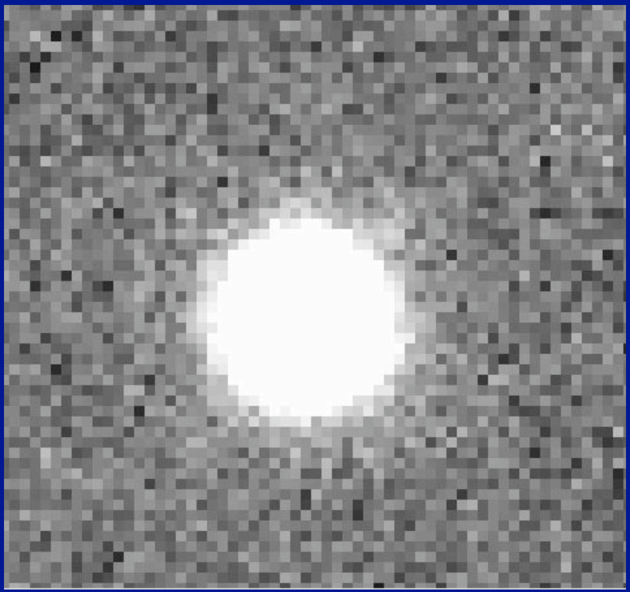
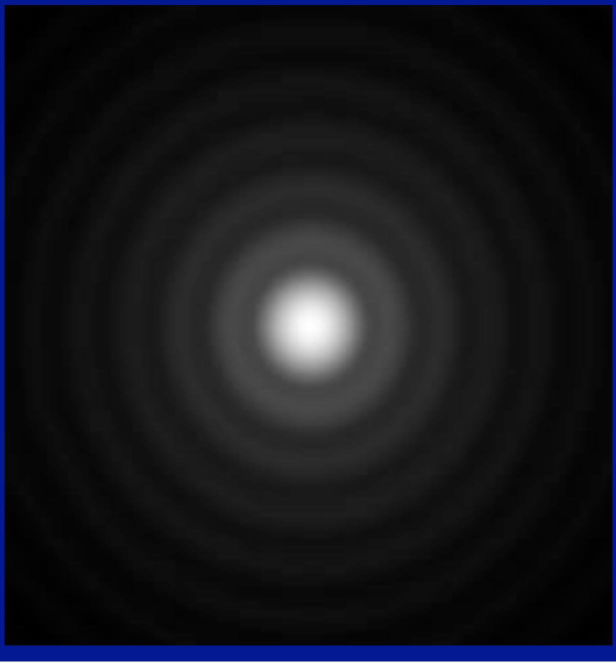
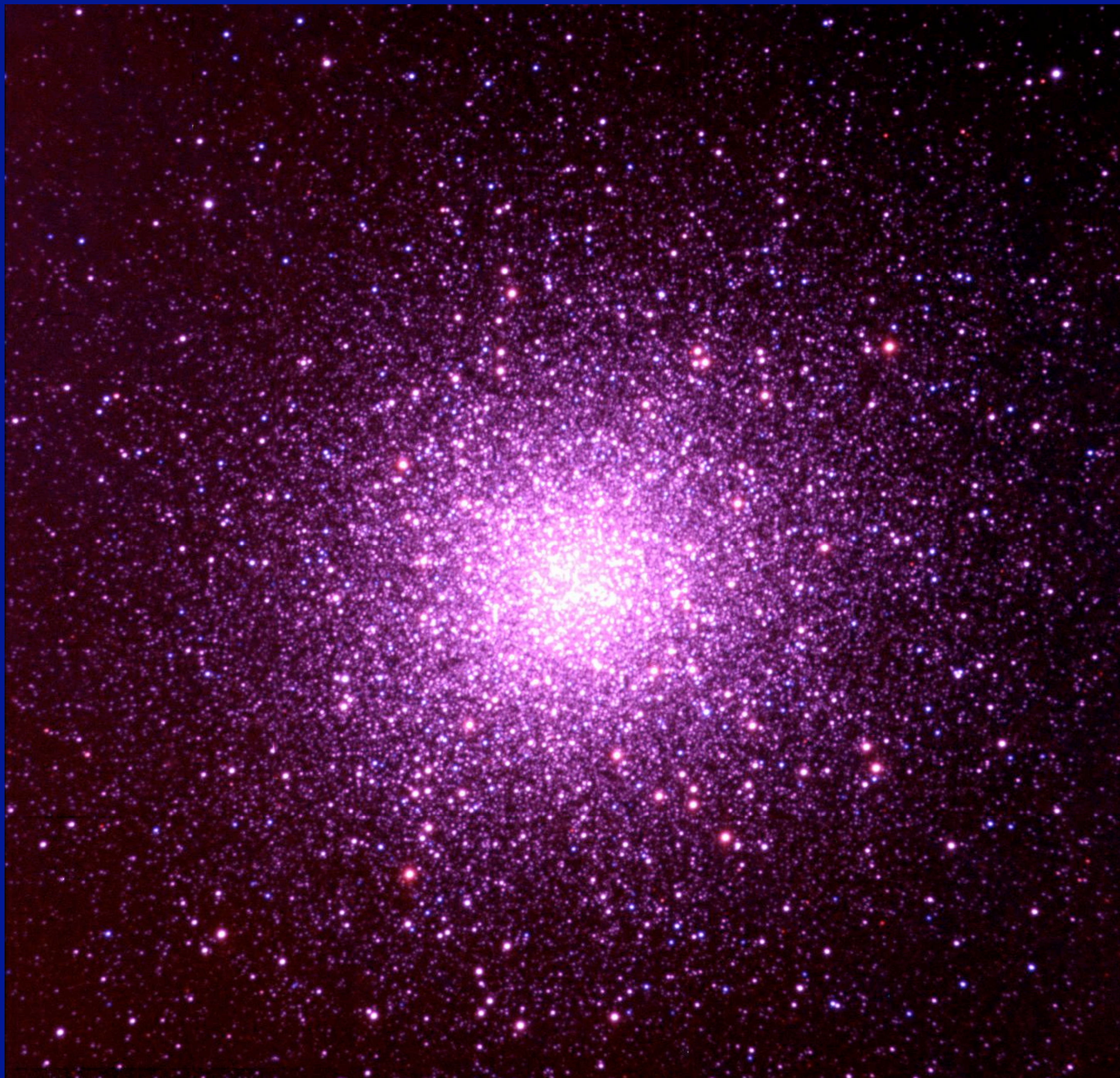
Basics of Photometry

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. Galaxy Photometry

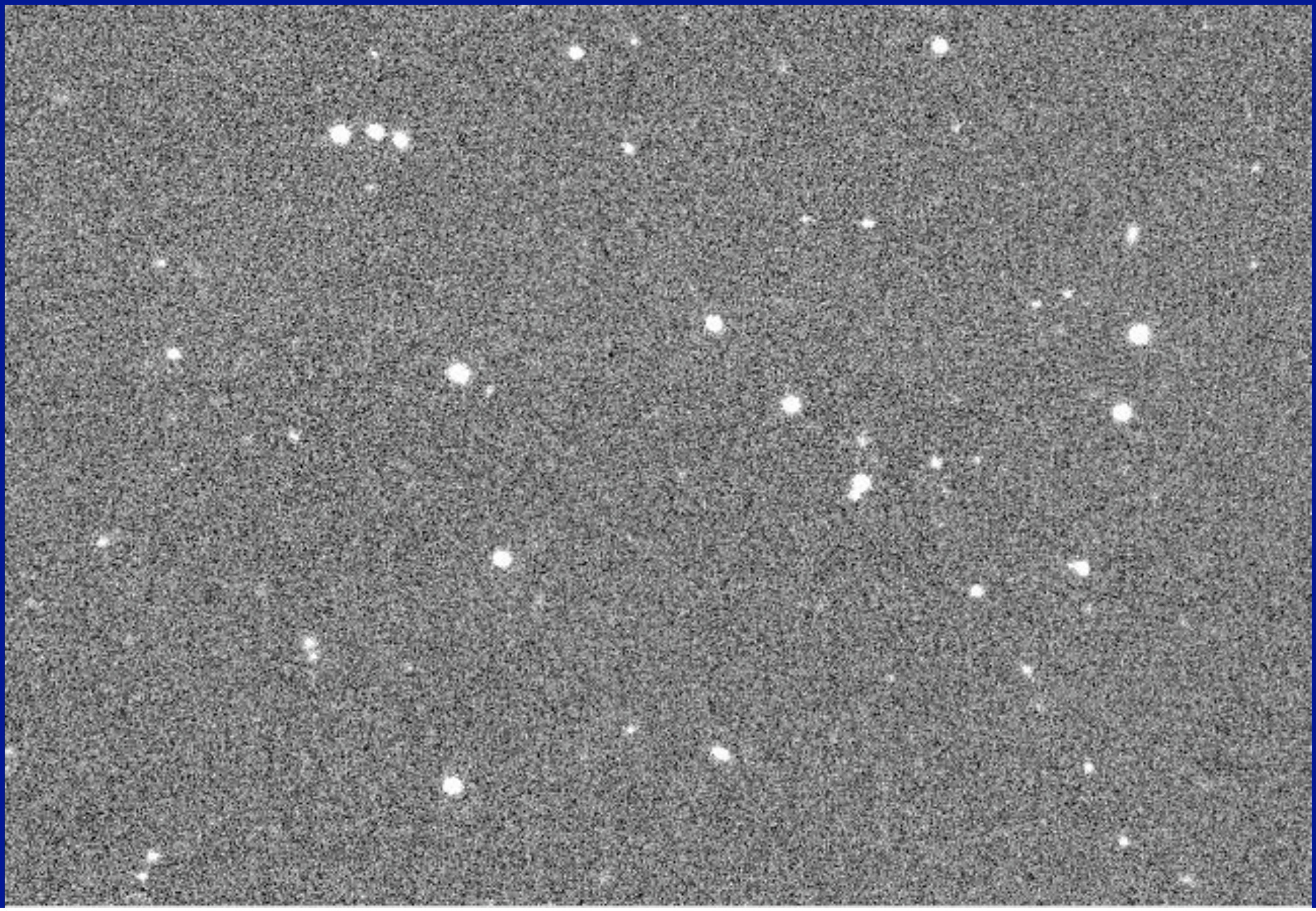
I: General Considerations

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

I: General Considerations

- Object Detection

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

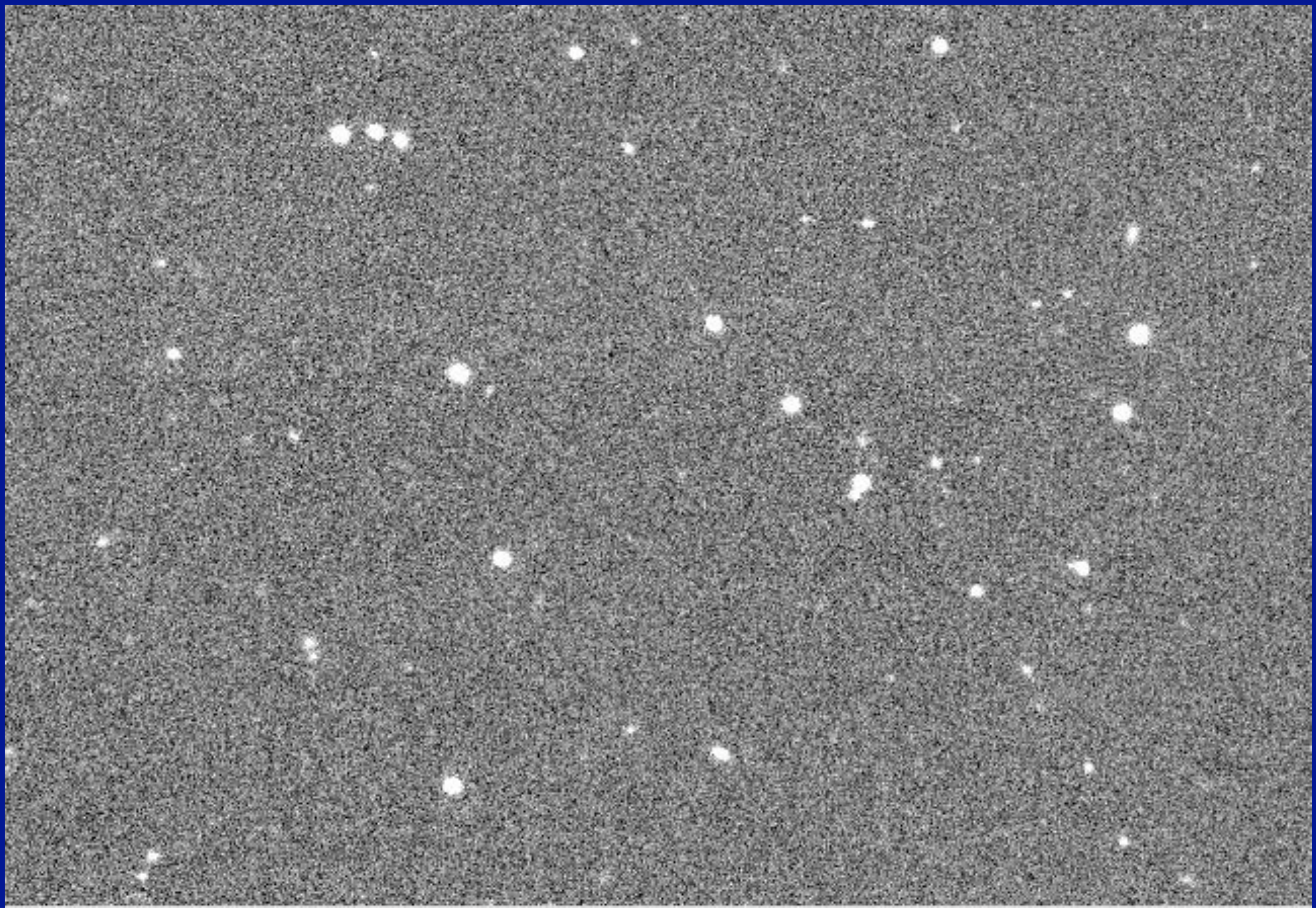


I: General Considerations

- 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

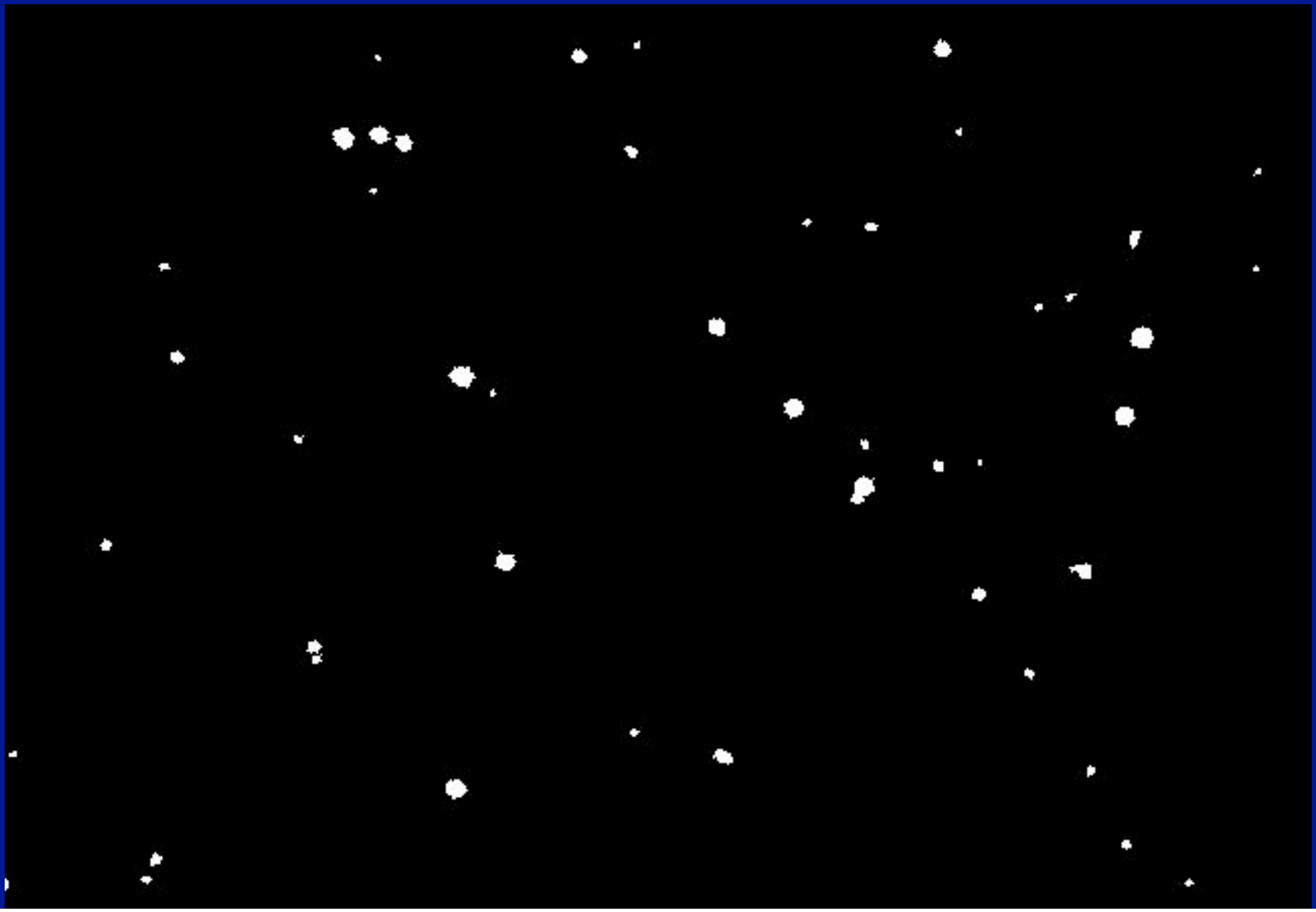
I: General Considerations

- Object Detection



I: General Considerations

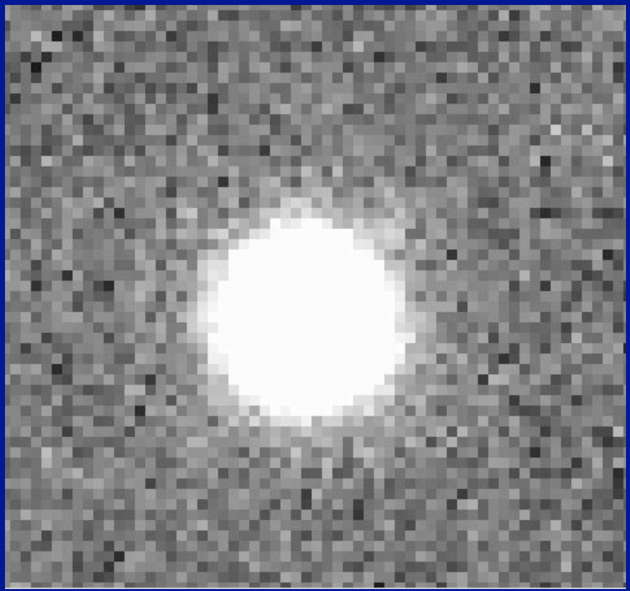
- Object Detection

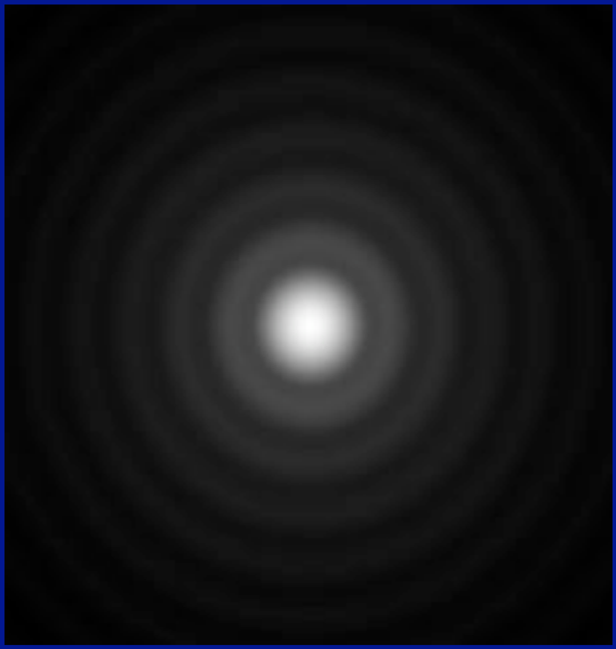


Measuring Flux in an Image

- 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.



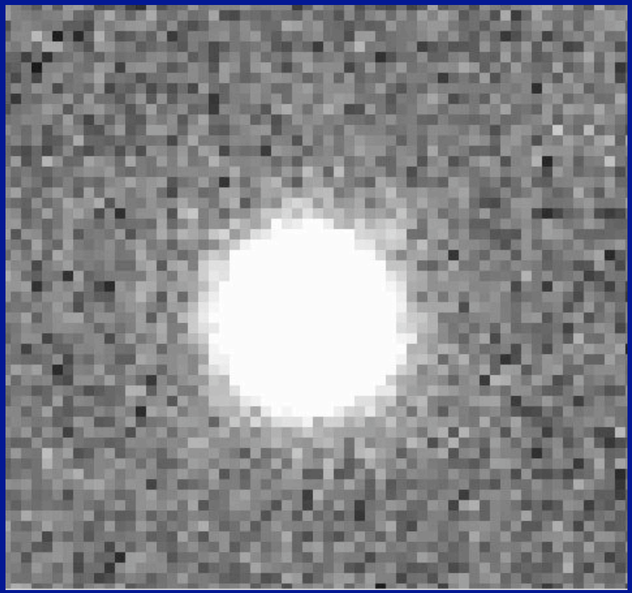


Background (Sky) Flux

- 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 obtaining meaningful photometry (We'll return to this a bit later.)



Photometric Errors

Issues impacting the photometric uncertainties:

- Poisson 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

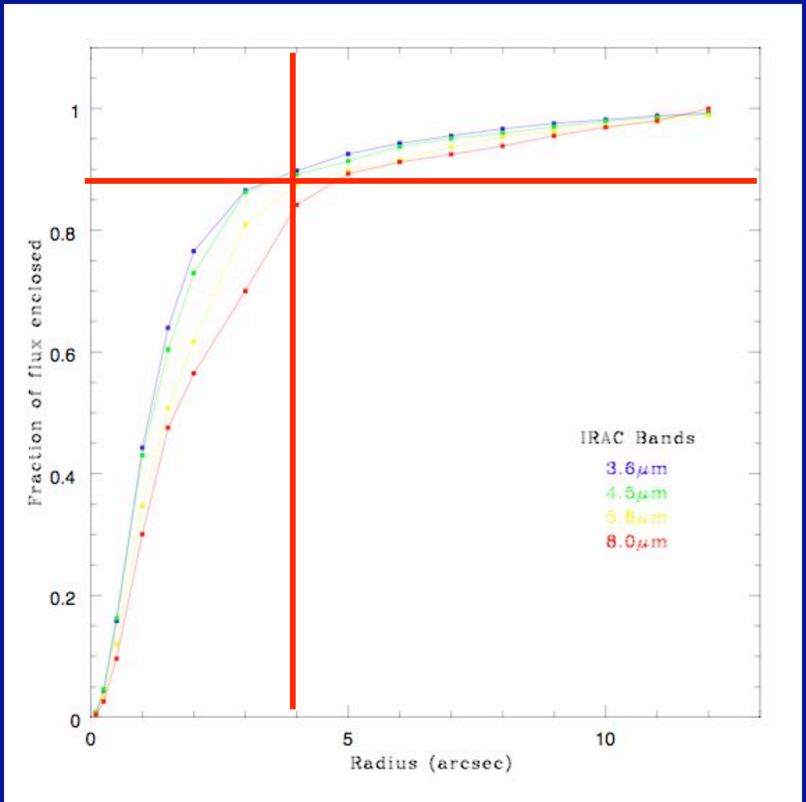
- Correlated pixel statistics
  - Interpolation when combining images leads the uncertainties to be non-Poisson because the pixels are correlated.

We will discuss later optimal ways to deal with crowded fields and correlated pixel statistics.

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

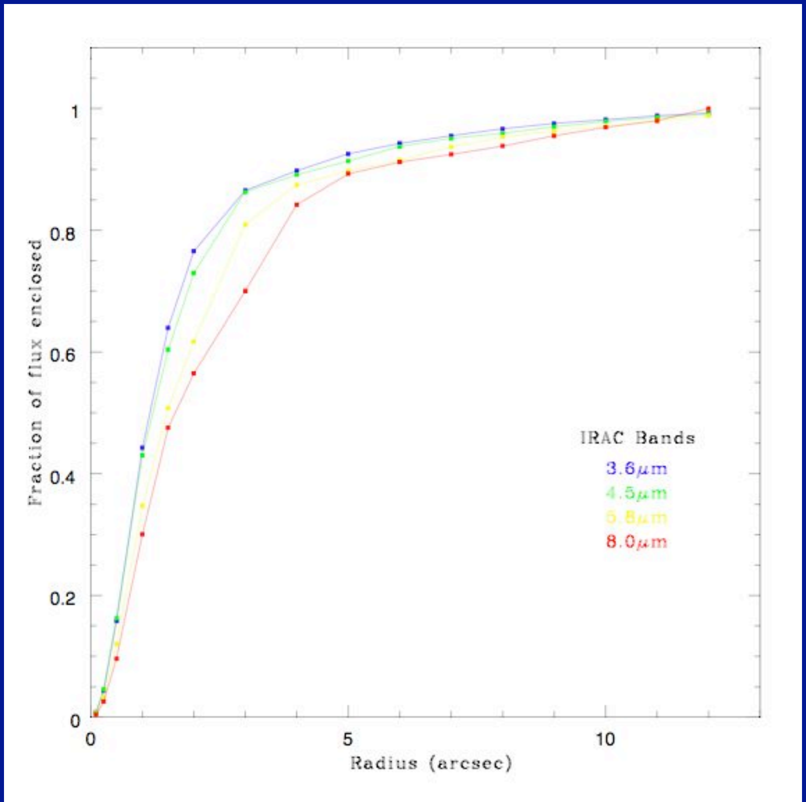


http://www.cfht.hawaii.edu/~morrison/home/GOODS/curve_of_growth.html

II. Stellar Photometry

- How do you measure the light?

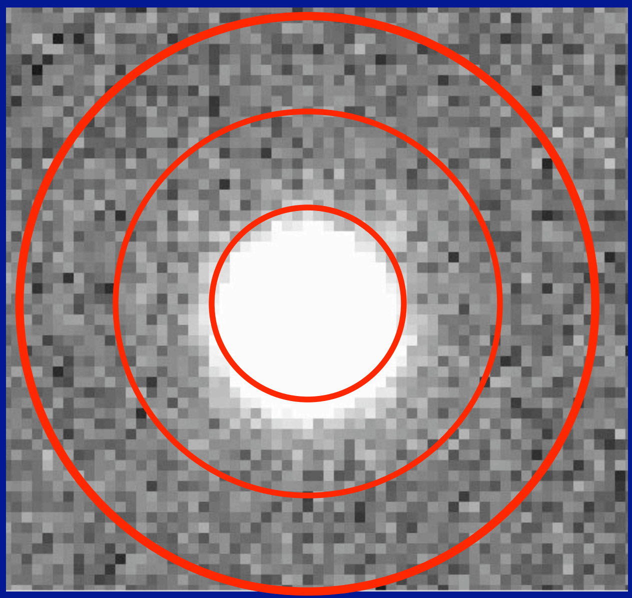
- Options:
  - Aperture photometry
  - PSF fitting

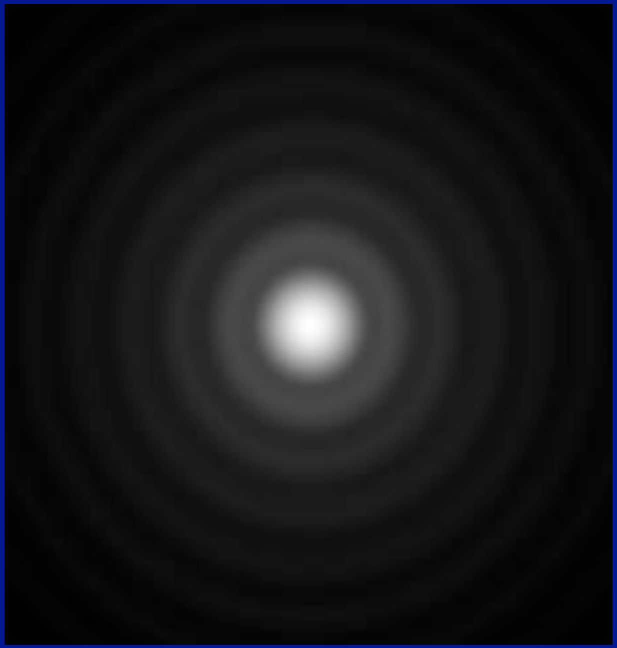


http://www.cfht.hawaii.edu/~morrison/home/GOODS/curve_of_growth.html

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?

II. Stellar Photometry

- PSF fitting:
  - Determine the form of the PSF and then fit the amplitude to all the stars in the image.
  - Typical parameterizations of PSF
    - Gaussian

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

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

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

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

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

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

    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:
  - Determine the form of the PSF and then fit the amplitude to all the stars in the image.
  - Typical parameterizations of PSF

Gaussian

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

$$F(r) = 1 - e^{-r^2/2\sigma^2}$$

$$FWHM = 2\sigma\sqrt{2\ln 2}$$

Moffat

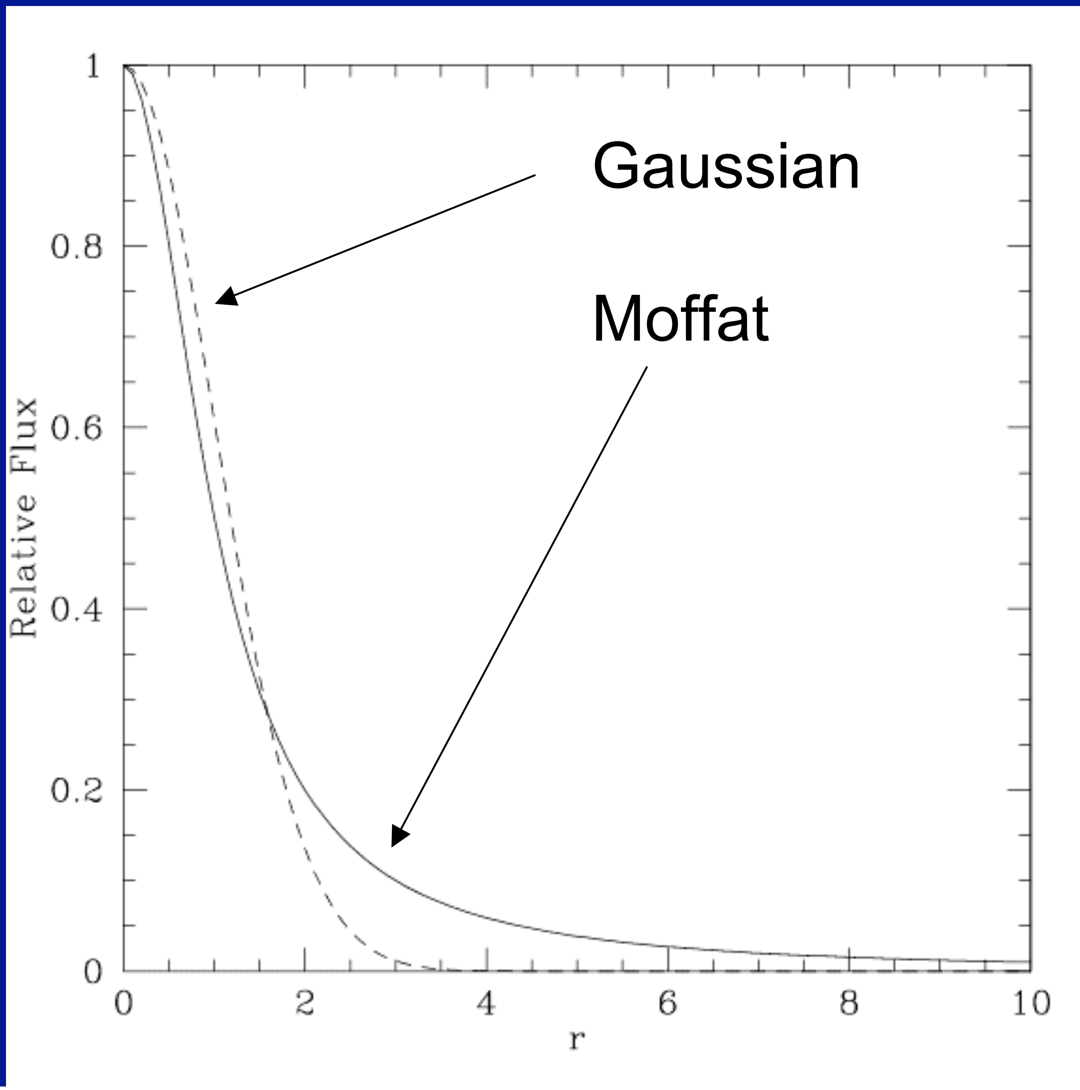
$$I(r) = \left(1 + \left(r/\alpha\right)^2\right)^{-\beta}$$

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

$$FWHM = 2\sigma\sqrt{2^{1/\beta} - 1}$$

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



Gaussian: σ=1

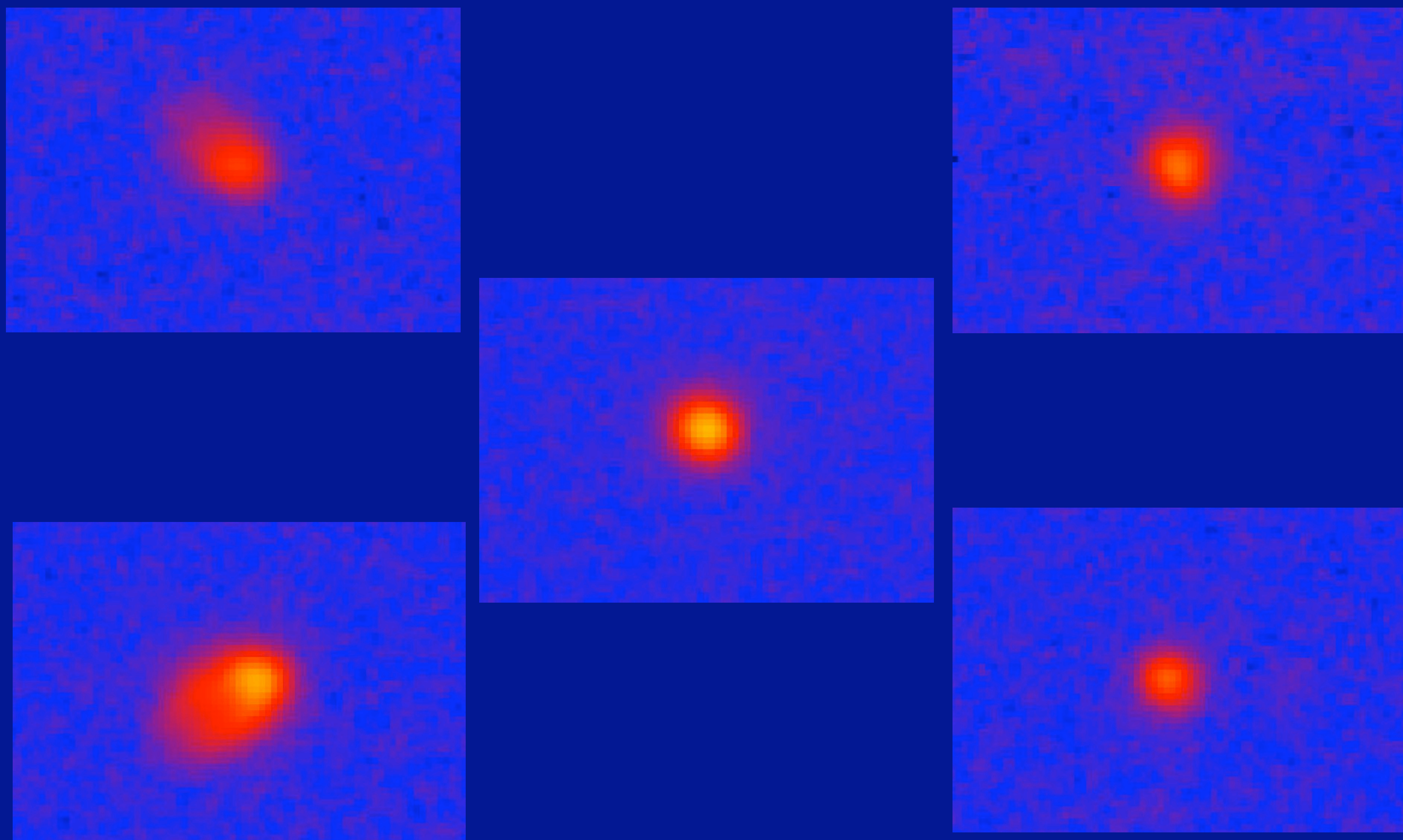
Moffat: α=1

β=1

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

  - 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

Stellar Photometry: Codes

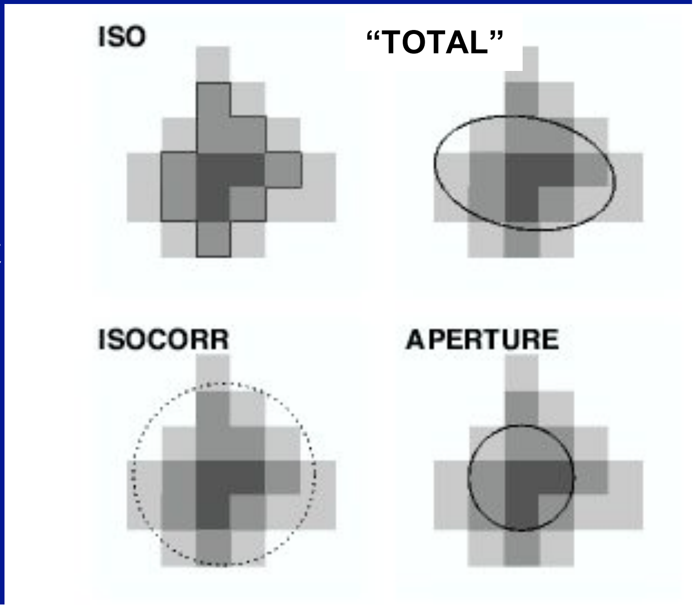
- DAOPHOT
  - Written by Peter Stetson
  - The standard in the field for several decades
  - Can be run standalone or as part of IRAF
  - Handles PSF variations and aberrations
  - Can perform artificial star tests to get uncertainties
  - Steep learning curve
- Starfinder (www.bo.astro.it/~giangi/StarFinder/index.html)
  - IDL routines, relatively new
  - Straightforward interface
  - Not currently designed to handle PSF variations

Galaxy Photometry

- The Challenge:
  - Extended sources
  - Don’t know the form of the profile
  - Don’t know precisely how far out the galaxy extends

Galaxy Photometry

- Types of magnitudes that can be measured:
  - Aperture Magnitudes
    - Optimal size of aperture depends on galaxy
  - Isophotal Magitudes
    - Total light above a given surface brightness level
    - *Surface brightness changes with redshift, so end up measuring different portion of galaxies at different redshifts*
  - "Total" Magnitudes
    - Extrapolated estimates of total galaxy light
      - Kron
      - Petrosian
  - Galaxy profile model fit magnitudes

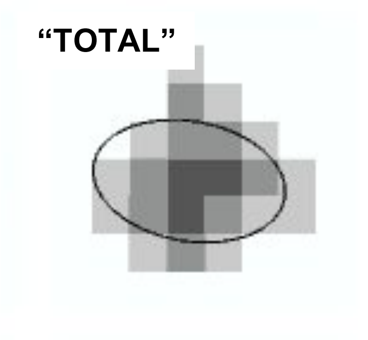


Galaxy Photometry

- Kron magnitudes (Kron 1980; MAG_AUTO in Source Extractor)
  - Basic idea:
    1. Estimate the half-light radius.
    2. Measure the light within the half-light radius
    3. Multiply by 2 to get the total light

  - Do the above using elliptical apertures
  - Estimate the half-light radius by computing the luminosity-weighted characteristic "Kron" radius:

$$r_1 = \frac{\sum rI(r)}{\sum I(r)}$$



Galaxy Photometry

- Petrosian magnitudes (Petrosian 1976; used by Sloan Digital Sky Survey)
  - Similar basic idea: based upon the ratio at a given radius of the local surface brightness to the mean interior surface brightness. The Petrosian index is:

$$\eta(R) = \frac{L(<R)}{\pi R^2 I(R)} = \frac{\langle I \rangle_R}{I(R)}$$

  - For SDSS, a Petrosian radius is defined such that $1/\eta=0.2$ ($\eta=5$) and the total magnitude is defined as being the light within twice the Petrosian radius.

Galaxy Photometry Codes

- Source Extractor (E. Bertin)
  - Standard code in the field
  - Fast, flexible
  - Kron, Petrosian, aperture, isophotal magnitudes
  - Numerous additional quantities (locations, moments of distribution, star/galaxy classification,...)

- Galaxy Modelling Codes
  - GALFIT, GIM2D
  - Codes that model the galaxy profile typically require very good knowledge of the PSF, particularly for compact sources.

Galaxy Photometry Codes

- Example from GALFIT

http://zwicky.as.arizona.edu/~cyp/work/galfit/galfit.html

Centroiding

- Image Centroiding

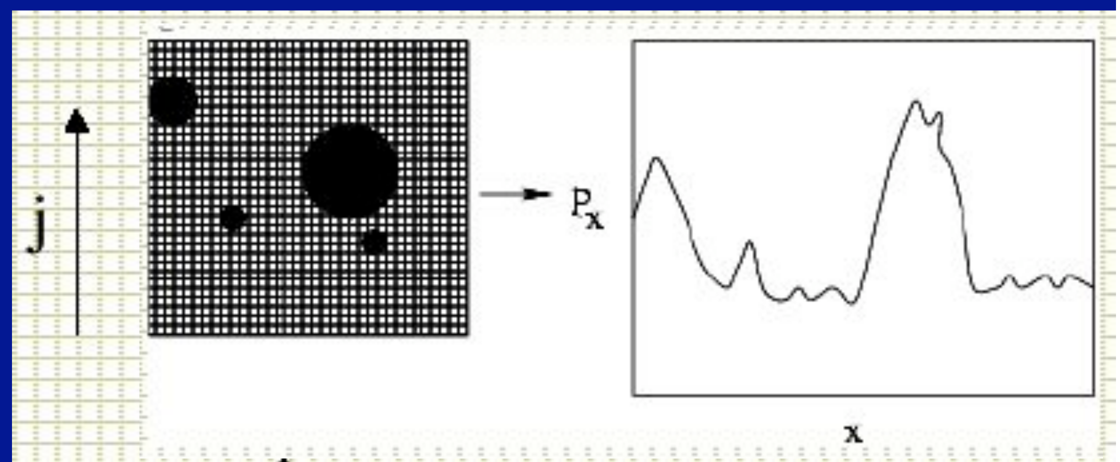
Consider an image with flux levels f(i,j) in pixel i,j. The ***marginal distribution*** along a given axis is obtained by extracting a subsection of the image and summing along the row or columns. Consider subsection centered on the star of size 2L+1 pixels.

$$I_i = \sum_{j=-L}^{j=L} I_{i,j}$$

$$J_j = \sum_{i=-L}^{i=L} I_{i,j},$$

$$\bar{I} = \frac{1}{2L+1} \sum_{i=-L}^{i=L} I_i$$

$$\bar{J} = \frac{1}{2L+1} \sum_{j=-L}^{j=L} J_j;$$



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

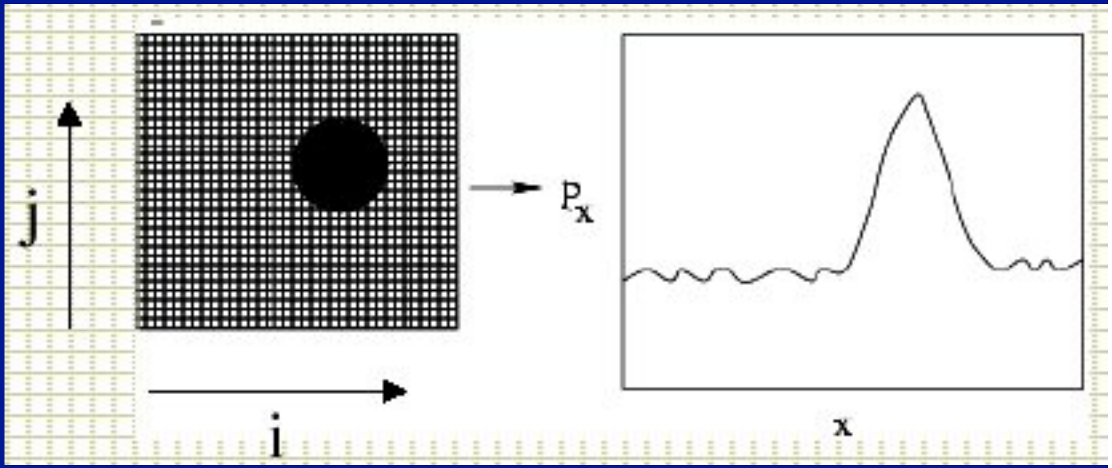
Centroiding

- Centroiding

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.



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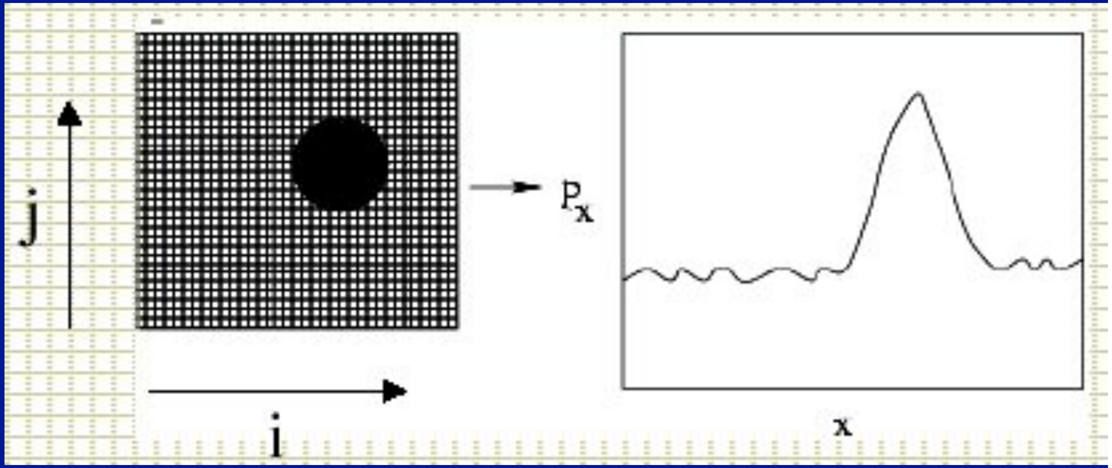
Centroiding

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

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

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

These are the marginal distributions.



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Centroiding

- Centroiding: Marginal Distribution
  - Step 2: Determine an intensity-weighted centroid

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

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

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

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

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Centroiding

- Centroiding: Marginal Distribution
  - Uncertainties in the centroid locations

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

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

$$\sigma_x^{\ 2} = \frac{\sum_i x_i^{\ 2} \cdot P_{xi}}{\sum_i P_{xi}} - x_i^{\ 2}$$

$$\sigma_y^{\ 2} = \frac{\sum_j y_j^{\ 2} \cdot P_{yj}}{\sum_j P_{yj}} - y_j^{\ 2}$$

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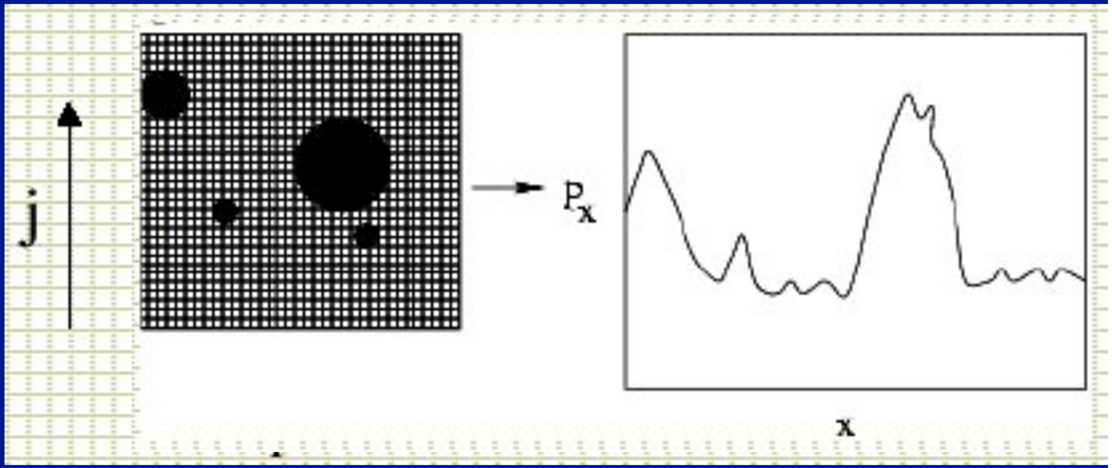
Centroiding

- Complication: Noise and multiple sources in image
  - Must decide what is a source and isolate sources.



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