Astronomy 330

Lecture 1

3 Sep 2010

Outline

- Course Overview
- Introduction to Galaxies
  - History of the field
  - Properties of individual galaxies
    - Morphology & classification
    - Variations
    - Physical attributes
  - Statistical properties of galaxies
  - Sample surveys

Introductions

- Course Web Page:
  - www.astro.wisc.edu/~mab/education/astro330/
- Instructor:
  - Matthew Bershady / 6215 Chamberlin
  - Office Hours: 2:30-3:30 W/F (or by appointment)
  - mab@astro.wisc.edu
  - 265-3392
- Grading
  - Final Exam: 30%
  - Midterm Exam: 20% (October 27 in class)
  - Homework: 30%
  - Final Project: 20% (details TBD)

Course Overview

- Lectures
  - Outlines posted after class
- Readings
  - Required Textbook:
    - "Galaxies in the Universe" – Sparke & Gallagher, 2nd edition
  - On Reserve in Woodman Library
    - Roughly a dozen texts on galaxies, cosmology and AGN.
    - See web page for list and description
  - Topical articles
    - Largely from professional, peer-reviewed journals such as AJ, ApJ, A&A, MNRAS
  - Course web page will give reading assignments, updated as the course progresses.
- Acknowledgements
  - Thanks to Eric Wilcots (UW) and Chris Mihos (CWRU) for material used in this course.

Homework & Exams

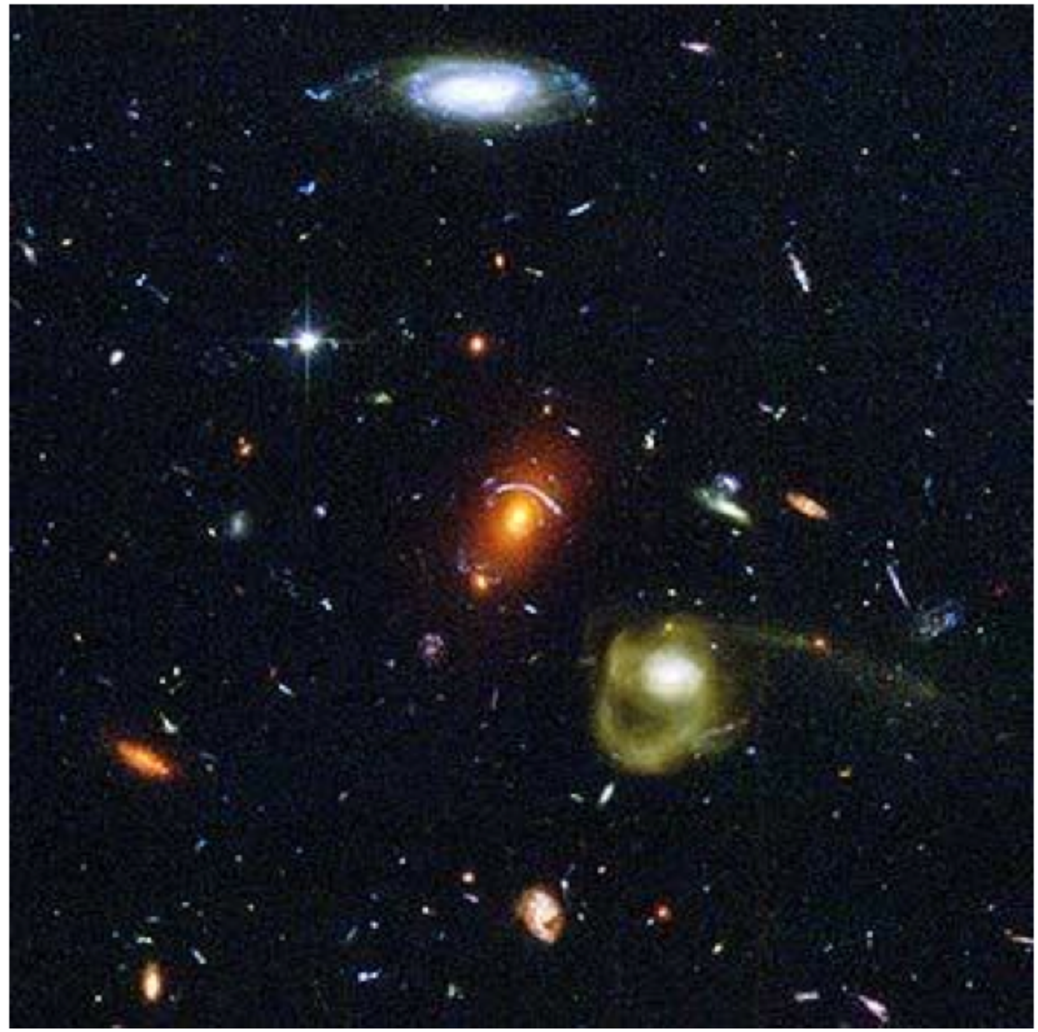
- Homework Assignments
  - Mostly quantitative problems
  - Some programming (IDL, Fortran, C++)
  - Handed out on Wednesday, due Friday of the following week
  - Work together, but your answers must be your own
- Exams
  - Problems like the HW plus a few qualitative bits thrown in
  - You're responsible for all the assigned reading and whatever we cover in class
  - Closed book, some equations will be given, constants will be provided

Project

- "real" astronomy
  - Astronomical datasets (e.g. SDSS)
  - Software, image analysis, plotting, etc
- Population synthesis to model the observed spectrum of the disk of a typical "spiral galaxy"
- 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, fusion, some radiative processes)
- Unresolved Issue – the assembly and growth of galaxies



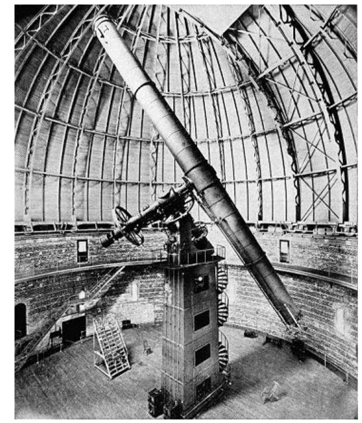
Course Outline

I. Intro - 5 lectures
II. Milky Way As Galaxy - 2 lectures
III. Gravity & Orbits - 3 lectures
IV. Disk-dominated systems - 4 lectures
V. Spheroidal-dominated systems - 3 lectures
VI. Dwarfs - 3 lectures
VII. Structure on the largest scales – 3 lectures
VIII. AGN & Evolution – 3 lectures
IX. Future and Summary – 2 lectures

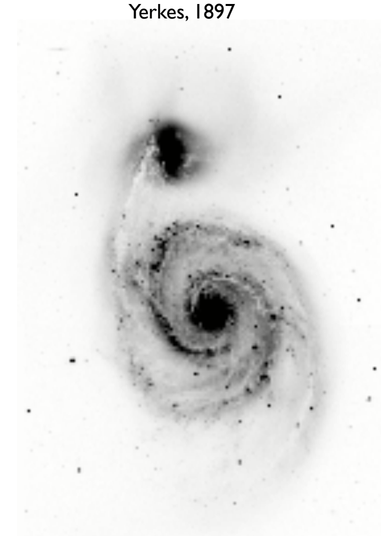
Think of this as the sketch only.
The real schedule will be more fluid.

History

- At end of 19th century – Yerkes was just being built
  - Stars were "fixed" points on the sky – proper motion on the cusp of discovery
  - Clusters and nebulae were fuzzy blobs Messier cataloged in late 1700's from down-town Paris – to be avoided by comet-hunters
  - Clusters: Open (e.g. Pleiades), and Globular
  - 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 in the universe
  - Not a lot was known because spectroscopy was hard
  - 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
- Missing: *distances*



Yerkes, 1897



M 51, V band

Spiral Nebulae

NGC 891 observed with WIYN

MW

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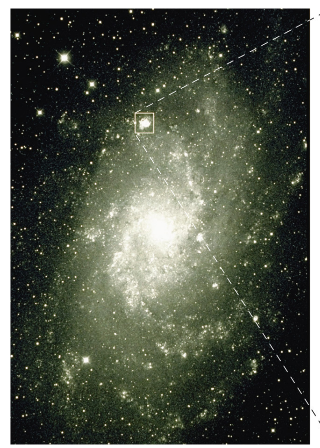
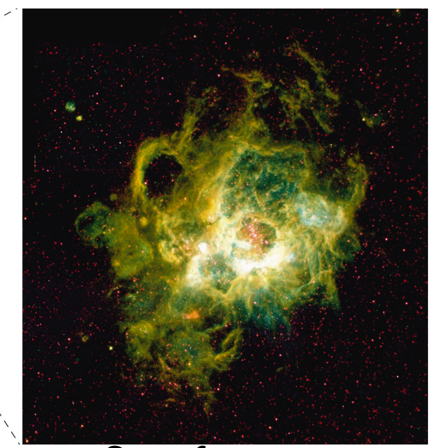
compress ↓



M33



Star-forming nebula in M33

- dust lanes and bulge…a clue?

Early Distances

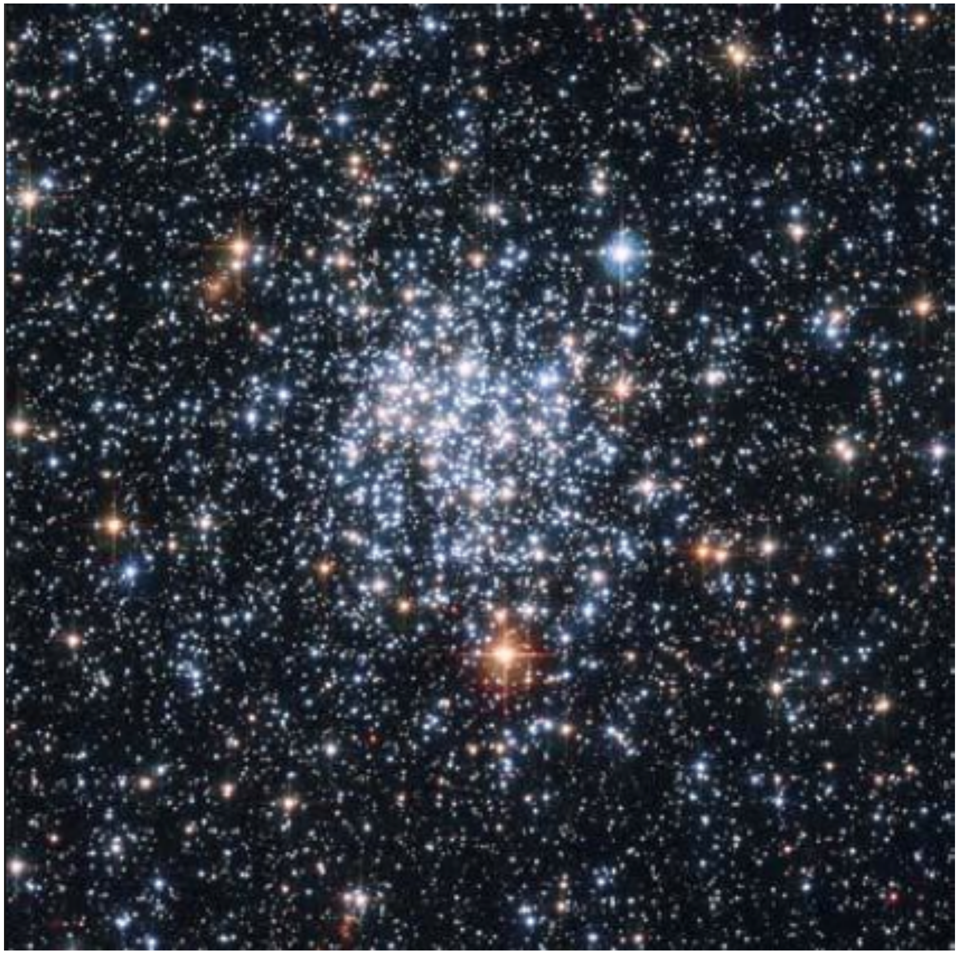
- Trigonometric Parallax
  - D(pc) = 1/θ (arcseconds)
  - In 1900 this was good out to 30 pc (1 pc = 3.1×10^{18} cm)
  - Hipparcos satellite went out to about 200 pc; GAIA satellite (2012) will go farther (*)
- Other distance indicators needed
  - Statistical parallax (for clusters) – using vertex motion
  - Spectroscopic parallax
  - Variable stars
    - 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")
- Continues to this day: Cepheids used by HST to measure H_0
- Supernovae (Sne) and galaxies (via scaling-relations) used as standard candles at even larger distances

* See: http://sci.esa.int/science-e/www/area/index.cfm?fareaid=26

Cepheid Variables

- Most stars have constant luminosities…(within limits)
- Some vary…
  - Binaries – orbital eclipsing
  - Novae - mass-accreting white dwarves (WD) or neutron stars
  - Supernovae (SNe) – exploding massive stars or critical-mass WDs
  - Mira variables – asymptotic giant branch stars (ABG) of intermediate mass; red, long term pulsation (100 days)
  - RR Lyrae: low-mass giants (evolved stars), short periods (~day), fainter luminosities, lower mass stars (Horizontal Branch, HB)
  - Cepheids: evolving, luminous massive stars (> $3M_{\odot}$); blue, w/ periods of 10-100 days, easy to find w/ sufficient resolution and timing
- Clusters: young vs old
- Magellanic Clouds – all Cepheids at the same distance, so the period-luminosity relationship really shows up

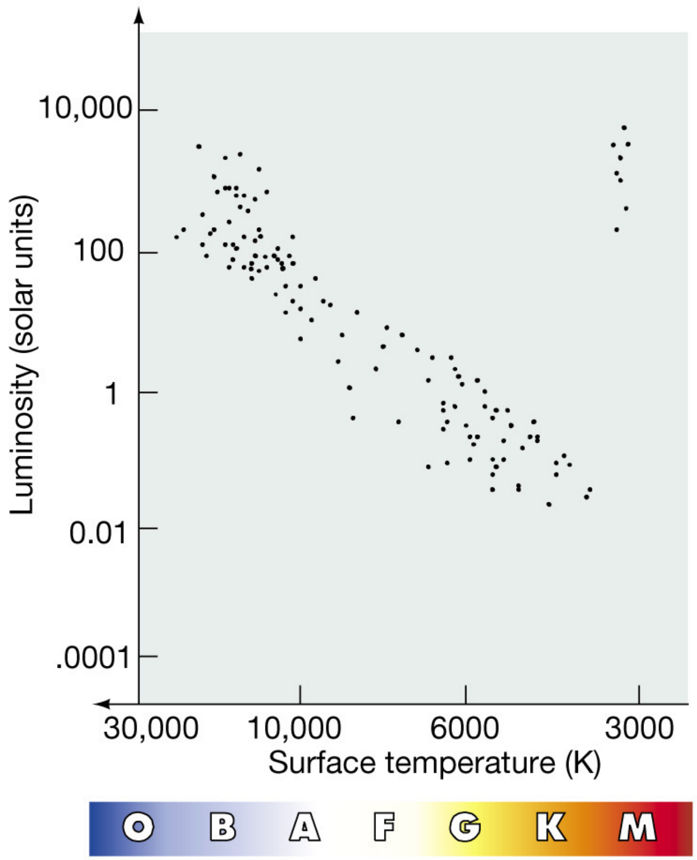
Star Clusters



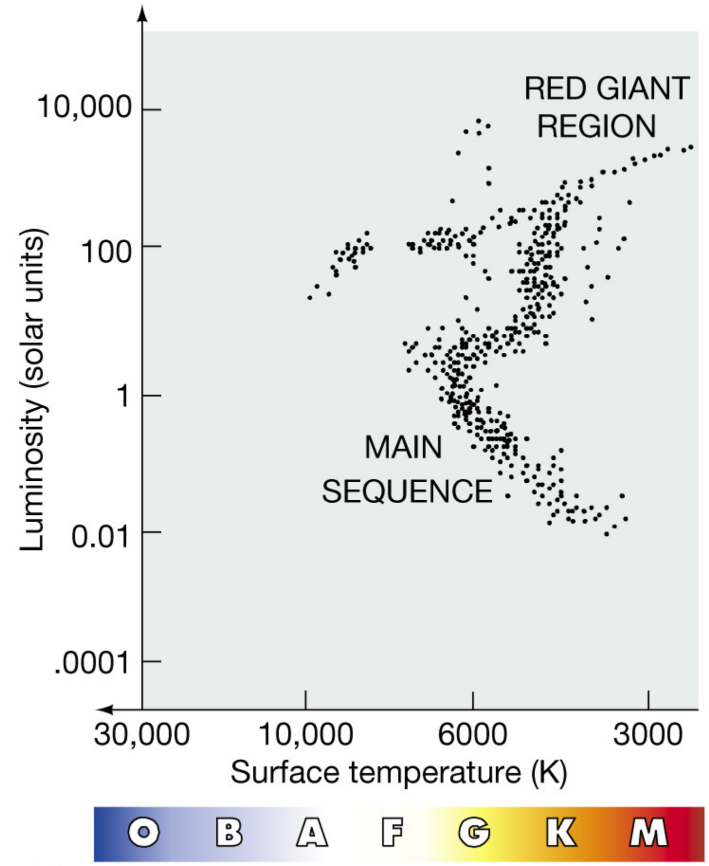
NGC 265 – open cluster in SMC

M80 – MW globular cluster

Star Clusters

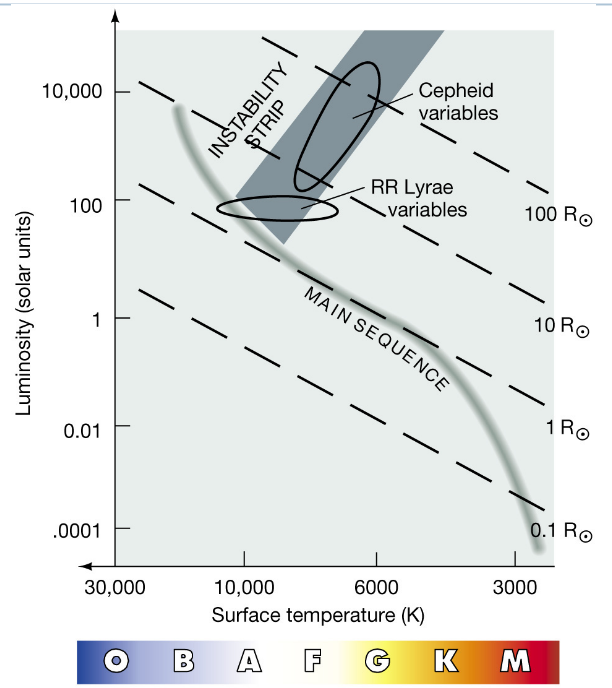


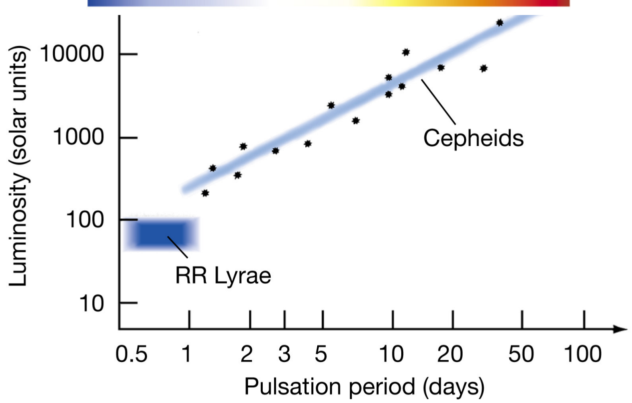
young

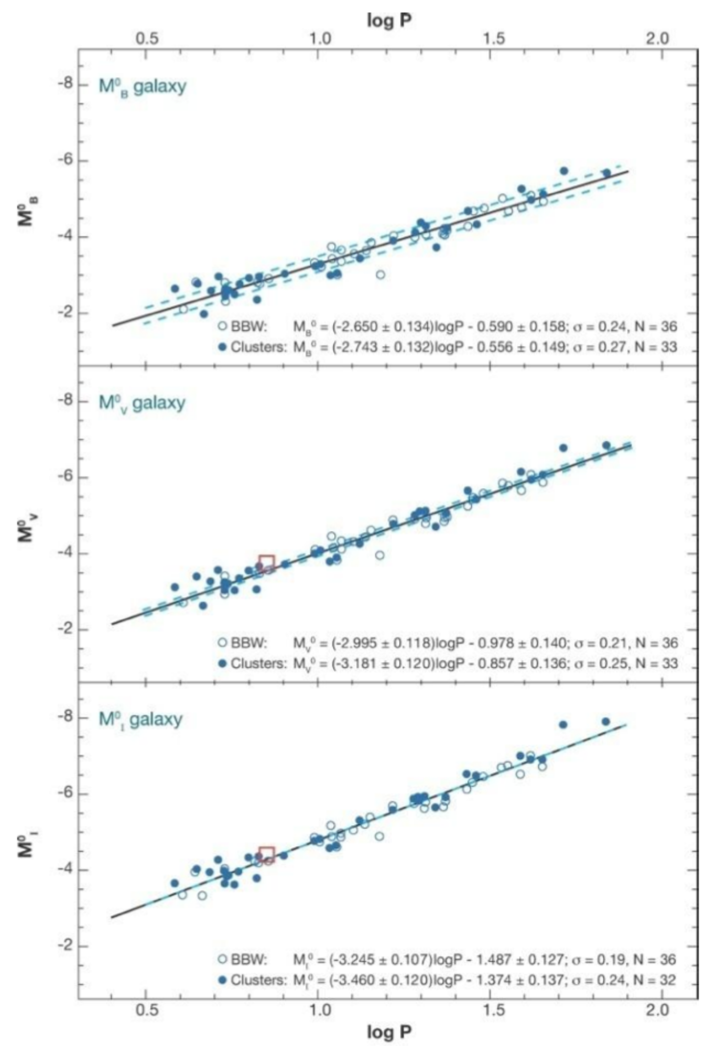


old

Variables & Cepheid P-L relationship





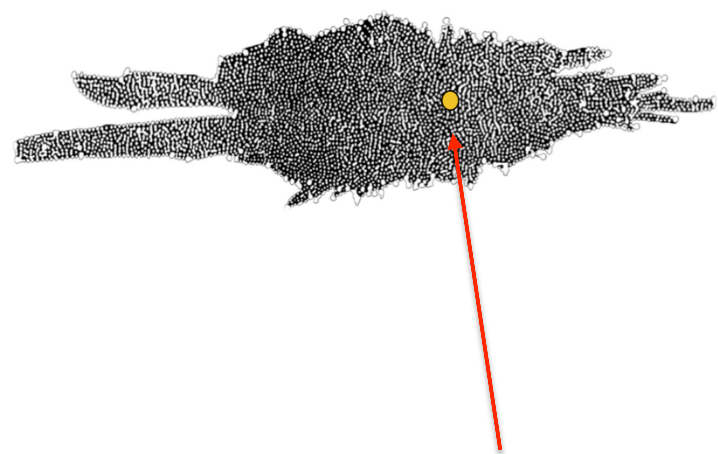


Sandage A, Tammann GA. 2006.
Annu. Rev. Astron. Astrophys. 44:93–140

Shapley

- 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 pc (old size based on star-counts was only 8 kpc)
  - Implication: spiral nebulae had to be contained within the Milky Way!
- Mistake
  - Wrong variable stars! They were RR Lyraes!
  - Didn't account for reddening (then again, nobody really did)

Picture of our "universe" pre-Shapley



You were thought to be here

Curtis

- 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 (clue for Hubble)
- Band of dark material seen in some edge-on spiral systems
- Kapteyn used star counts to conclude we live in a flat, heliocentric conglomeration about 15 kpc in diameter (about the same size of M31 if it were 150 kpc away)

Resolution

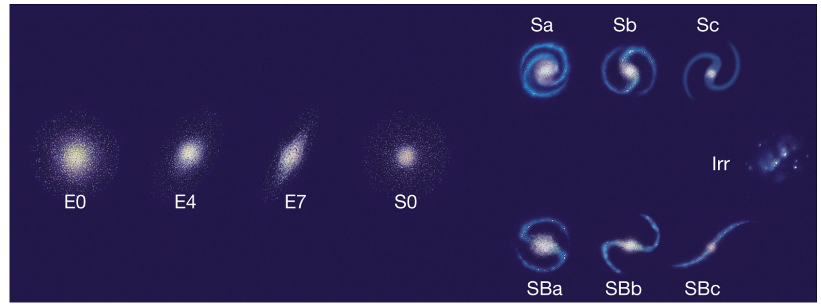
- 1923: Edwin Hubble used the 100-inch telescope at Mt. Wilson
  - Resolved parts of nearby galaxies into stars
  - Detected Cepheids in M31 and measured their periods
  - Used radial-velocity measurements from Slipher at Lowell observatory made with smaller telescopes!
  - Later determined velocity-distance relationship yielding $H_0 \sim 600$ km s^{-1} (bad Cepheid distance calibration)
- 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)

Modern times

- 1940-1950's: Understanding of stellar evolution (fusion).
- 1960's: Discovery of CMBR; Big Bang model consolidated.
- 1970's: Distant universe opened by radio astronomy (quasars, radio galaxies); early-universe nucleosynthesis calculated.
- 1980's: modern era of CCD astronomy begins; particle-physics and early-universe meld (unified theories); dark-matter accepted phenomenon.
- 1990's: era of Hubble Space Telescope (HST) and 10m telescopes (Keck, VLT) begins; galaxy evolution confronted; CMBR probed; basic cosmological parameters determined.
- 2000: multi-wavelength satellites, large ground-based surveys, more 10m telescopes than 4m telescopes; dark-energy accepted phenomenon.
- 2010-2010: ALMA, JWST, and ELTs; epoch of reionization and earth-like planets.

Properties of Galaxies: Classification

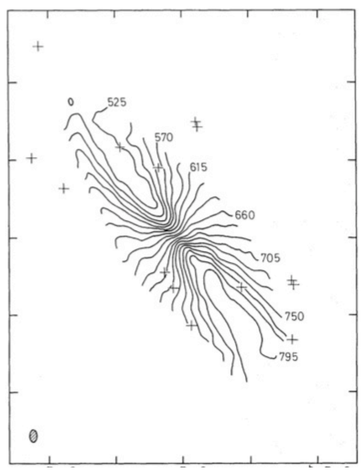
- Hubble types – quite subjective
  - Ellipticals (E0-E7), where n=10[1-(b/a)])
  - Lenticulars (S0): a transition type
  - Spirals
    - "tightness" of spiral (Sa-Sd)
    - Prominence of central bulge (Sa-Sd)
    - Presence of a "bar" (B, as in SBc)
    - Presence of a ring (r) or lens (s); added by de Vaucouleurs
  - "Morphed" into numerical T types: E = - 5, Sb = 3, Irr = 8-10
    - But note! These are ***not*** quantitative.

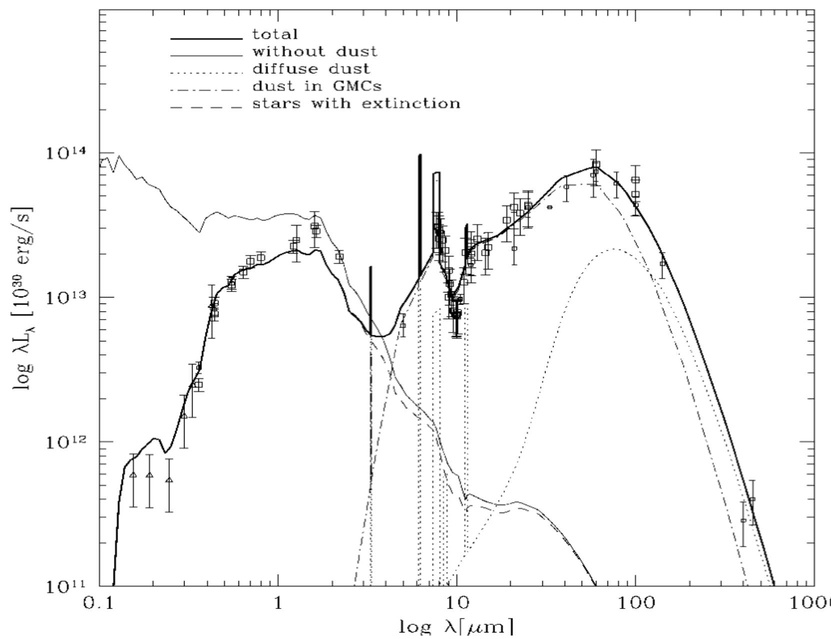


- Other classification schemes
  - Luminosity scale (van den Bergh)
  - Spectral "types" (Morgan)
  - bulge/disk ratio – requires light-profile decomposition (Kent)
  - Structural parameters (image concentration, asymmetry and flocculence)
  - Gas/stellar ratios
  - Kinematic "temperature" (rotational/random velocities)

Physical Properties of Galaxies

- Observables
  - Scales: size (s), luminosity (L) (surface-brightness, μ)
  - Shapes: light concentration (c), azimuthal structure ($a_1 \ldots a_n$)
  - Kinematics: rotation (V), random motion (σ)
  - Content: spectral energy distributions interpreted as…
    - Stellar populations: age, metallicity, and mass (τ,z, $\mathcal{M}_*$)
    - Dust, gas (all phases): densities (ρ_i)





Statistical Properties

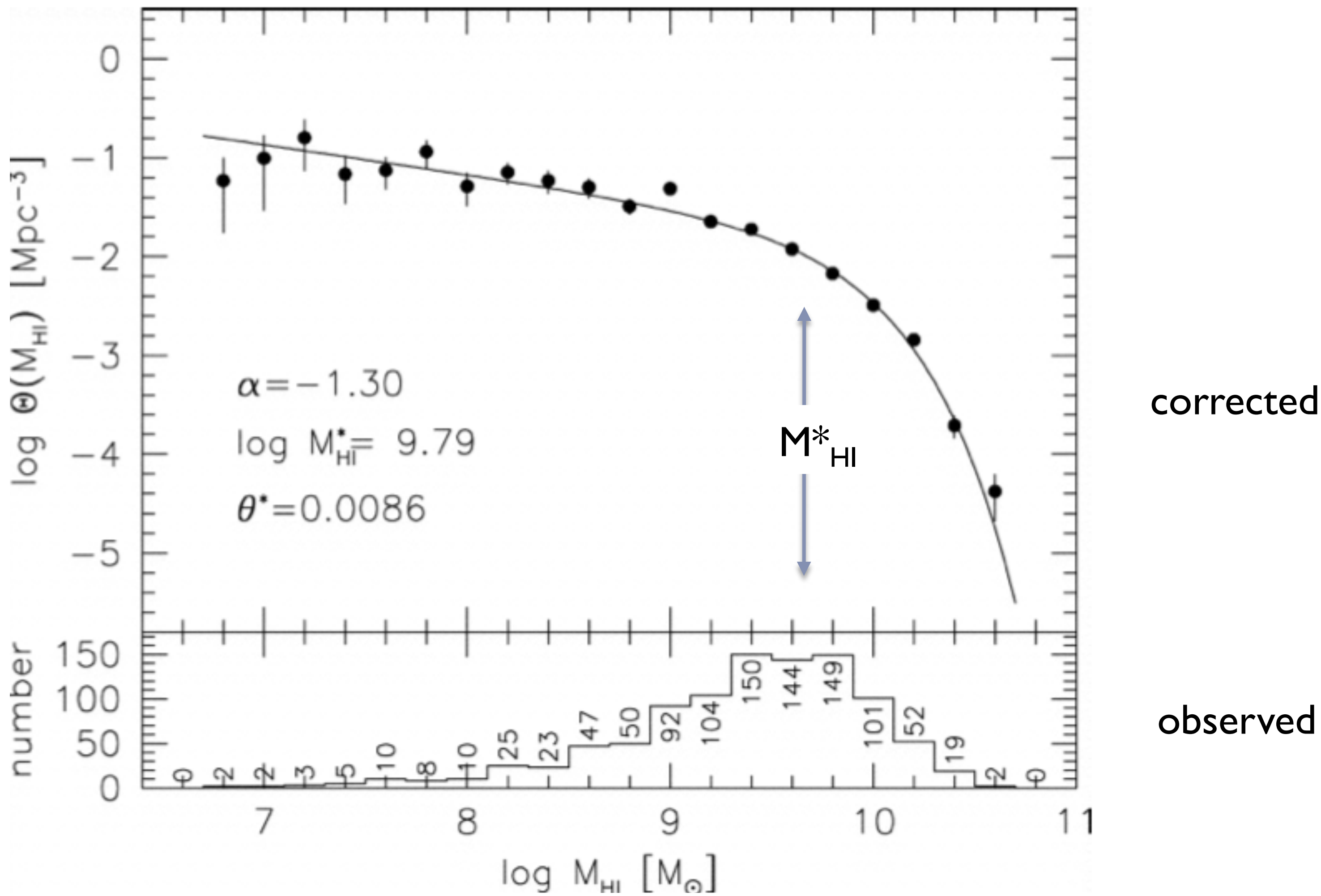
- Crudely defined by the luminosity function (LF)
  - $\int \Phi(M)dM = \nu$, where v is the total number of galaxies in the magnitude range M, M+dM
  - Need large volume: sample all environments
  - Need unbiased sample (we'll talk about the Malmquist bias later)
  - Convert magnitudes into real luminosities: $m = -2.5 \log 10(L/L_0) + \text{constant}$
- Schecter function
  - $\Phi(L) = (\Phi^*/L^*)(L/L^*)^{\alpha} \exp(-L/L^*)$
  - L* is the characteristic luminosity above which the number of galaxies falls off rapidly ($1.2\times10^{10}\ L_\odot$), i.e., the "*knee*"
  - Φ^* = normalization of the galaxy density (0.016 Mpc^{-3})
  - α is the faint end slope (-0.8 to -1.8)

- Both luminosity and mass (HI) functions are reasonably well fit by this near L*, *but there is substantial variation in the slope and normalization between wavelengths, and that a single Schecter function is not enough.*

- We really want Φ(all observables):

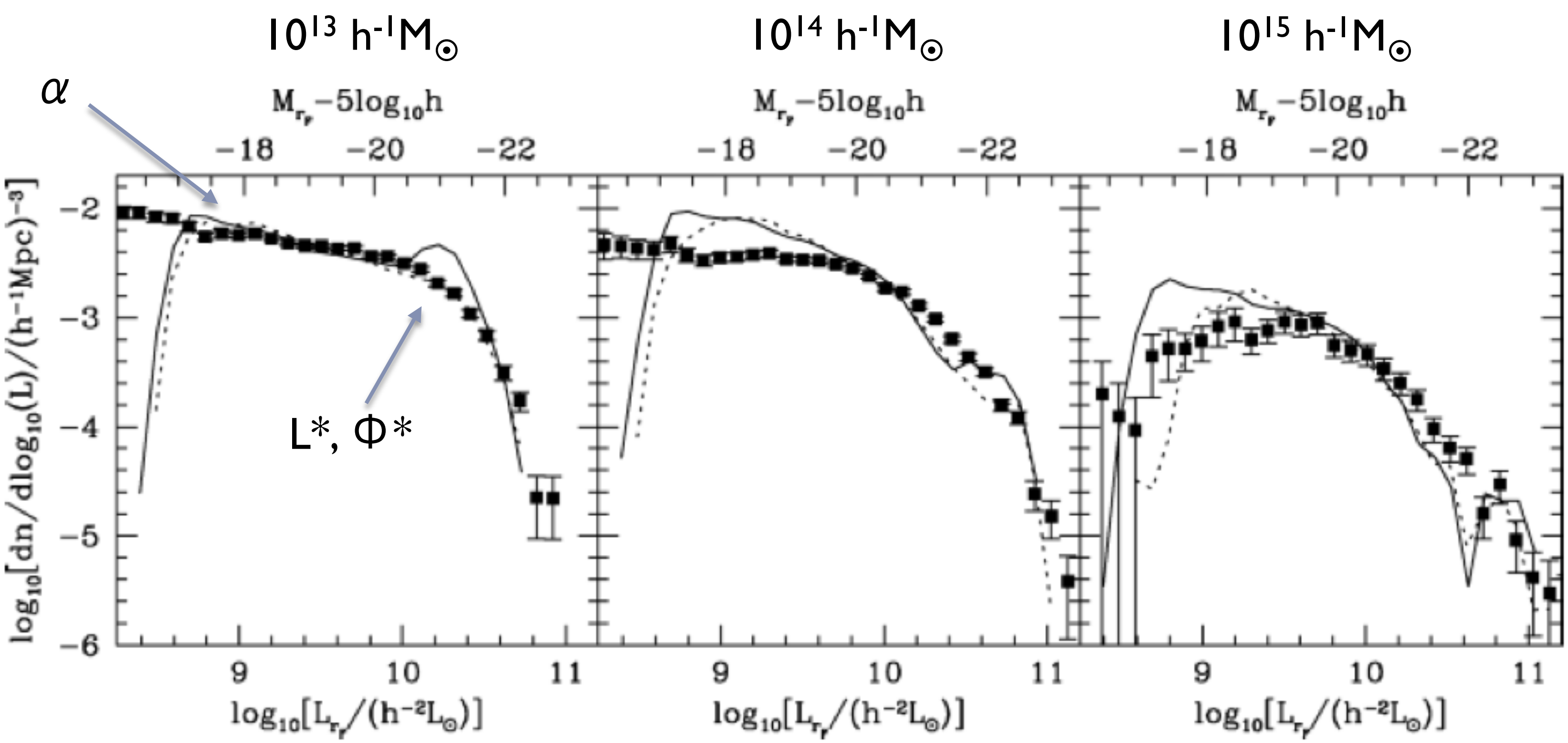
$$\Phi\ (s, L, c, a_1 \ldots a_n, V, \sigma, \tau, z, \mathcal{M}_*, \rho_i)$$

HI Mass function



Optical luminosity functions

As a function of group environment (group total mass): Eke et al. (2004)



Red light (R_F band);
$h = H_0$ / 100 km s^{-1} Mpc^{-1}

Squares: actual data
Solid lines measured from simulations, corrected
Dashed lines measured from simulations, uncorrected

- Φ $(s, L, c, a_1 \ldots a_n, V, \sigma, \tau, z, \mathcal{M}_*, \rho_{i;}\ e)$ -- e is environment

Stopped here

Stellar mass function

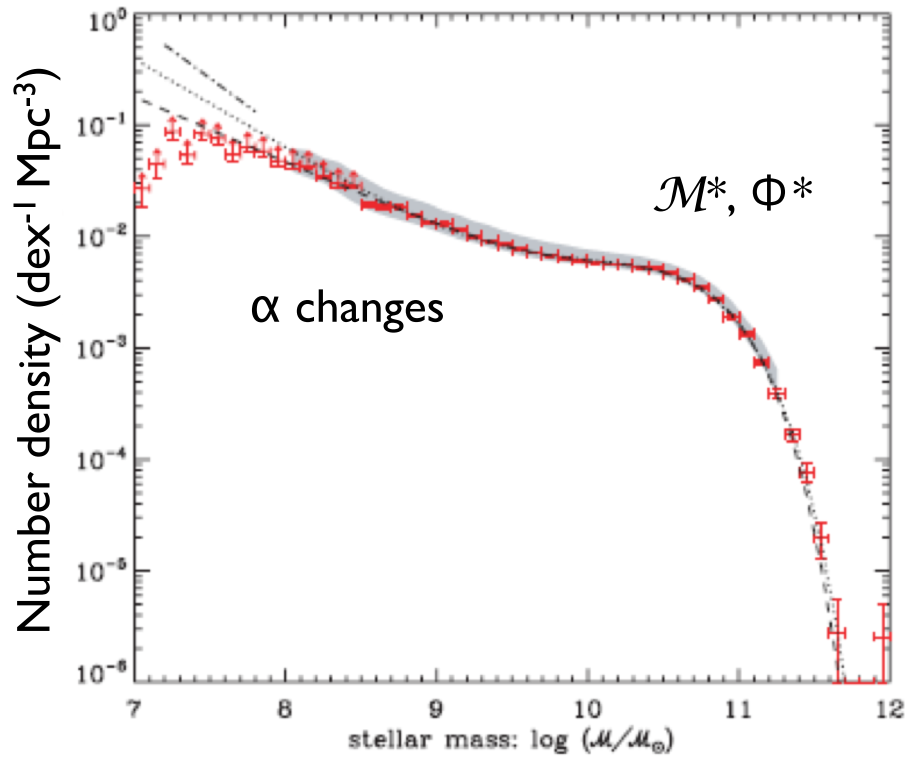
Baldry et al. 2008

Stellar mass estimated from red/near-infrared light assuming a mass-to-light ratio (M/L or ϒ), which depends on stellar populations (colors), assumptions about:

- the stellar mass function (IMF)
- neutral and molecular gas content,
- dark-matter

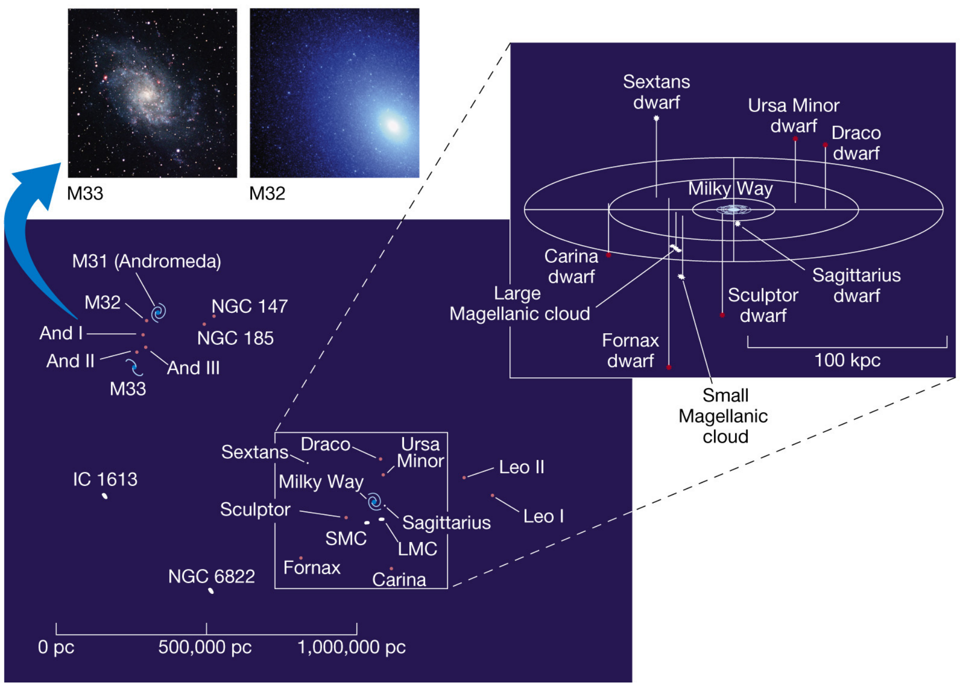
We will discuss these issues.

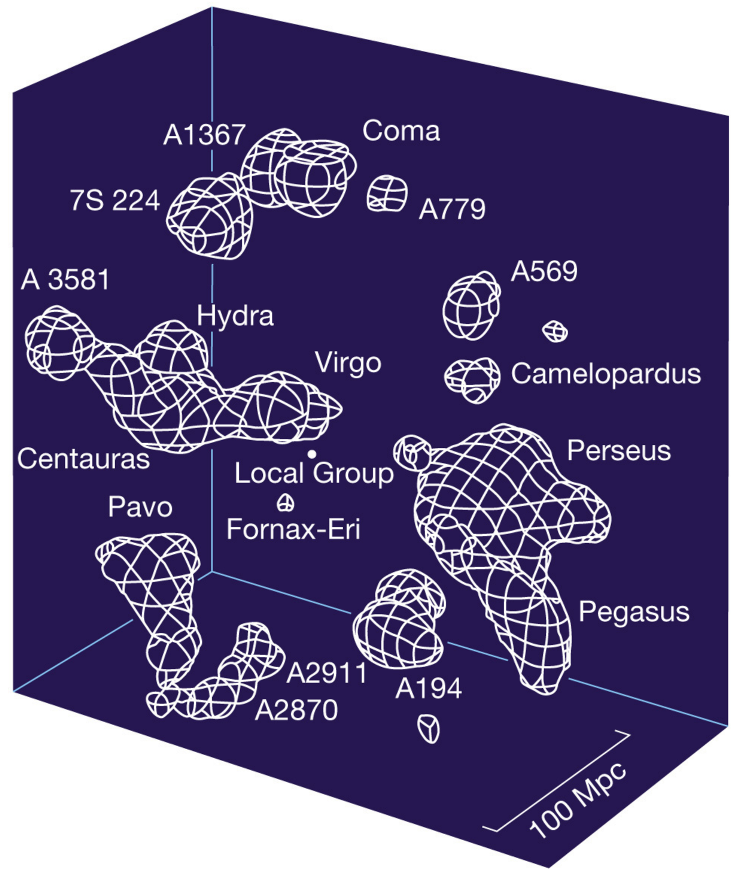
In this case, stellar mass function is modeled as composite of two Schecter functions with different α and ϕ*.



Large Scale Structure

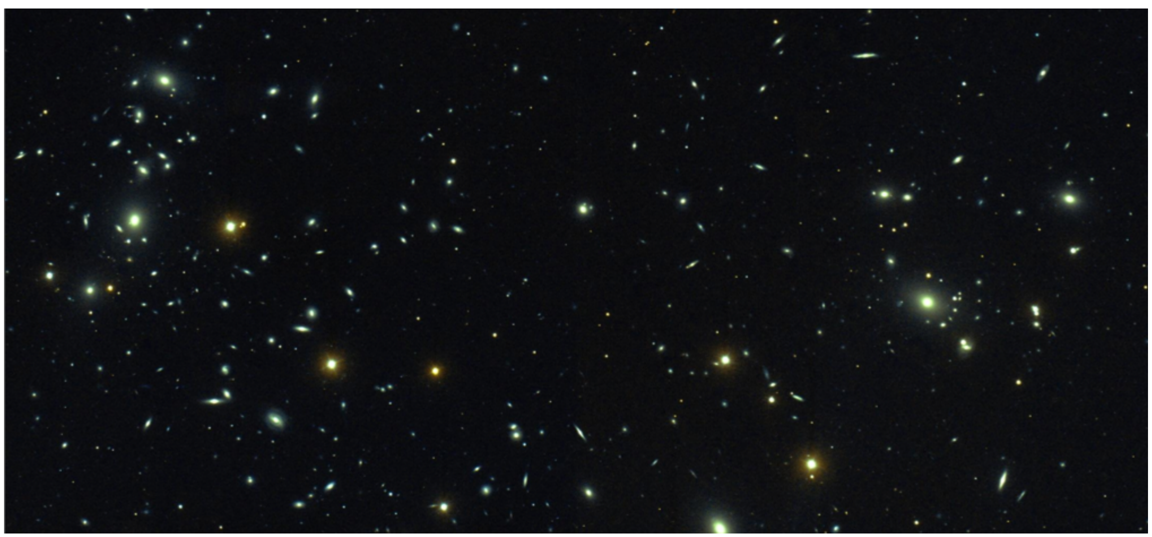
- What's bigger than a galaxy?
- Groups: where most galaxies live
  - Local Group:



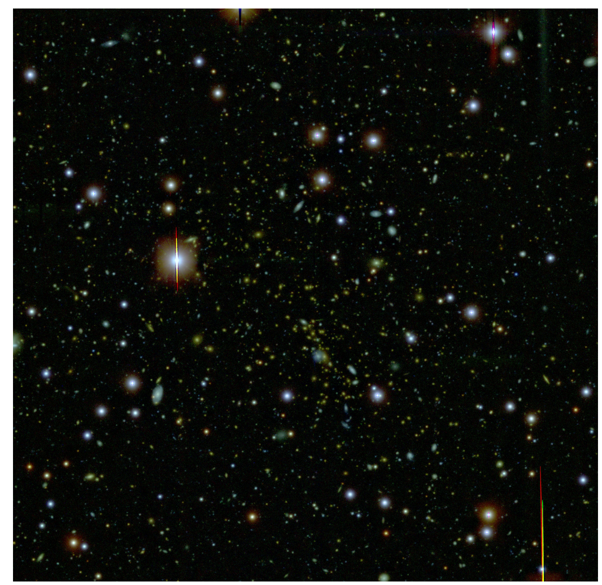


Large Scale Structure

- Bigger still: Clusters
  - 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) ➔ dark matter dominated
  - Gravitationally bound



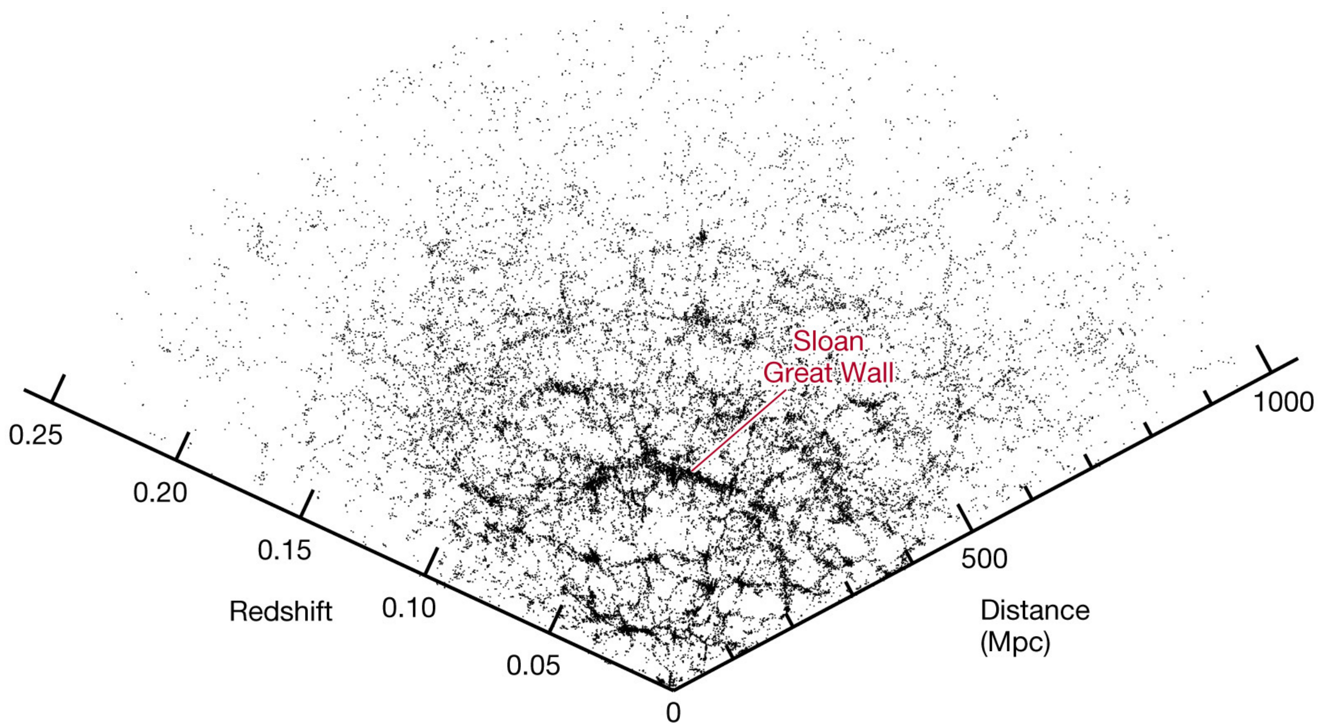
Abell 98 nearly next door



MS0415 at z = 0.54

Large Scale Structure

- Filaments and voids
  - Great Attractor
  - Characteristic scales: 40-120 Mpc



Surveys

- Palomar Sky Survey (POSS) – blue/red photographic imaging (all sky)
  - digitized version (DSS)
- Sloan Digital Sky Survey (SDSS) – modern multi-band optical CCD imaging *and spectroscopy*
  - www.sdss.org
- 2-Micron All-Sky Survey (2MASS) – J,H,K band imaging (all sky)
  - http://www.ipac.caltech.edu/2mass/
- GALEX – UV all-sky survey
  - http://www.galex.caltech.edu/
- IRAS – all sky survey (old satellite: http://irsa.ipac.caltech.edu/IRASdocs/iras.html)
- FIRST/NVSS
  - http://sundog.stsci.edu
  - www.cv.nrao.edu/nvss}
- Arecibo Surveys (ALFALFA)
  - egg.astro.cornell.edu/alfalfa}
- Various "Deep Fields"
  - Hubble Deep Fields (HDF): north and south
  - Chandra (X-ray), Spitzer (IR) 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

- I Zw 18 – Matthew K.
- NGC 4449 – Nick M.
- NGC 6166 – Ali B.
- NGC 4594 – Megan J.
- NGC 5128 – Nick P.
- NGC 3115 – Elise L.
- NGC 1300 – Cody G.
- NGC 3370 – Sara S.
- NGC 7742 – Hanna H.
- NGC 1512 – Capri P.
- NGC 1569 – Rob G.
- NGC 3949 – Justin S.