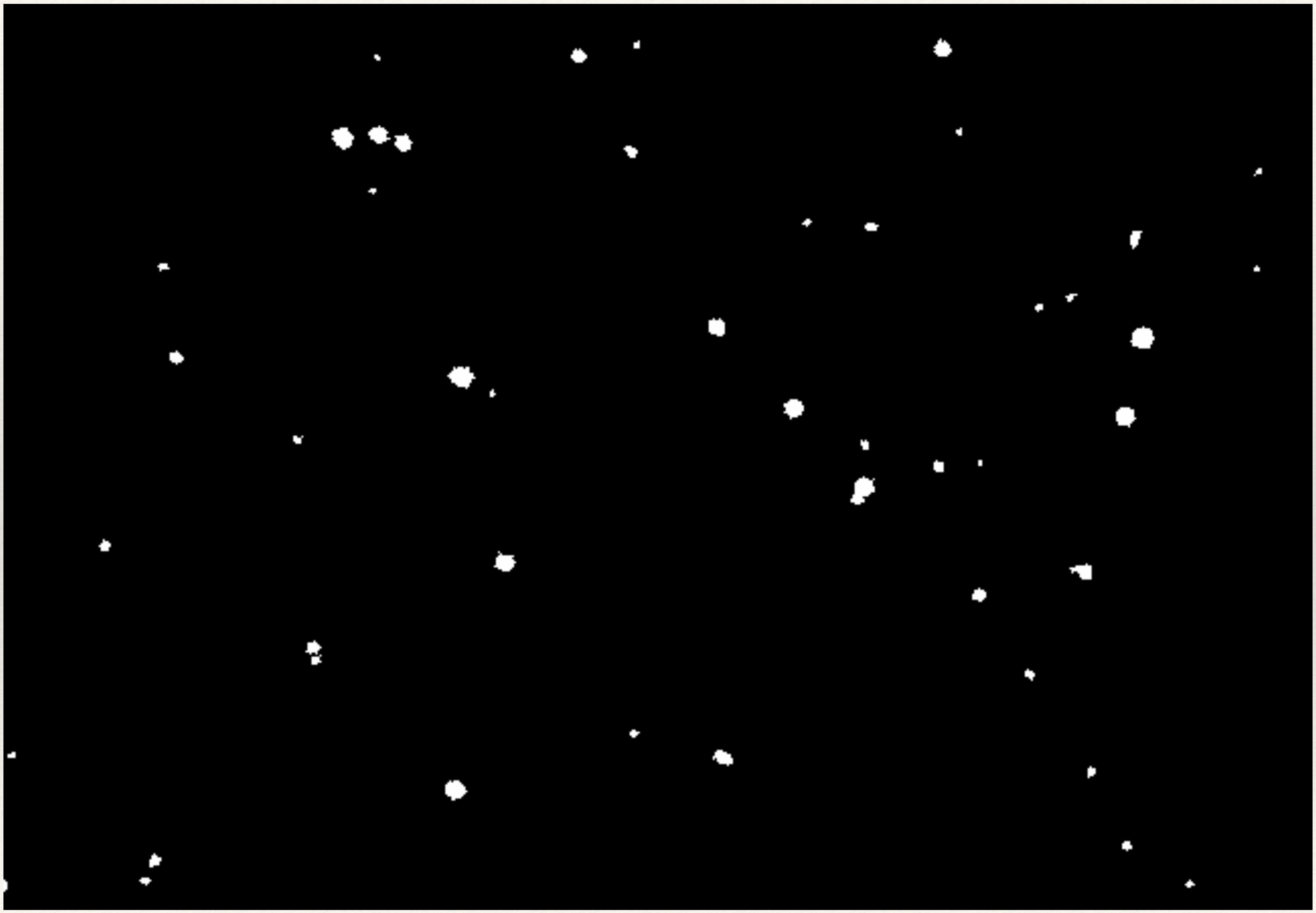




Object Detection



Object Detection



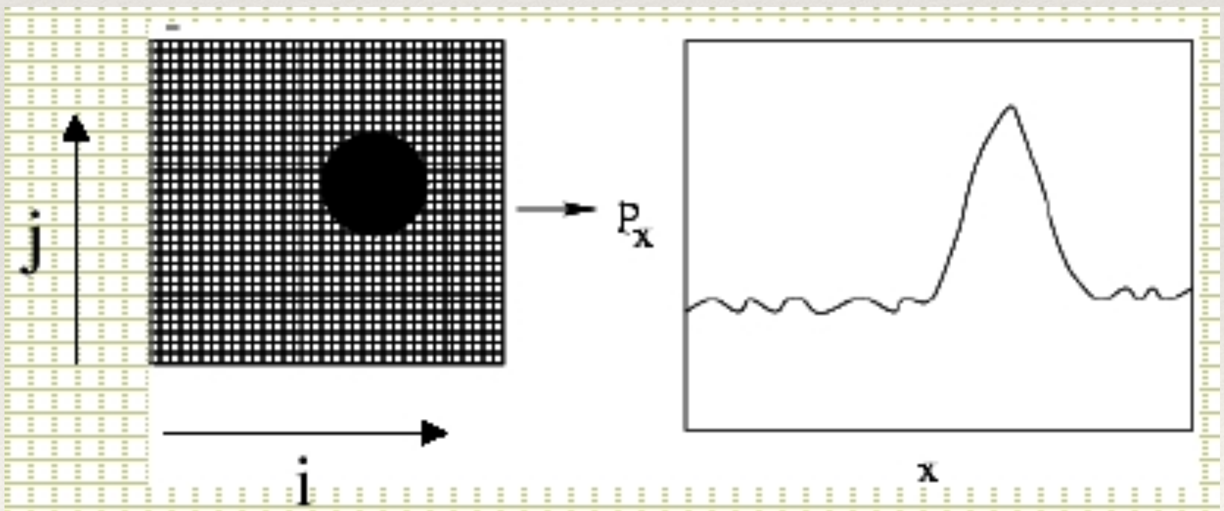
Measuring the Position

- Centroiding

How do you determine the centroid of an object?

Consider an image with flux levels
I(i,j) in pixel i,j. The ***marginal distribution*** along a given
axis is obtained by extracting a subsection of the image and summing along the row or columns.

Note that this is not the only way to find the centroid.



Examples of marginal distributions. From Mike Bolte's lecture notes: http://www.ucolick.org/~bolte/AY257/ay257_2.pdf and Steve Majewski's lecture notes: http://www.astro.virginia.edu/class/majewski/astr313/lectures/photometry/photometry_methods.html

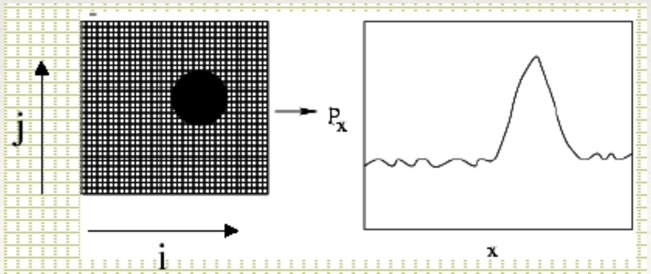
Centroiding

- Centroiding: Marginal Distribution
  - Step 1: Sum the pixel values I_{ij} along the 2N+1 rows and columns around the object.

    These are the marginal distributions.

$$P_{xi} = \sum_{j=-N}^{N} I_{ij}$$

$$P_{yj} = \sum_{i=-N}^{N} I_{ij}$$



Centroiding

- Centroiding: Marginal Distribution
  - Step 2: Determine an intensity-weighted centroid
  - xi, yi are the pixel coordinates

$$x_{cen} = \frac{\sum_i x_i \cdot P_{x_i}}{\sum_i P_{x_i}}$$

$$y_{cen} = \frac{\sum_j y_j \cdot P_{y_j}}{\sum_j P_{y_j}}$$

Centroiding

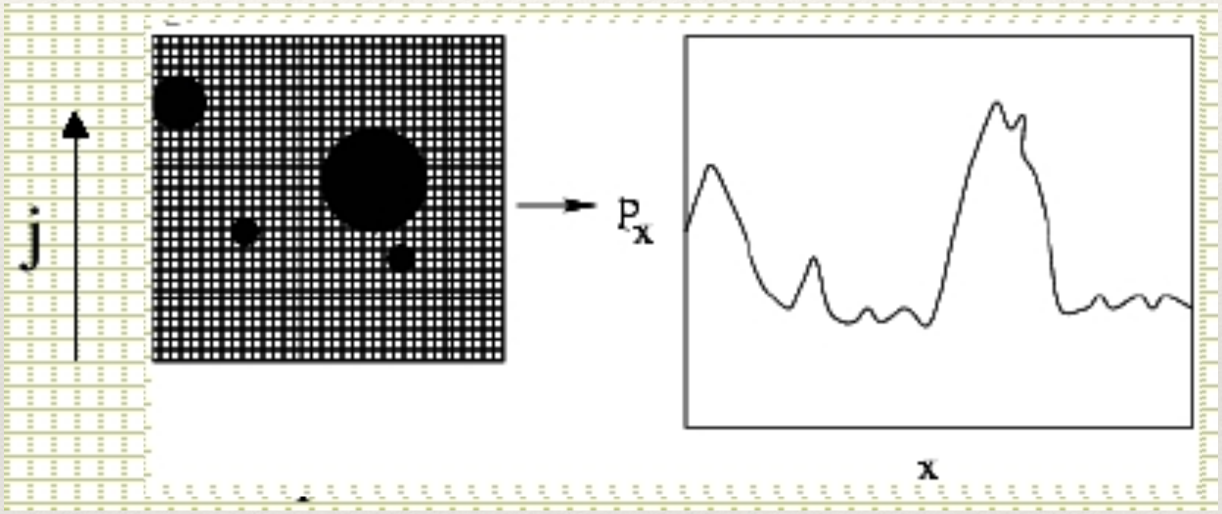
- Centroiding: Marginal Distribution
  - Uncertainties in the centroid locations

$$\sigma_x^2 = \frac{\sum_i (x_i - x_{cen})^2 \cdot P_{x_i}}{\sum_i P_{x_i}}$$

$$\sigma_y^2 = \frac{\sum_j (y_j - y_{cen})^2 \cdot P_{y_j}}{\sum_j P_{y_j}}$$

Centroiding

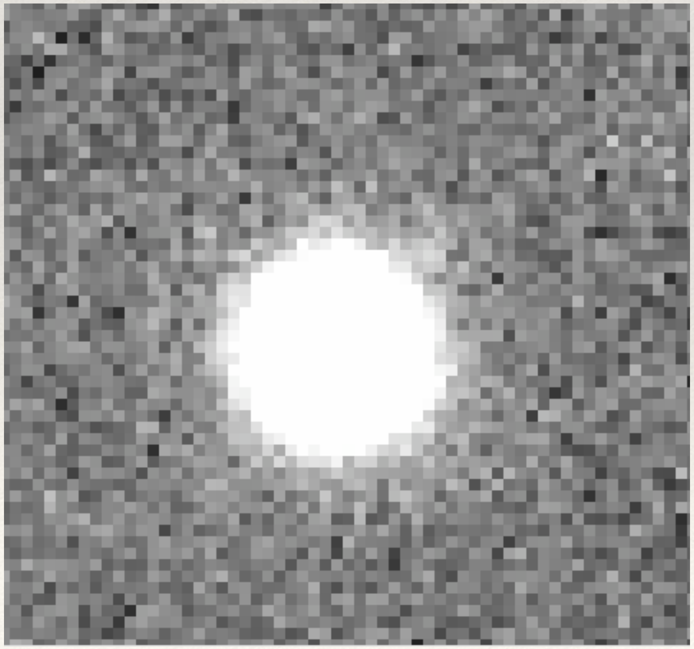
- Complication: Noise and multiple sources in image
  - Must decide what is a source and isolate sources (e.g. segmentation regions).
  - Compute the marginal distributions within isolated subregion.

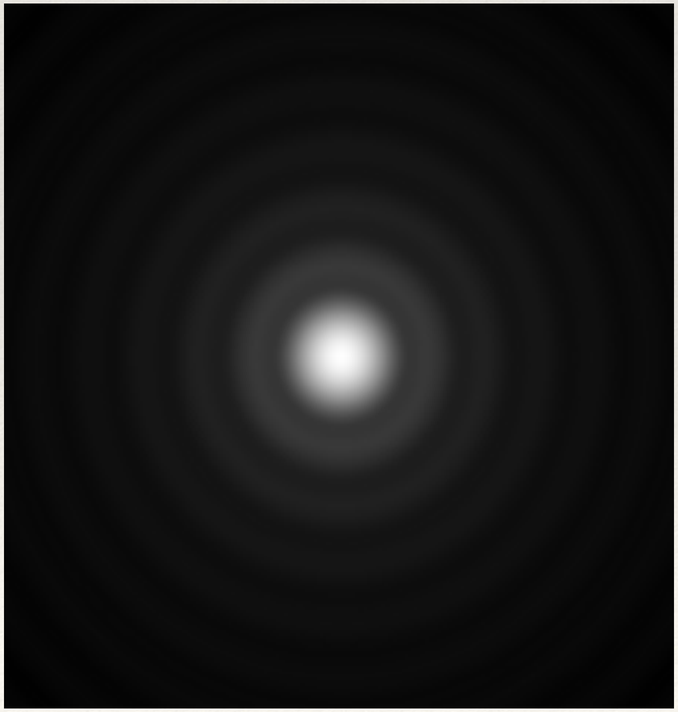


Measuring Flux in an Image

- How do you measure the flux from an object?
- Within what area do you measure the flux?

The best approach depends on whether you are looking at resolved or unresolved sources.

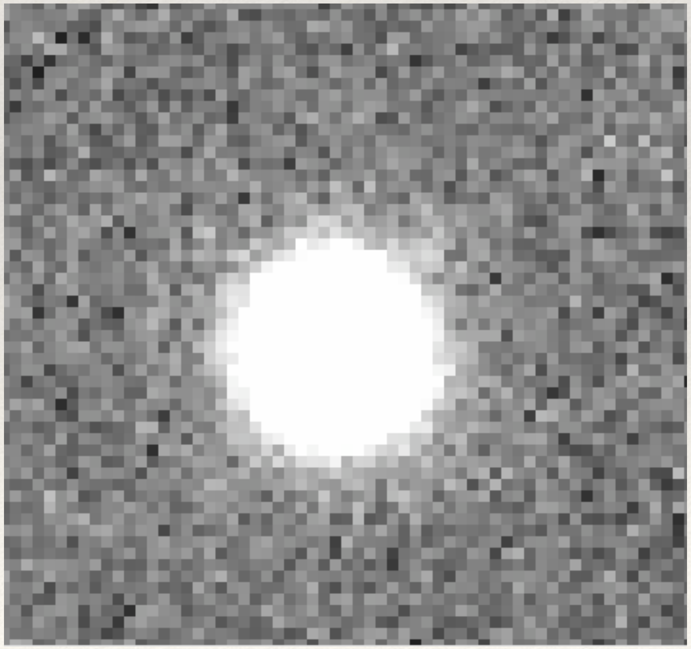




Background (Sky) Flux

- Background
  - The total flux that you measure (*F)* is the sum of the flux from the object (I) and the sky (S).

$$F = I + S = \sum I_{ij} + n_{pix} \cdot sky / pixel$$



- Must accurately determine the level of the background to obtain meaningful photometry (We'll return to this a bit later.)

Photometric Errors

Issues impacting the photometric uncertainties:

- Poison Error
  - Recall that the statistical uncertainty is Poisson in electrons rather than ADU. In ADU, the uncertainty is

$$\boxed{\sigma_{ADU} = \sqrt{ADU / Gain}}$$

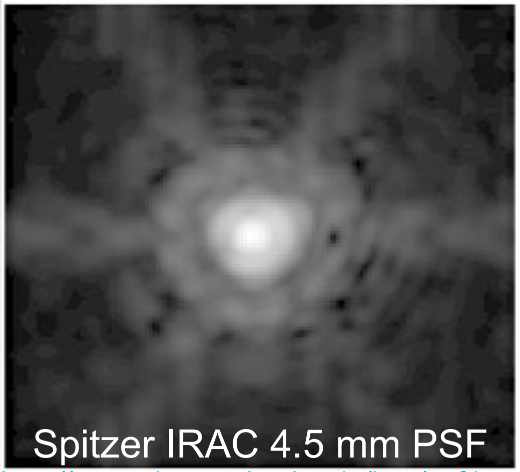
- Crowded field contamination
  - Flux from nearby objects can lead to errors in either background or source flux
- Gradients in the background sky level
- Correlated pixel statistics
  - Interpolation when combining images leads the uncertainties to be non-Poisson because the pixels are correlated.

II. Stellar Photometry

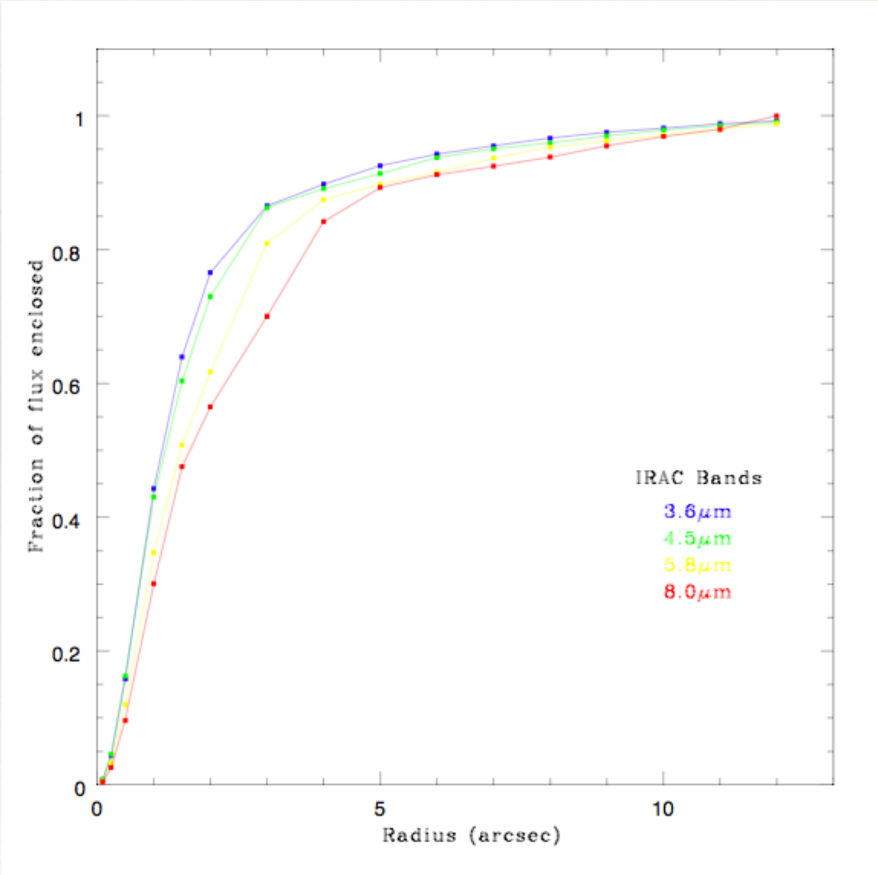
- Stars are unresolved point sources
  - Distribution of light determined purely by point spread function (PSF)
  - How do you measure the light?

Options:

- Aperture photometry
- PSF fitting



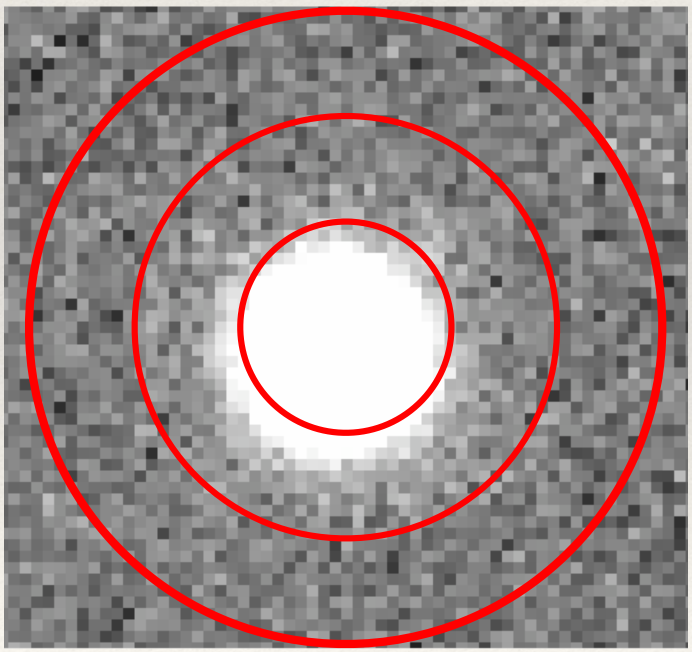
http://ssc.spitzer.caltech.edu/irac/psf.html

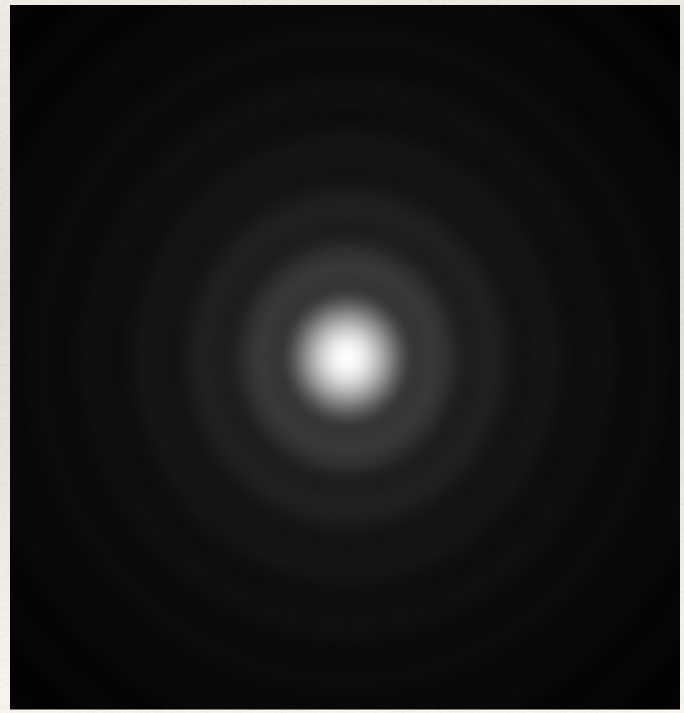


http://www.cfht.hawaii.edu/~morrison

II. Stellar Photometry

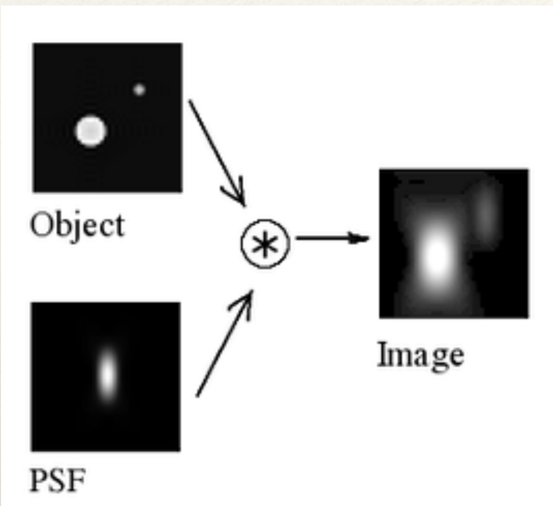
- Aperture Photometry:
  - Measure the flux within an pre-defined (typically circular) aperture.
  - Can calibrate as long as you use the same aperture for your standard star.
  - Can compute total flux if you know curve of growth.

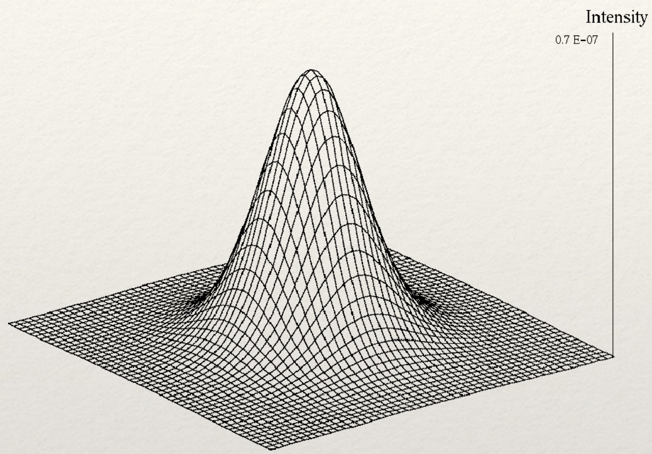


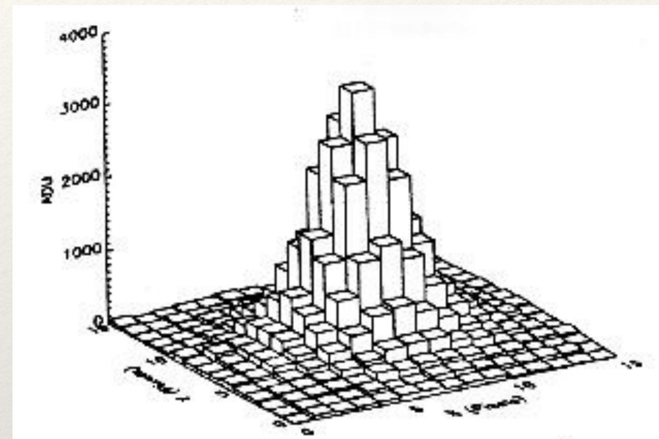


What are the potential drawbacks?

Point Spread Function



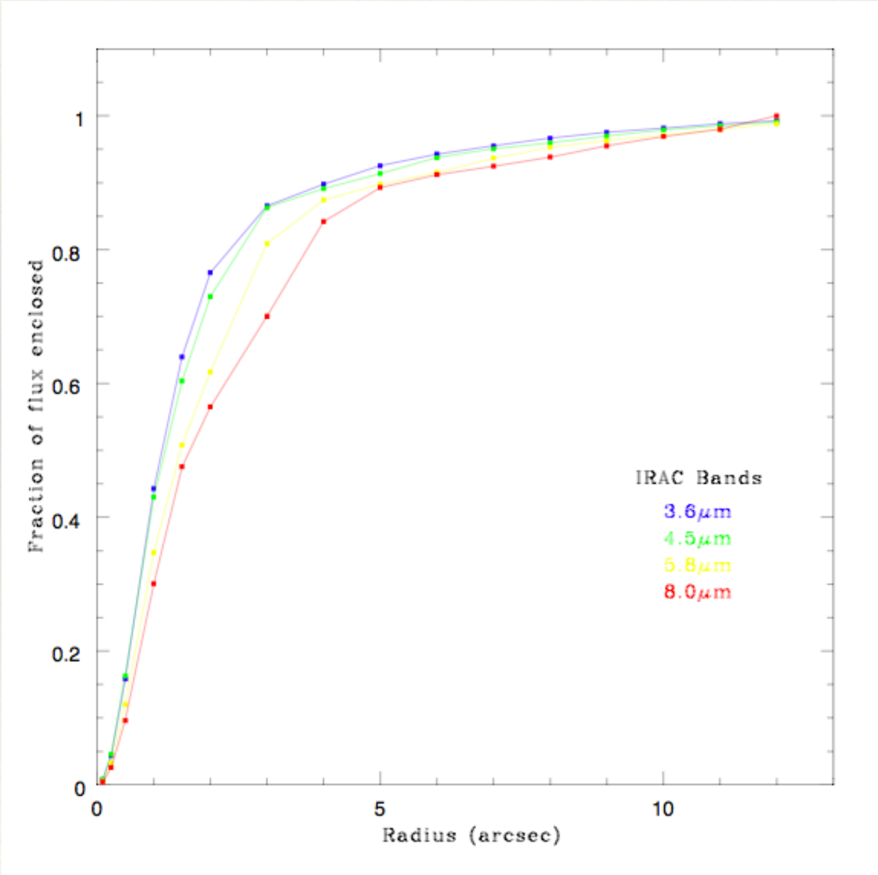




The point-spread function is the distribution of light on the detector. It is made up of the Airy disk of the source, seeing, defocus, etc.

II. Stellar Photometry

- Stars are unresolved point sources
  - Distribution of light determined purely by point spread function (PSF)
  - How do you measure the light?



- “Curve of Growth”
  - Radial profile showing the fraction of total light within a given radius

http://www.cfht.hawaii.edu/~morrison

II. Stellar Photometry

- PSF fitting:
  - Determine the form of the PSF and then fit the amplitude to all the stars in the image.
  - Can use an empirically constructed PSF or an analytic parameterization
  - Typical parameterizations of PSF
    - Gaussian

      $I(r) = \exp(-0.5 * (r/\sigma)^2)$

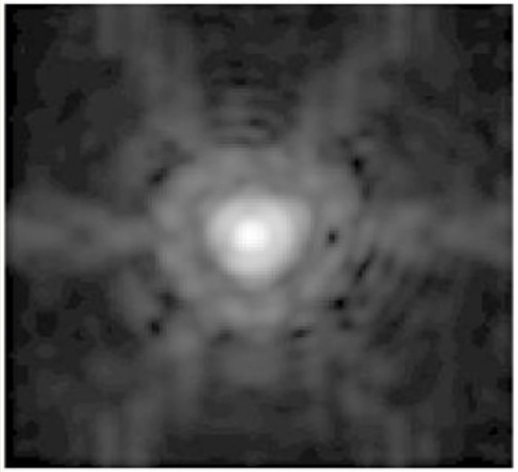
      $F(r) = 1 - \exp(-0.5 * (r/\sigma)^2)$

      $\mathrm{FWHM} = 2\sigma * \mathrm{sqrt}(2 * \ln(2))$
    - Moffatt

      $I(r) = (1 + (r/\alpha)^2))^{-\beta}$

      $F(r) = 1 - (1 + (r/\alpha)^2))^{(1-\beta)}$

      $\mathrm{FWHM} = 2\alpha * \mathrm{sqrt}(2^{1/\beta} - 1)$

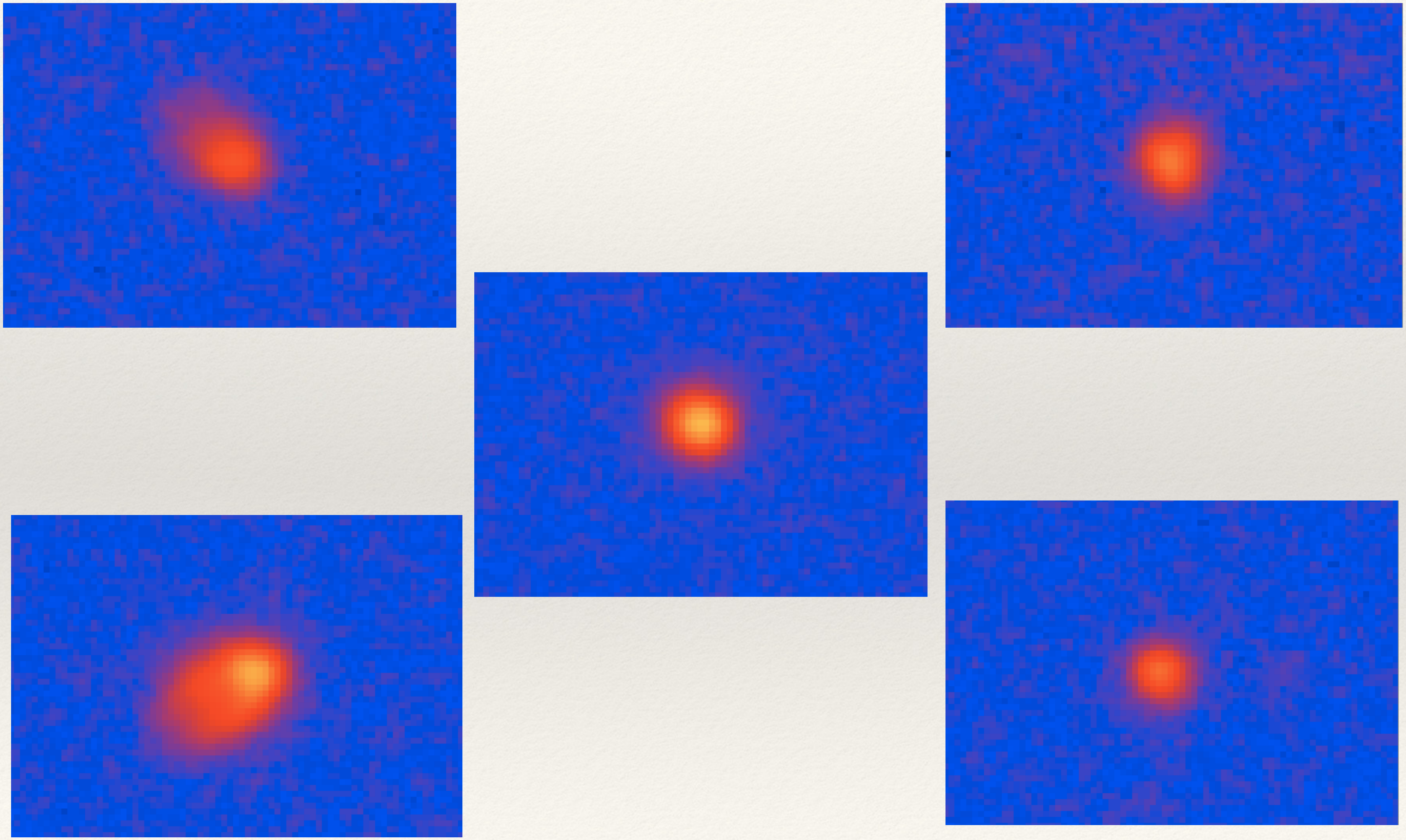


where I(r) is the intensity profile and F(r) is the enclosed flux profile. F(r) is typically what is fit to determine the best parameters. The FWHM formulae correspond to what you would see in IRAF using imexam.

II. Stellar Photometry

- PSF fitting:
  - Advantages:
    - Still works in crowded fields (can fit the center)
    - Regions with highest S/N have most weight in determining fit
    - Background is included as one additional parameter (constant in the fit)
  - Potential problems:
    - The PSF is not well described by the parametric profiles.
    - The PSF varies across the detector.

II. Stellar Photometry



Example PSFs from a FLAMINGOS image.

II. Stellar Photometry

- Potential problems:
    - The PSF is not well described by the parametric profiles.
    - The PSF varies across the detector.

- Solutions:
  - PSF variations
    - Generate multiple PSF models for different parts of the detector and interpolate between these models

  - If parametric representation bad
    - Empirical PSF or include a non-parametric component in your PSF model
      - Use a very bright star
      - Fit the best psf model
      - In based upon parametric fit, keep a map of the residuals to correct for variations.

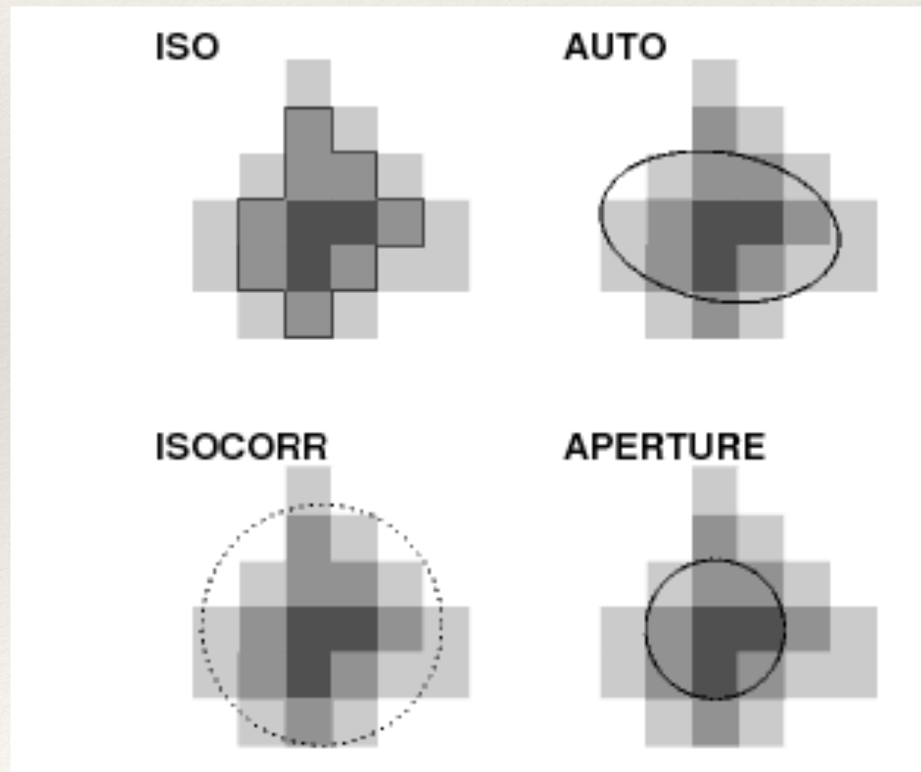
II. Stellar Photometry

- Determining Photometric Errors
  - Best approach: Artificial Star Tests
    - Basic idea - Insert a large number of fake stars into image and then obtain photometry for these objects.
    - Provides a direct measure of the scatter between true and observed magnitudes
    - Caveat: Requires that you have a good model for the PSF

III. Extended Source Photometry

- Galaxies, HII regions, and many other astronomical objects are extended
  - Distribution of light determined by convolution of PSF and intrinsic shape
  - How do you measure the light?
  - How far out does the galaxy extend?

- Multiple Methods
  - Non-parametric
    - Aperture magnitudes
    - Isophotal magnitudes
    - Kron magnitudes
    - Petrosian magnitudes
  - Parametric
    - Assume profile for object



5-10% accuracy generally considered decent for galaxies.

From Source Extra

III. Extended Source Photometry

<u>Non-parametric</u>

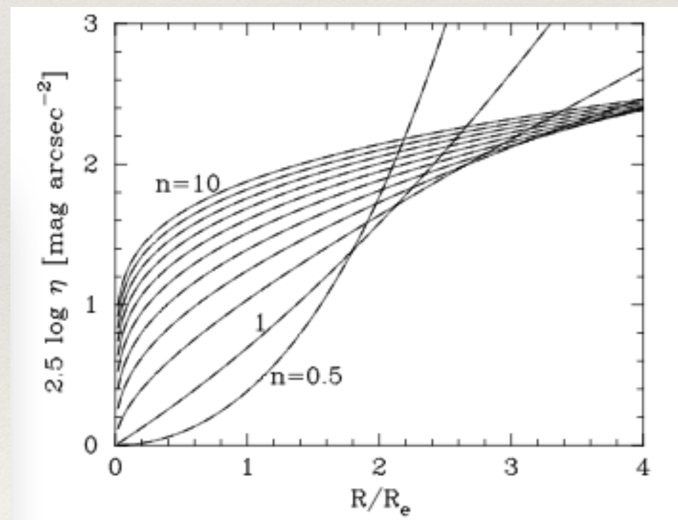
Petrosian magnitudes (Petrosian, 1976) *Used for SDSS*

Define a standard radius based upon the Petrosian index and use that to determine the aperture for each galaxy.

$$\eta_P = \frac{2\pi \int_0^R I(x)\,x\,dx}{\pi R^2 I(R)} = \frac{L(<R)}{\pi R^2 I(R)}$$

The Petrosian index is the ratio of the average brightness within radius R to the brightness at radius R.

It is standard to define the Petrosian radius, R_P, as the distance at which η_P=5 and then measure the light within 2 R_P.



For most galaxies the above definition gets >80% of the light.

Caveat: R_P is correlated with profile shape.

Figures and Reference: Graham &

III. Extended Source Photometry

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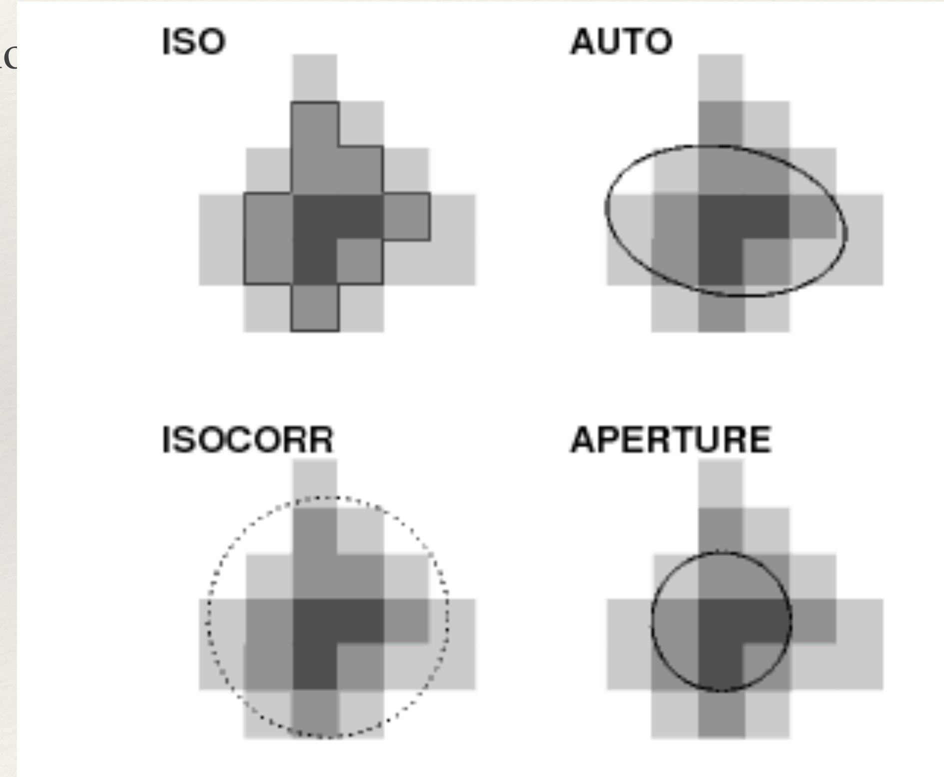


From Source Extractor Manual

- Multiple Methods
  - Non-parametric
    - Aperture magnitudes
    - Isophotal magnitudes
    - Kron magnitudes
    - Petrosian magnitudes

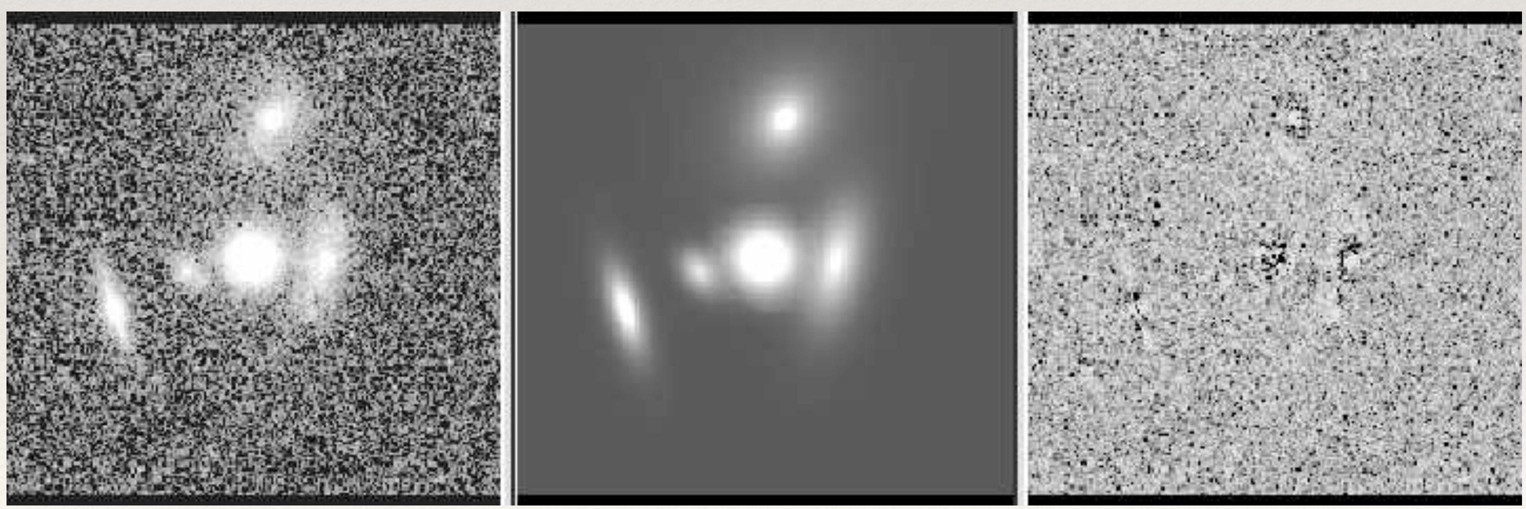
What do you see as the advantages/disadvantages of each?

III. Extended Source Photometry

Parametric

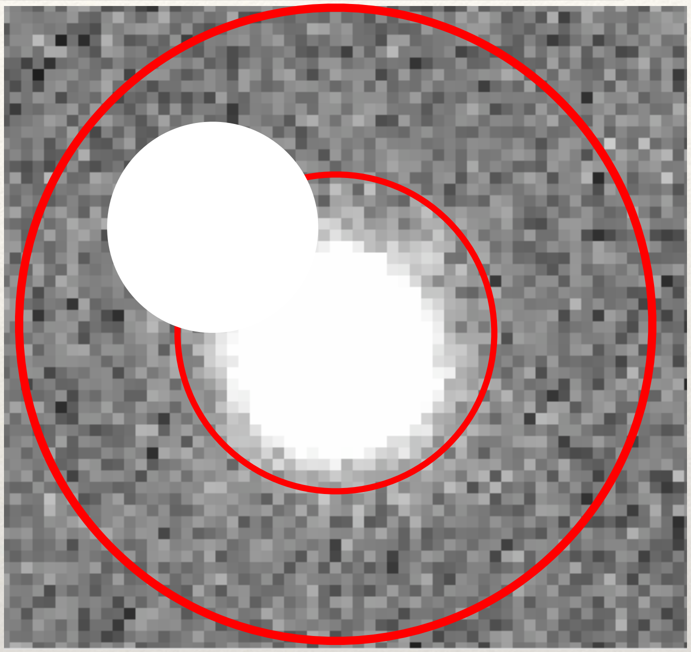
1. Assume a parametric model for the object.
   Examples: Exponential disk, Disk+Bulge, Sersic Profile

2. Perform a chi-squared minimization to obtain the best fit for the object
   Outputs will be position and model parameters, from which one can derive the total flux.



Galfit Home Page -- : http://users.oc

IV. More General Considerations



- What do you do if objects overlap?
- How / where do you determine the sky level?
  - Global (mean sky for image) or
  - Local (some annular region around object) ?
- How do you determine the uncertainty?
  - Do you have Poisson noise in the image?
    - If sky-subtracted, then you need to know what the original sky level was.
    - If N frames have been averaged, then you need to account for this
    - If pixels are correlated (i.e. smoothed data), then most codes will significantly underestimate the errors.