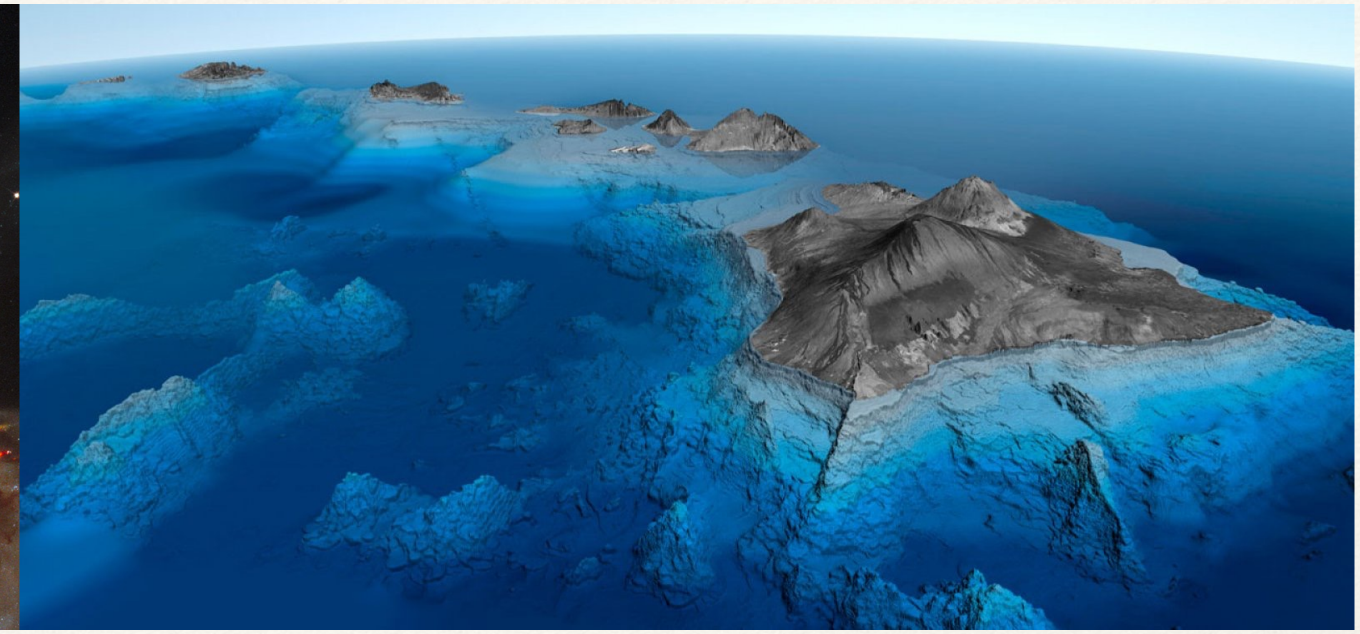


Getting to know the "island universes" out there.

Galaxies I

ASTR 555
Dr. Jon Holtzman

Outline for Today

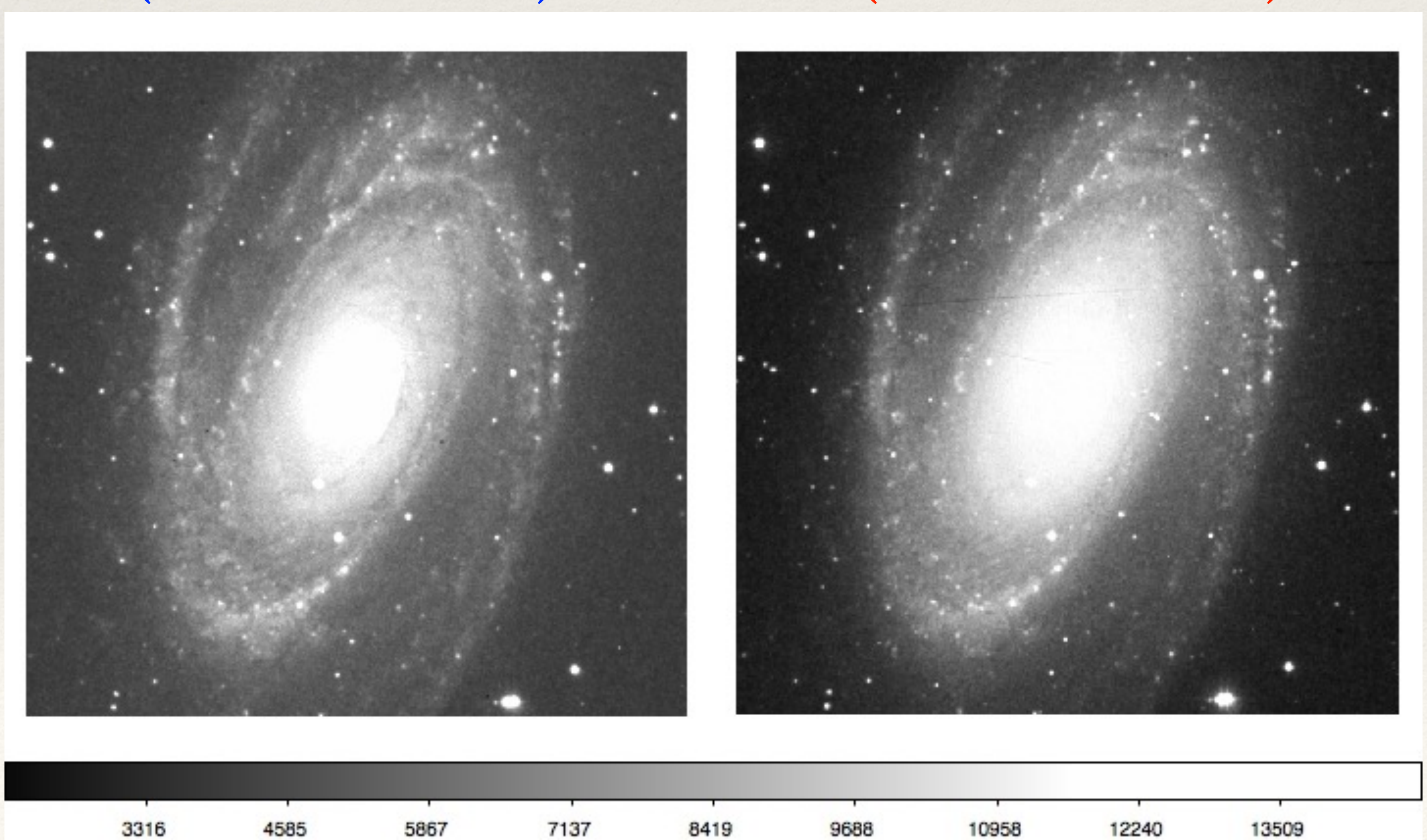
- Observing Galaxies - Imaging:
  - Surface Brightness Profiles
  - Sizes / Integrated Brightness
  - Extinction
  - K corrections

NGC1232 (ESO)

Observing Galaxies - Imaging: Sizes

- Generally, galaxies do not appear to have sharp edges
- How to measure the **size** of fuzzy things in a consistent way?:

M81 (POSS I - B band) **M81 (POSS I - R band)**



POSS I/II: The 48-inch Oschin Schmidt telescope, Mount Palomar Observatory

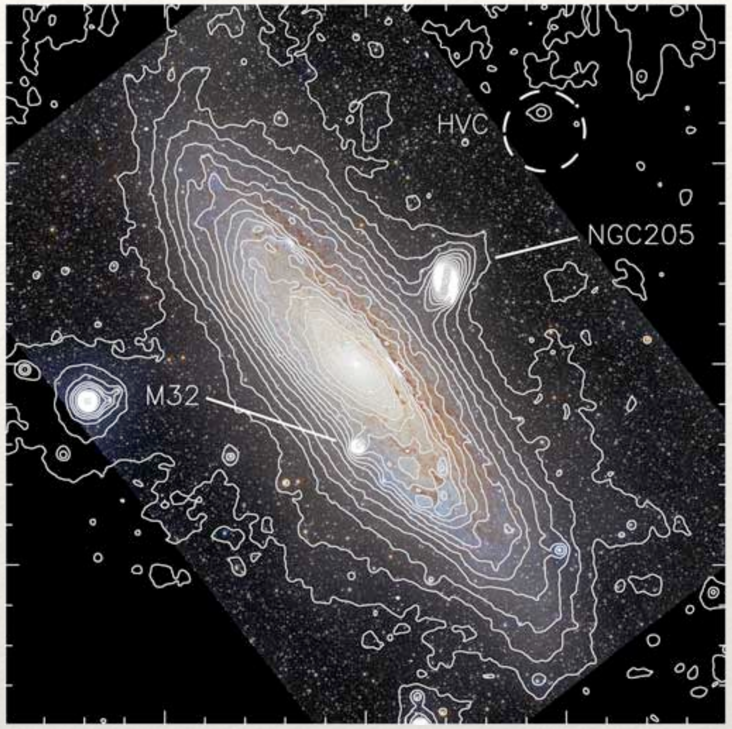
- POSS surveys (1950s/1980s) — very uniform quality, so could measure galaxies down to same isophotal level
- Reference Catalogs 1, 2, & 3 (1960s-1990s)

Observing Galaxies - Imaging: Sizes

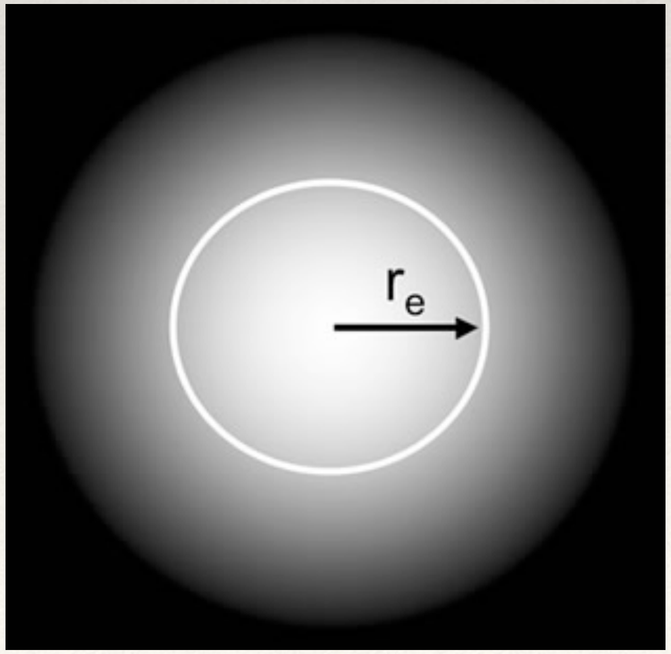
- How to measure the **size** of fuzzy things in a consistent way?:
  - **isophotal radius**:
    - Holmberg radius at SB_B=26.5 mag/sq.arcsec (POSS I/II)
    - R_{25} at SB_B=25.0 mag/sq.arcsec (RC3)
  - **half-light radius**:
    - r_e — radius which contains half the total light of the galaxy

What are some problems with these?

- To compare galaxies at different distances in a fair way, we must find some description which doesn't depend on image depth / distance.



M31 isophotes — Image Credit: Vahid K. Alilou, MathWorks.com



http://astronomy.swin.edu.au/cosmos/E/effective+radius

Observing Galaxies - Imaging: Sizes

- In looking for a way to test observationally if elliptical galaxies evolve, Petrosian came up with a way.

SURFACE BRIGHTNESS AND EVOLUTION OF GALAXIES

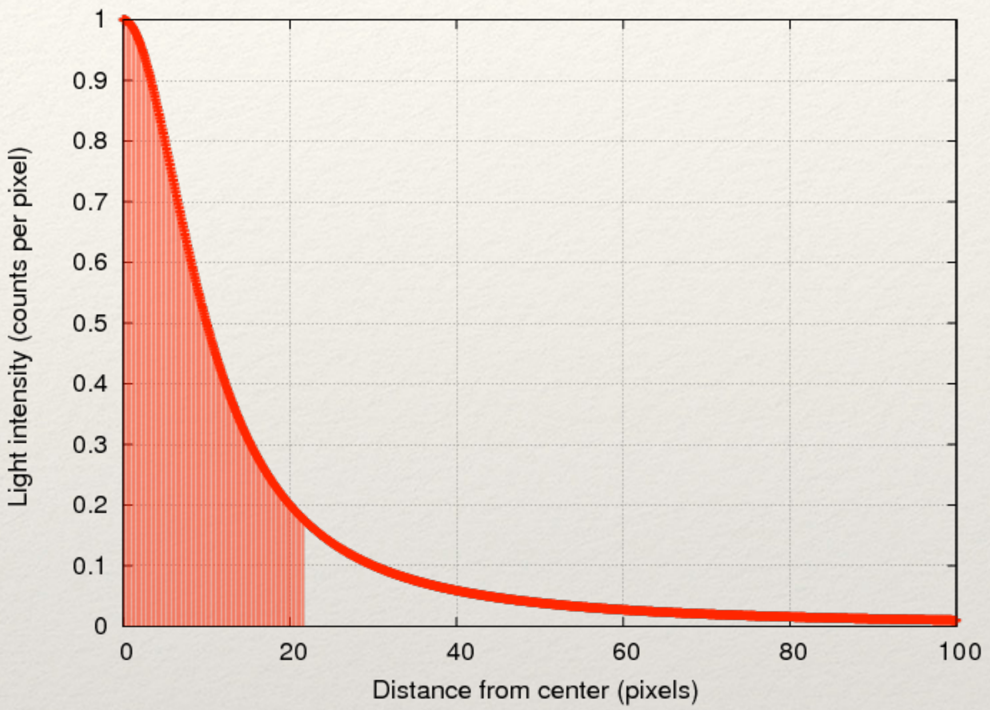
VAHÉ PETROSIAN*
Institute for Plasma Research, Stanford University
Received 1976 January 23; revised 1976 July 13

ABSTRACT

It is well known that before the redshift-magnitude diagram of galaxies could be used for determination of the cosmological parameters one must know the evolution of the galaxies. We propose use of apparent surface brightness—which depends only on the redshift and is independent of the cosmological model and the inhomogeneities in the universe—for observational determination of the evolution of galaxies. The needed observations are isophotal angular diameters and apparent magnitudes within this or any other reasonable angular diameter. The application of the results for determination of q_0 is discussed briefly.

Observing Galaxies - Imaging: Sizes

- **Petrosian radius**:
  - radius at which local surface brightness drops to some fraction (e.g., SDSS uses 0.2) of average surface brightness within this radius
  - independent of distance!



surface brightness at Rp

e.g., 0.2

average surface brightness within Rp

at the Petrosian radius R_P $$I(R_P) = \eta \left(\frac{\int_0^{R_P} I(r) 2\pi r dr}{\pi R_P^2} \right)$$

http://spiff.rit.edu/classes/phys443/lectures/gal_1/petro/petro.html

Observing Galaxies - I s

- Typical sizes (of luminous component!):
  - Angular size:
    - ~4 degrees for Andromeda (M31)
    - ~0.5 degree for the Moon
    - arcminutes for nearby galaxies
    - arcseconds for distant galaxies
  - Physical sizes:
    - ~1-30 kpc for galaxies
    - need distance estimate (which depends on cosmology)

Moon and M31 (Image Credit: REU program, N.A.Sharp/NOAO/AURA/NSF)

NGC 2865 (NASA)
z~0.009 (1.4′x1.1′)

Observing Galaxies - Imaging: Integrated Brightness

How to consistently measure the **total brightness** of fuzzy things?:

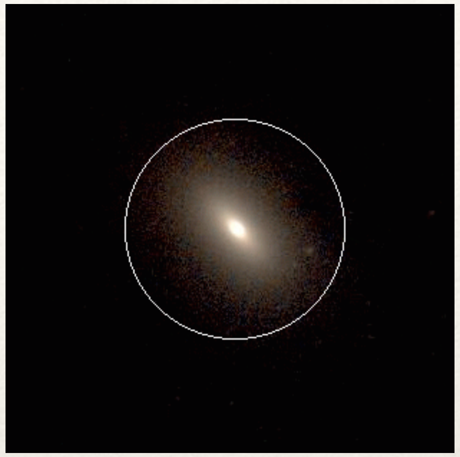
- **metric magnitude** — within an aperture of fixed angular or physical size
- **isophotal magnitude** — within a specified surface brightness contour,

  e.g., Holmberg magnitude
- **model magnitude** — sum over entire model profile

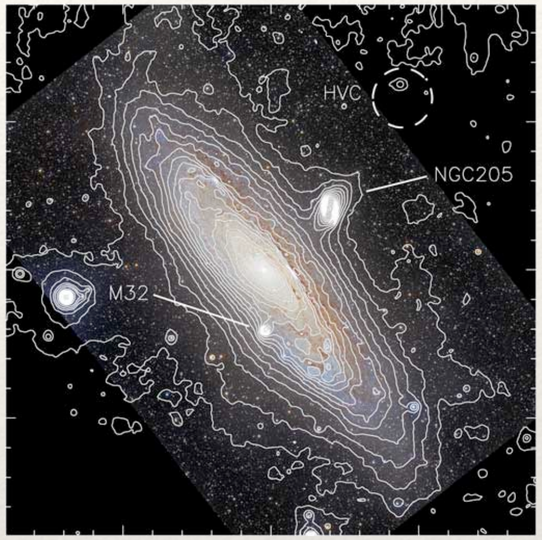
Petrosian magnitude — within a fixed number of Petrosian radii (e.g., SDSS uses 2)

- Note: Petrosian magnitude includes different fraction of total light for objects with different Sersic indices, need to correct for this if comparing brightnesses of different objects

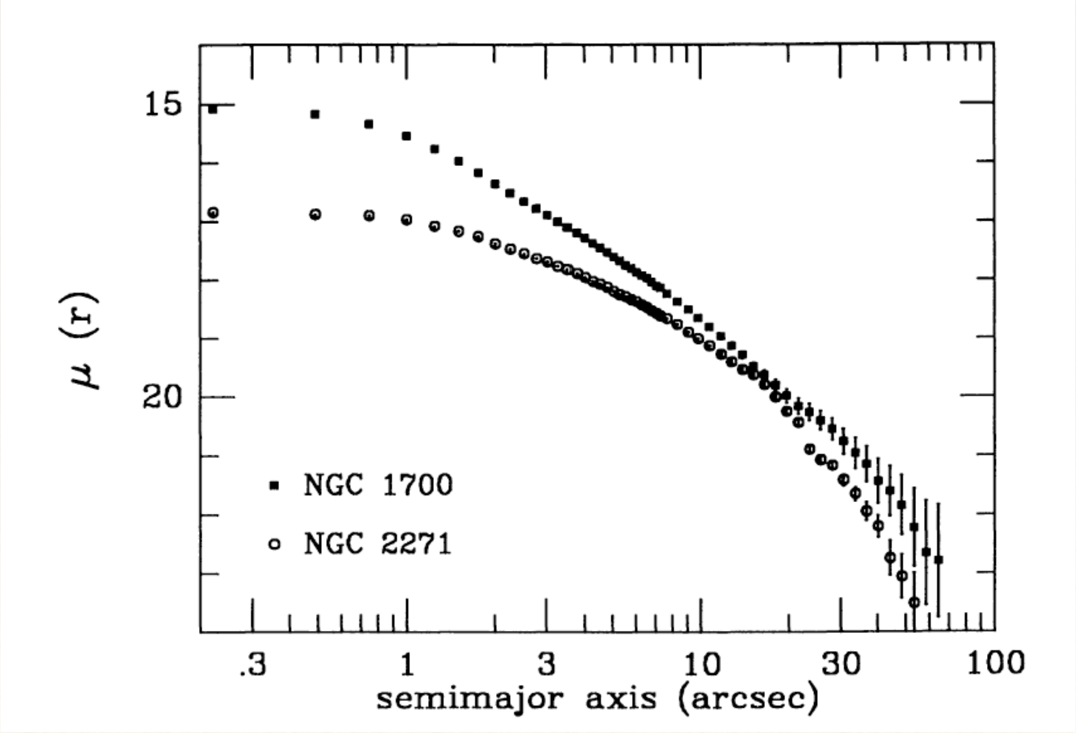
Petrosian magnitudes have significantly less dependence on distance (see Dalcanton 1998)



https://www.astro.ufl.edu

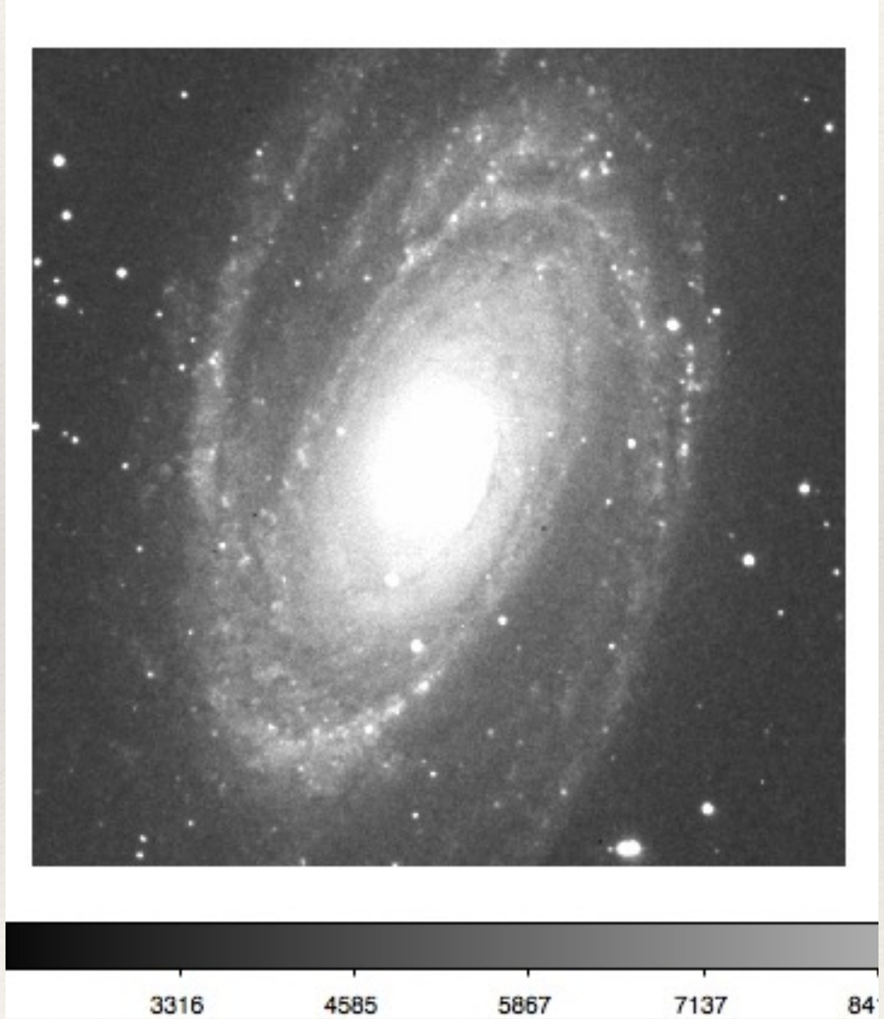


Vahid K. Alilou, MathWorks.com



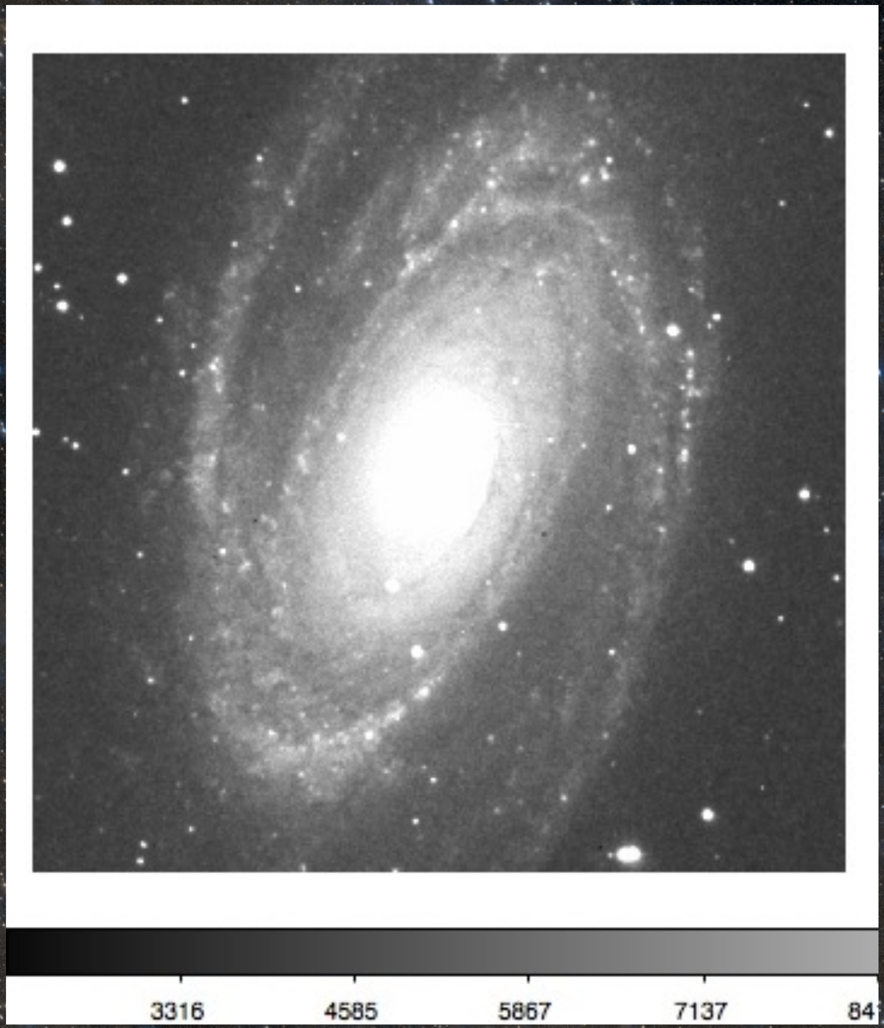
Question

M81 (POSS I - B band)



- In order to compare measurements of different galaxies, what else do we have to worry about?

M81 (POSS I - B band)

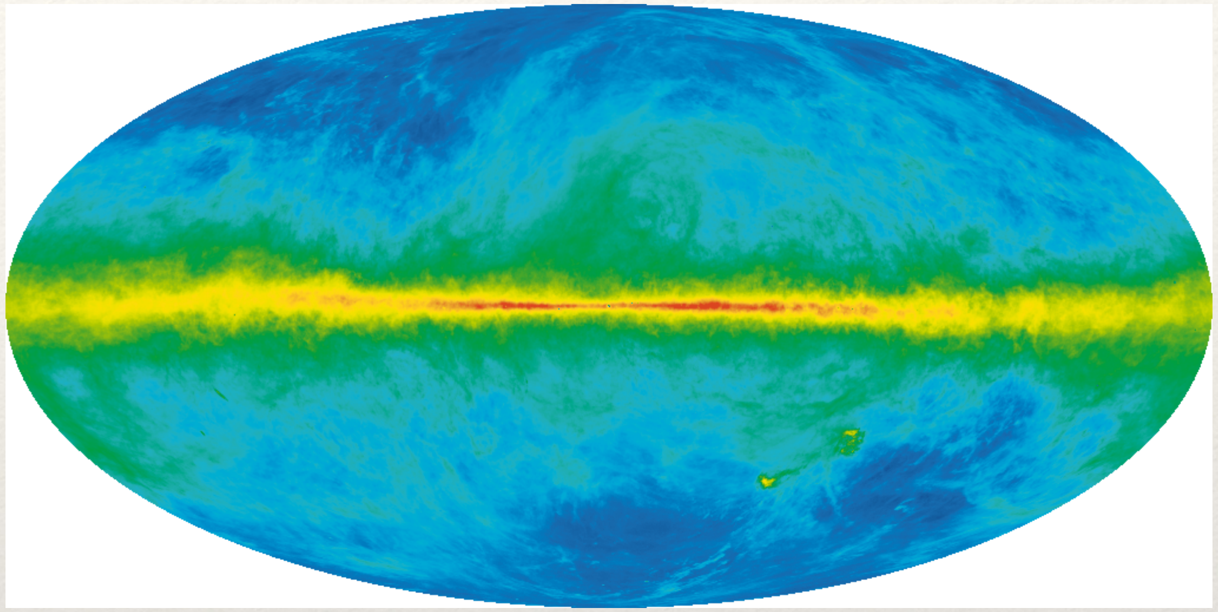


https://www.cloudynights.com/topic/519524-drowned-in-dust-m81m82volcano-nebula/

Observing Galaxies - Imaging: Extinction

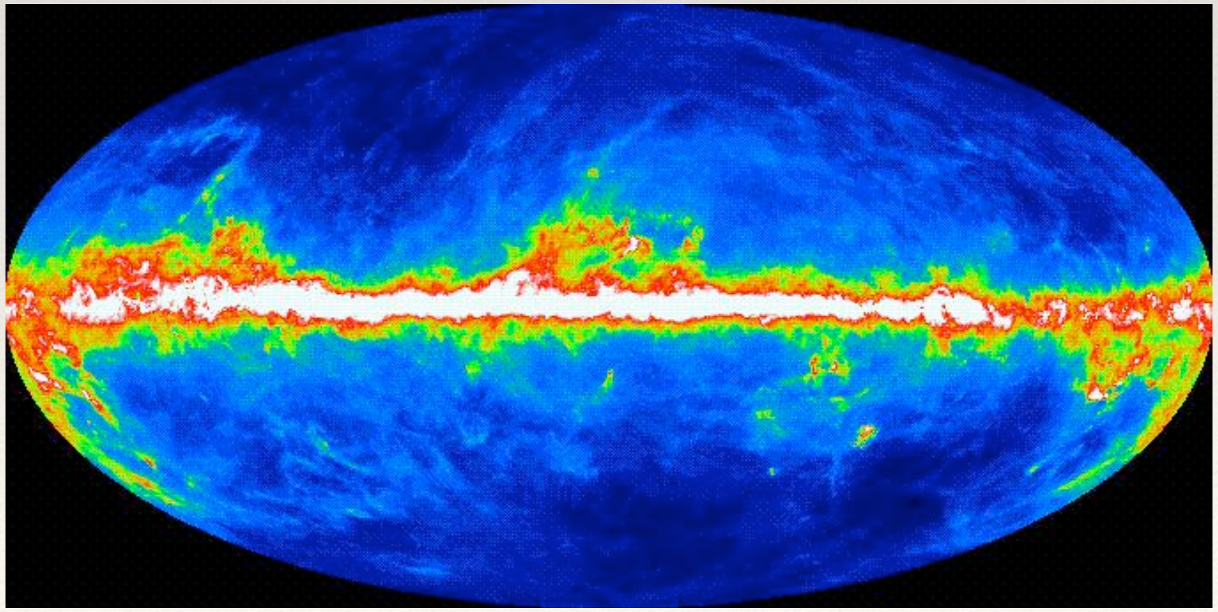
- **Foreground extinction**, depends strongly on Galactic latitude
  - Burstein & Heiles, 1984 —based on neutral Hydrogen (HI) and faint background galaxy counts
  - Schlegel, Finkbeiner, & Davis 1998 — based on far-IR sky maps of dust emission
- $m_{0,X} = m_X - A_X$

Galactic neutral hydrogen column density



HI4PI Collaboration 2016; LAMBDA Data Products

Galatic dust — IRAS 100 micron imaging



Schlegel, Finkbeiner & Davis 1998; https://irsa.ipac.caltech.edu/applications/DUST/

Observing Galaxies - Imaging: Extinction

- **Internal extinction**, depends on inclination, galaxy type, band
  - higher inclination = longer path length through the galaxy = greater extinction
  - correction can be significant! (e.g., up to ~1.5 mag in Reference Catalog 3)

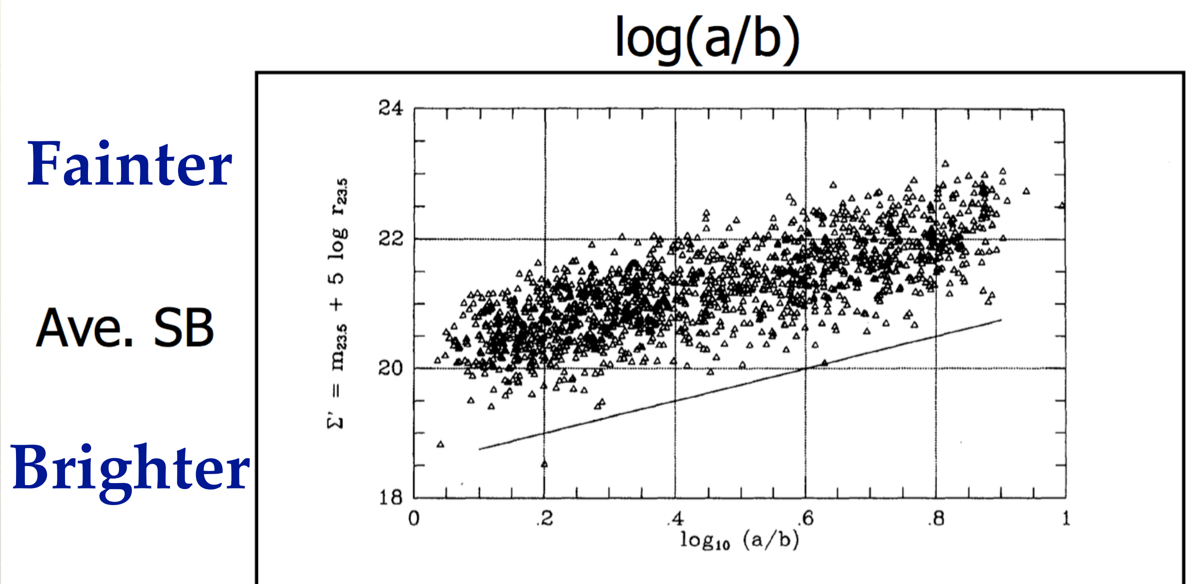


FIG. 8. Surface magnitude averaged over a circular aperture of radius $r_{23.5}$ vs log of the axial ratio, for our sample of 1235 objects. The solid line is an arbitrary linear law of slope 2.5.

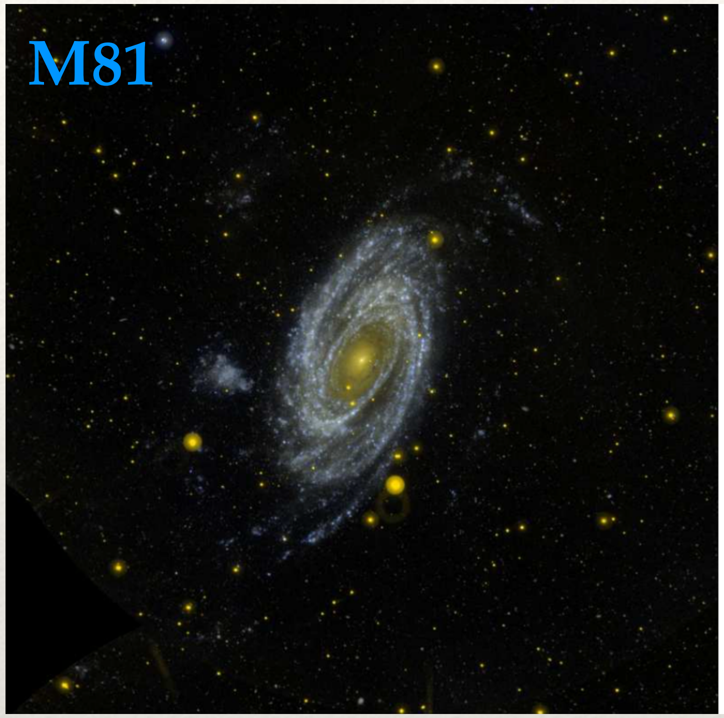
Face-on **Edge-on**

Giovanelli et al. (1994)

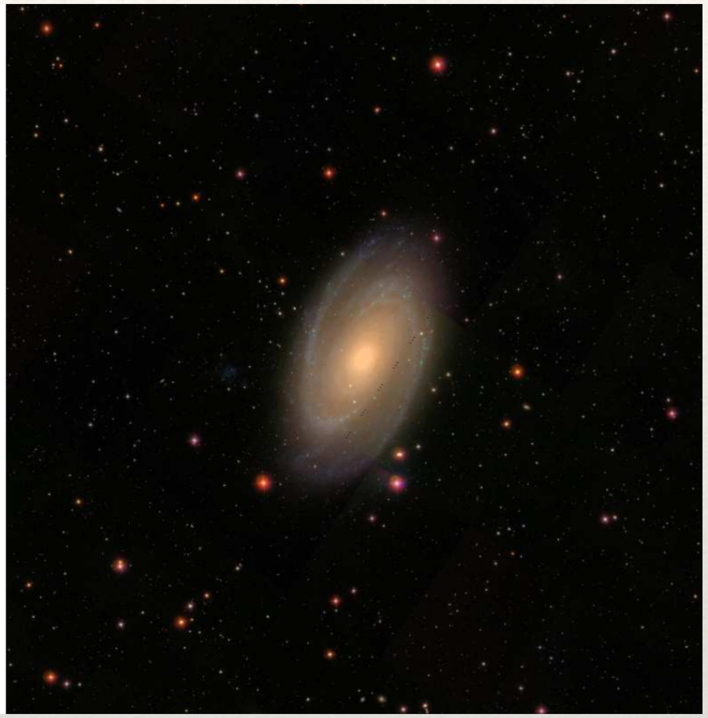
Observing Galaxies - Imaging: K-corrections

- A fixed **observed** wavelength range corresponds to a different **rest frame** wavelength range at different redshifts (distances)!
- Need a **K-correction**:
  - corrects magnitude in observed band to what it would be in rest-frame band
  - requires knowledge of (or assumptions about) the intrinsic spectrum
  - less sensitive to assumptions if use observed bands that are close to desired rest frame band
- $m_Q = m_X - K_{QX}$
  to correct observation in band X to one in band Q

UV

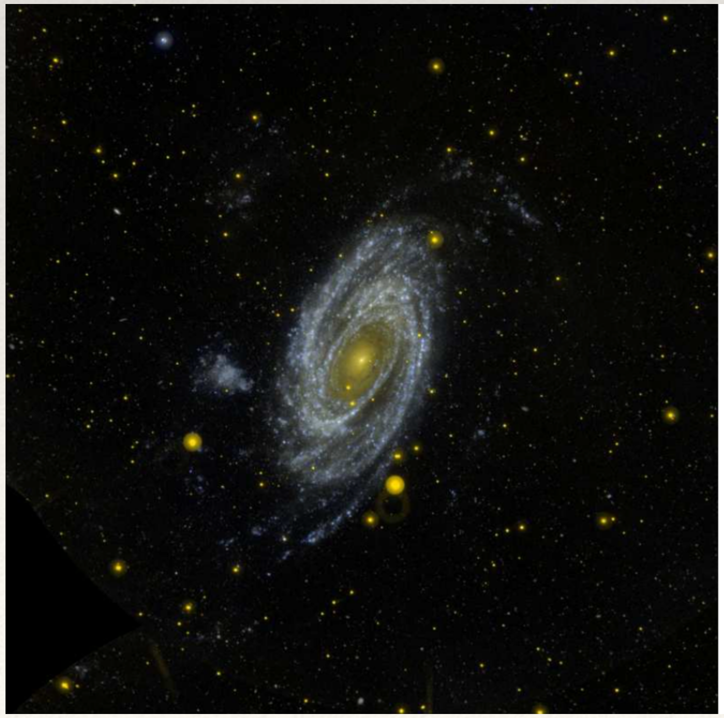


Optical



Bianchi et al. 2011, 2017

Higher redshift



Observing Galaxies - Imaging: K-corrections

- $m_Q = m_X - K_{QX}$
  to correct observation in band X to one in band Q

- Plot shows some typical galaxy spectra (as we'll discuss more next time!)

- What is the sign of a K correction if comparing a galaxy at moderate redshift to the local galaxy population if using a red filter?

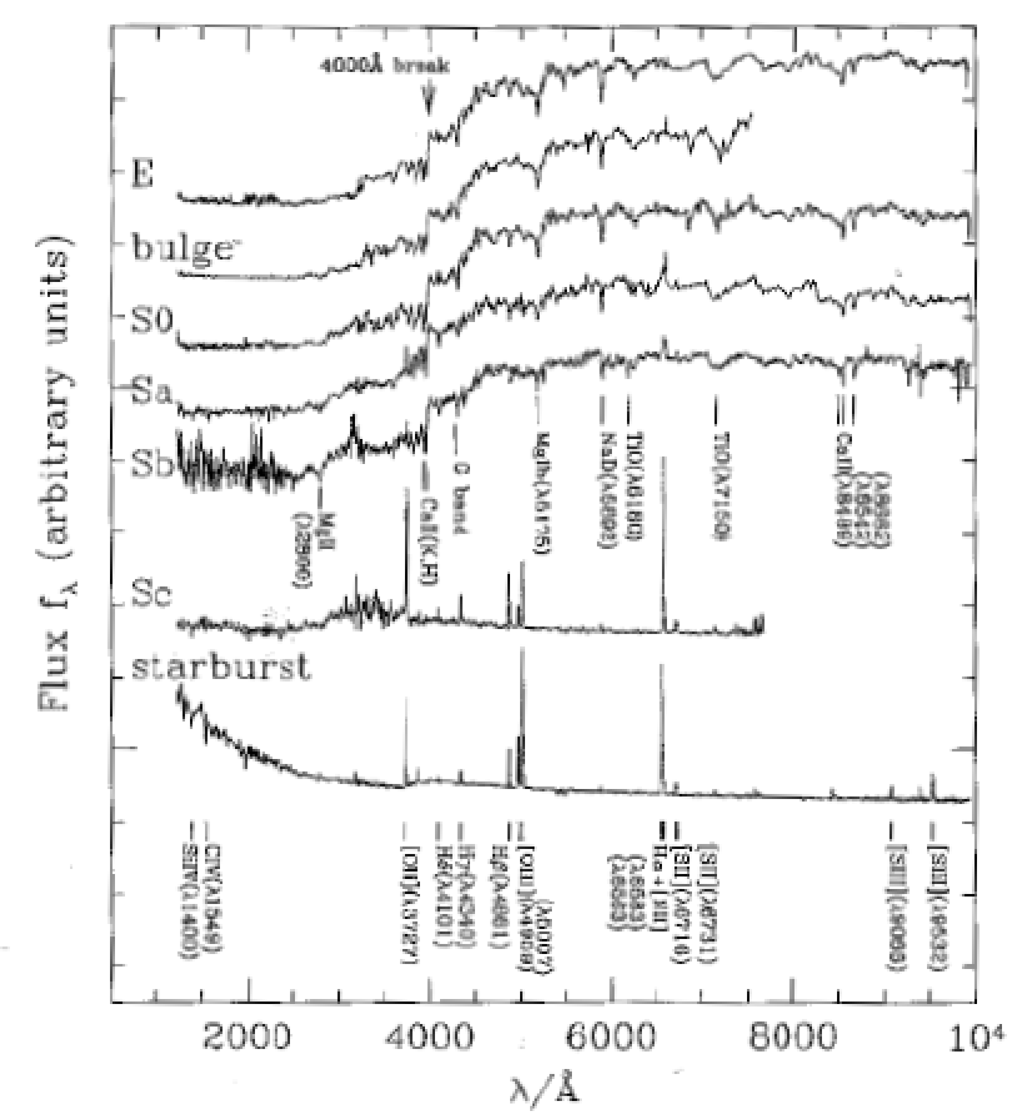


Fig. 2.12. Spectra of different types of galaxies from the ultraviolet to the near-infrared. From ellipticals to late-type spirals, the blue continuum and emission lines become systematically stronger. For early-type galaxies, which lack hot, young stars, most of the light emerges at the longest wavelengths, where one sees absorption lines characteristic of cool K stars. In the blue, the spectrum of early-type galaxies show strong H and K absorption lines of calcium and the G band, characteristic of solar type stars. Such galaxies emit little light at wavelengths shorter than 4000 Å and have no emission lines. In contrast, late-type galaxies and starbursts emit most of their light in the blue and near-ultraviolet. This light is produced by hot young stars, which also heat and ionize the interstellar medium giving rise to strong emission lines. [Based on data kindly provided by S. Charlot]

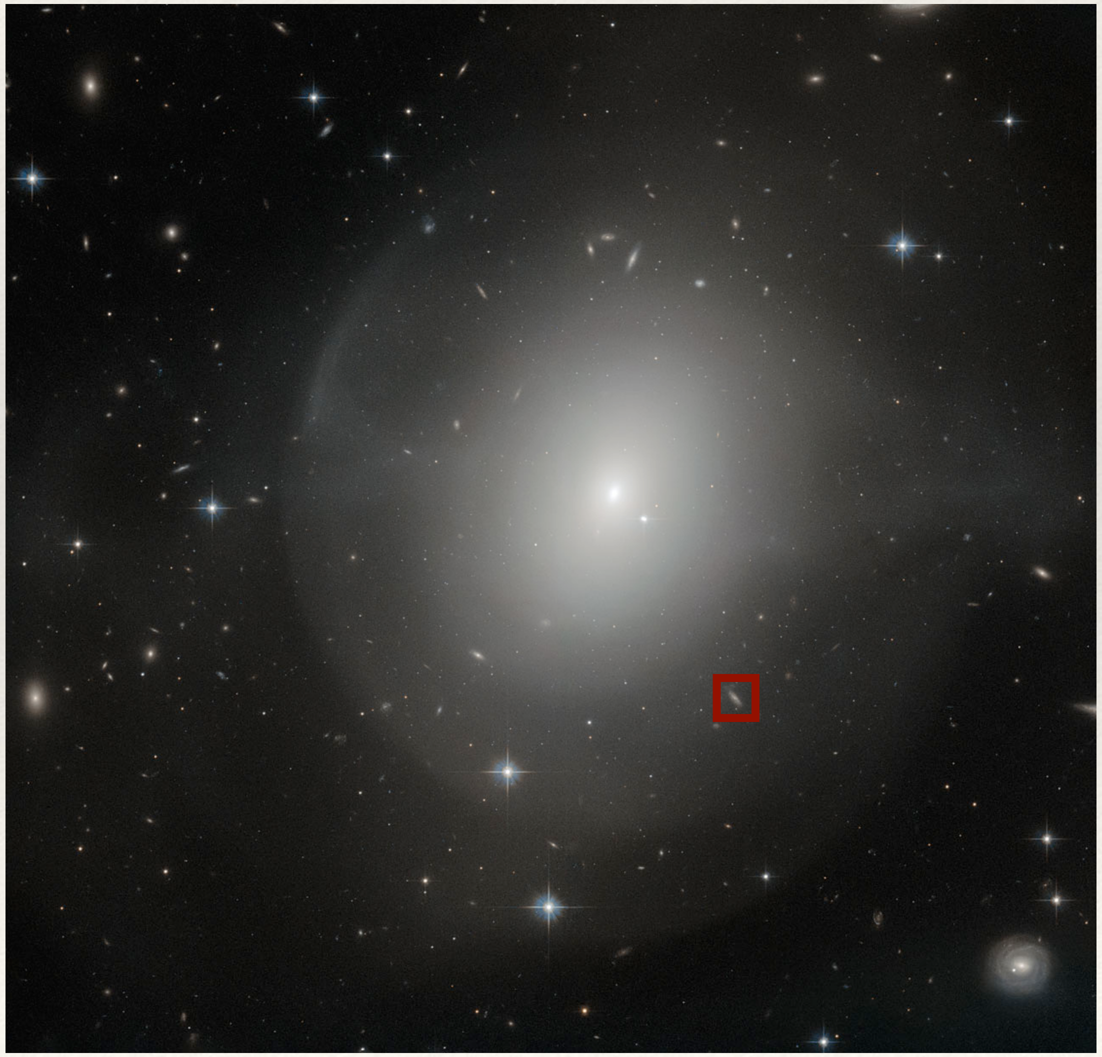
Assignments

- Weekly summary and question(s)
- Paper summary 1
- Problem 1

Problems

- The spiral galaxy NGC 4414 has a total magnitude in the V band of m_V=11 mag. You measure major and minor axis sizes of 3.6 arcmin x 2.0 arcmin. What is the average V-band surface brightness?
- A particular patch in an elliptical galaxy has a surface brightness of 21 mag/arcsec^2. Directly behind it is the center of a more distant spiral with a surface brightness of 21 mag/arcsec^2. What is the combined surface brightness within that patch?

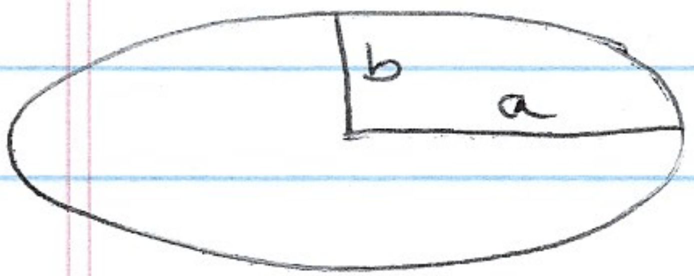
NGC 4414 (NASA)



NGC 2865 (NASA)

Problems

$m_V = 11$



$a = \frac{3.6'}{2} = 1.8'$

$b = \frac{2'}{2} = 1'$ → arcmin

$A_{ellipse} = \pi a b$ (note → πr^2 if $a=b=r$)

$\mu_V = m_V + 2.5 \log_{10}(A)$

↳ in arcsec^2

$\mu_V = 11 + 2.5 \log_{10}\left(\pi (1.8')\left(\frac{60''}{1'}\right)(1')\left(\frac{60''}{1'}\right)\right)$

$\mu_V = 11 + 2.5 \log_{10}(20357.5)$

$\boxed{\mu_V = 21.77 \text{ mag/arcsec}^2}$

Problems

$\mu_\epsilon = 21 \text{ mag/arcsec}^2$

$\mu_s = 21 \text{ mag/arcsec}^2$

$\mu_\epsilon - \mu_s = -2.5 \log_{10}(I_\epsilon / I_s)$

$= 0$

so $I_\epsilon = I_s$

$\mu_{tot} = ?$ $\quad I_{tot} = I_\epsilon + I_s$ (assuming no absorption, etc.)

$$\mu_{tot} - \mu_\epsilon = -2.5 \log_{10}(I_{tot} / I_\epsilon)$$

$$= -2.5 \log_{10}(2 I_\epsilon / I_\epsilon)$$

$$= -2.5 \log_{10}(2)$$

$$\mu_{tot} = \mu_\epsilon - 2.5 \log_{10}(2) = 21 \frac{\text{mag}}{\text{arcsec}^2} - 2.5 \log_{10}(2)$$

$$\boxed{\mu_{tot} = 20.25 \text{ mag/arcsec}^2 \quad (\text{not } 42!)}$$

Observing Galaxies - Imaging: Surface Brightness

$$m_1 - m_2 = -2.5 \log_{10} (f_1/f_2)$$

for objects 1 and 2

Can also write in relation to a standard reference object (e.g. Vega)

$$m - m_0 = -2.5 \log_{10} (f/f_0)$$

Rearrange:

$$m = -2.5 \log_{10}(f) \underbrace{- 2.5(-\log_{10}(f_0)) + m_0}$$

$$m = -2.5 \log_{10}(f) \qquad + C$$

(zeropoint, a constant)

Similarly:

$$\mu = -2.5 \log_{10}(I) \quad + \quad a$$

(constant)