Outline

- Introductions
- Course Overview
- Introduction to Galaxies
  - What is a galaxy?
  - Morphological properties
    - Hubble diagram
    - Variations
  - Statistical properties of galaxies
  - Sample surveys
Introductions

- Course Web Page:
  - www.astro.wisc.edu/~ewilcots/courses/astro330f06.html

- Instructor
  - Eric M. Wilcots/6211 Chamberlin
  - Office Hours: 2:30–3:30 T/Th (or by appointment)
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  - 262–2364

- Grading
  - Final Exam: 30%
  - Midterm Exam: 20% (October 23 in class)
  - Homework: 30%
  - Final Project: 20% (details TBD)
Course Overview

- **Readings**
  - **Textbook:** “Galaxies in the Universe”
    - Sparke & Gallagher (available in bookstore)
  - **On Reserve in Woodman Library**
    - Binney & Merrifield, Binney & Tremaine, Pagel, Krolik
  - **Random Readings**
Homework Assignments
- Mostly quantitative problems
- Some programming (IDL, Fortran, C++, etc)
- Handed out on Tuesdays, due Thursday of the following week
- Work together, but your answers must be your own

Exams
- Problems like the HW problems plus a few qualitative bits thrown in
- You’re responsible for all the assigned reading and whatever we cover in class
- Closed book, some equations will be given, constants will be provided
“real” astronomy
- Astronomical datasets (e.g. SDSS)
- Software, image analysis, plotting, etc

Last time – population synthesis to model the observed spectrum of an “elliptical galaxy”
- Might change it this time

Milestones along the way

Grading – everyone in the group gets the same grade
Course Goals

- Overview of Galactic and Extragalactic Astronomy
  - Basic properties of galaxies and large scale structure of the Universe
  - Evolution of galaxies and large scale structure
  - Underlying astrophysics (gravity, some radiative processes)

- Unresolved Issue – the assembly and growth of galaxies
What is a Galaxy?

- At end of 19th century
  - "fixed" stars
  - Clusters and nebulae were the fuzzy blobs Messier cataloged
    - Clusters
      - Open (e.g. Pleiades)
      - Globular (look like the name would suggest)
    - Nebulae
      - "planetary nebulae": disk-like with central star
      - Giant clouds
      - "spiral nebulae"

- What were the "spiral nebulae"?
  - Kant: "island Universes" – things like the Milky Way just farther away
  - Laplace: solar systems in formation (ever seen M51?)

- Types of Matter
  - Spectra of the "fixed" stars looked like the Sun
  - Spectra of the "nebulae" like Orion looked funny – lots of emission lines
  - "spiral nebulae" – not quite right: a little bit of both
Early Distances

- Trigonometric Parallax
  - $D(\text{pc}) = \frac{1}{p(\text{arcseconds})}$
  - In 1900 this was good out to 30 pc ($1 \text{ pc} = 3.1 \times 10^{18} \text{ cm}$)
  - Hipparcos went out to about 200 pc; GAIA will go farther

- Other distance indicators needed
  - Henrietta Levitt (Harvard) looking for variable stars discovered the brightness of Cepheid variables (in LMC) was proportional to the period.
  - Measure period, get brightness, get distance (Cepheids as “standard candles”)
Shapley applied Cepheid scale to globular clusters...
  ◦ Spherical distribution centered near Sagittarius (we’re not at the center any more)
  ◦ Size of the distribution: 100,000 kpc (old size was only 8 kpc)
  ◦ Implication: spiral nebulae had to be contained within the Milky Way!

Oops
  ◦ Wrong variable stars! They were RR Lyraes!
  ◦ Didn’t account for reddening (then again, nobody really did)
Most stars have constant luminosities...(within limits)
Some vary…
  ◦ Binaries
  ◦ Novae & supernovae
  ◦ Mira variables – long term
  ◦ Cepheids: periods of 10–100 days, easy to find with sufficient resolution and the right timing
  ◦ Magellanic Clouds – all Cepheids at the same distance, so the period–luminosity relationship really shows up (M > 3 M)
  ◦ RR Lyrae: similar periods, fainter luminosities, lower mass stars
Cepheid P–L relationship


Cepheid Variables

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Reported on apparent nova in M31 – derived a distance of 150 kpc (5 times too small, but large enough)

Radial velocities of spiral nebulae higher than anything else

Band of dark stuff seen in some edge-on spiral systems

Kapteyn used star counts to conclude we live in a flat, heliocentric thing about 15 kpc in diameter (about the same size of M31 if it were 150 kpc away)
Star Clusters

NGC 265

M80
NGC 891 (WIYN 3.5m)
Resolution...

- 1923: Edwin Hubble used the 100-inch telescope at Mt. Wilson
  - Resolved parts of nearby galaxies into stars.
  - Detected Cepheids in M31
  - Later figured out a funny velocity-distance relationship

- Discovery of the ISM
  - Spectra of nebulae showed they were gaseous
  - Stationary absorption lines seen in binary stars
  - Angular diameter vs luminosity distances for Galactic clusters (i.e. open clusters)
Properties of Galaxies

- Hubble Morphologies – quite subjective
  - Ellipticity (E0–E7, where n=10\left[1-(b/a)\right])
  - “tightness” of spiral (Sa–Sd)
  - Prominence of central bulge (Sa–Sd)
  - Presence of a “bar” (B, as in SBc)
  - Presence of a ring (added by de Vaucouleur)
  - Morphed into T types: E=−5, Sb = 3, Irr = 8–10

- Other schemes
  - Structure (bulge/disk ratio)
  - Gas/stellar ratios
  - Kinematics (rotational/kinetic velocities)
  - Role of evolution
  - Spectral “types”
Largely defined by the luminosity function
- \[ \int \Phi(M) dM = \nu, \text{ where } \nu \text{ is the total number of galaxies in the magnitude range } M, M+dM \]
- Need large volume, unbiased sample (we’ll talk about the Malmquist bias later)
- Convert magnitudes into real luminosities

Schecter function
- \[ \Phi(L) = \left( \frac{\Phi^*}{L^*} \right) \left( \frac{L}{L^*} \right)^\alpha \exp \left( - \frac{L}{L^*} \right) \]
- \( L^* \) is the characteristic luminosity above which the number of galaxies falls off rapidly \((1.2 \times 10^{10} \, L_\odot)\)
- \( \Phi^* = \) normalization of the galaxy density \((0.016 \, \text{Mpc}^{-3})\)
- \( \alpha = \) the faint end slope \((-1.07)\)
- Both luminosity and mass (HI) functions are reasonably well fit by this, but there is some variation in the slope and in the normalization.
Gunn r-band LF in different environments (Eke et al. 2004). Points are real data, but the lines are models. $h = H_0/100 \text{ km s}^{-1} \text{ Mpc}^{-1}$. 
\[
\phi_M \, dM = e^{-M/M^*} \left[ \phi_1^* \left( \frac{M}{M^*} \right)^{\alpha_1} + \phi_2^* \left( \frac{M}{M^*} \right)^{\alpha_2} \right] \frac{dM}{M^*},
\]

where \( \phi_M \, dM \) is the number density of galaxies with mass between \( M \) and \( M + dM \); with \( \alpha_2 < \alpha_1 \) so that the second term dominates at the faintest magnitudes. Fitting to \( M > 10^8 M_\odot \), the best-fitting parameters are

\[
\begin{align*}
\log(M^*/M_\odot) &= 10.648 \\
\phi_1^*/10^{-3} \text{Mpc}^{-3} &= 4.26 \alpha_1 = -0.46 \\
\phi_2^*/10^{-3} \text{Mpc}^{-3} &= 0.58 \alpha_2 = -1.58
\end{align*}
\]

Figure 6. GSMF extending down to \( 10^7 M_\odot \) determined from the NYU3C. The points represent the non-parametric GSMF with Poisson error; at \( M < 10^{8.5} M_\odot \) the data are shown as lower limits because of the incompleteness (Fig. 4). The dashed line represents a double-Schechter function extrapolated from a fit to the \( M > 10^8 M_\odot \) data points. The dotted line shows the same type of function with a faint-end slope of \( \alpha_2 = -1.8 \) (fitted to \( M > 10^{8.5} M_\odot \) data). The dash–dotted line represents a power-law slope of \(-2.0\). The shaded region shows the range in the GSMF from varying the stellar mass used and changing the redshift range.
HI Mass Function

\[ \alpha = -1.30 \]

\[ \log M_{\text{HI}}^* = 9.79 \]

\[ \theta^* = 0.0086 \]
Giant Clusters
- > 1000 galaxies
- D ~ 1–2 Mpc
- 1–3 giant elliptical galaxies residing at the center
- High fraction of elliptical galaxies
- Most have copious diffuse X-ray emission
  - Most of the observed mass in clusters is in hot gas
- Huge M/L ratios (~100) \(\rightarrow\) dark matter dominated
  - Gravitationally bound

Clusters of clusters?
- The Great Attractor
Abell 98
Surveys

- Sloan Digital Sky Survey
  - www.sdss.org
- FIRST/NVSS
  - http://sundog.stsci.edu
  - www.cv.nrao.edu/nvss
- Arecibo Surveys (ALFALFA)
  - egg.astro.cornell.edu/alfalfa
- Various “Deep Fields”
  - HDF north and south
  - Chandra, Spitzer have deep fields and various surveys of galaxies
  - ATCA is doing a radio deep field
- Ever-increasing chunks of sky, multiple wavelengths
Adopt-A-Galaxy List

- NGC 4881 – Josh
- NGC 7742 – Nikita
- NGC 1300 – Adam
- NGC 3370 – Lucas
- NGC 1512 – Melissa
- NGC 3310 – Angie
- I Zw 18 – Aaron
- NGC 3949 – Tom
- NGC 2403 – Ken
- Leo A – Fernando
- NGC 4594 – Jane
- M82 – Brad
- NGC 1275 – Jake
- NGC 4151 – Alex I.
- NGC 3079 – Rachel
- NGC 1569 – Jeff
- M87 – Chris
- NGC 4261 – Malanka
- NGC 6822 – Eric
- Mrk 501 – Tyler
- Cygnus A – Alex H.
- NGC 2685 – Jon