Welcome!

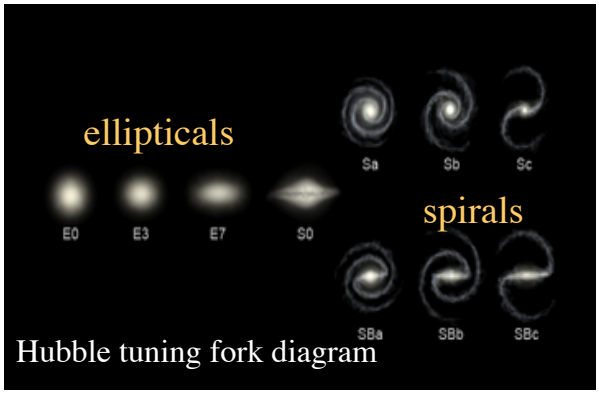
- What is this course about?
- Logistics
  - Textbook, web pages
  - Assignments, exams, grading
  - Academic integrity
  - Semester plan
- Discussion
  - galaxies the big picture

  - With the students in the class there is a wide range of knowledge about astrophysical objects... I hope to hit a middle level so that the students with the least background are not overwhelmed and the students with the most are not bored.
  - If I miss this middle ground please tell me as soon as possible !!

Galaxies in the Universe

Galaxies- Please Read Ch 1 and sec 2.1-2.4 in MBW

- What is a galaxy?
  - Observationally
  - Theoretically
- Observationally
  - A lot of matter in 'one' place
    - historically matter was traced by optical light (due mostly to stars)
    - Now can find and study galaxies by radio and mm emission from ionized gas and by emission in x-rays from their ISM+ black holes
- Theoretically
  - A bound system with a mass between that of a globular cluster (~10^6 $M_\odot$ and a group of galaxies ~10^{13} $M_\odot$)
  - Most of the mass (>65%) is dark matter (>20x more DM than stars)
    - **e,g compact condensation of baryons near the center of dark matter halos.**



Hubble tuning fork diagram

Galaxies come in a huge range of shapes and sizes

Generically divided into 3 generalized morphologies

spirals
ellipticals
irregulars

Textbook & web pages

Required text: Galaxy Formation & Evolution by H. Mo, F. van den Bosch & S. White

Authors' web page:

http://www.physics.utah.edu/~vdbosch/astro5580.html

- the first two chapters of MBW are on-line at

http://www.astro.umass.edu/~hjmo/astro330/htmldir/reading.pdf

secondary books

- Galaxies in the Universe: An Introduction (2nd Edition) by L. Sparke & J. Gallagher

http://www.astro.wisc.edu/~sparke/book/galaxybook.html

- Galactic Dynamics (2nd Edition) by J. Binney & S. Tremaine

- Course web page:

http://www.astro.umd.edu/~richard/teaching/ASTR620.html

  - Information, syllabus, lecture schedule
  - Assignments
  - Past lectures
- Lectures will be posted on the web page *after* they are given

Assignments & Grading

- Assignments:
  - Homework: 30%- including research reports
  - Midterm : 20%
  - Final : 30%
  - Project/term paper 20%
  - TOTAL : 100%
  - *Class participation is strongly encouraged*

  - *Mid-term date Oct 13*

Pre-requisites

- I will assume that you are familiar with basic astronomical terms and usage.
- If there is stuff you are not familiar with STOP ME and ASK QUESTIONS- this field is jargon rich !!!
- I will try and introduce the needed physics- Binney and Tremaine is a fairly formidable book in which the reader is assumed to be familiar with advanced dynamics.

The Different Takes

- Galaxies- ch 1 and sec 2.1-2.4 in MBW will give you a crash course in galaxies - lots of material quickly presented.
- A very different take on this material is in B&T ch1 pgs 1-29
- S&G in ch 1 present a lot of NECESSARY to know stuff about stars (can't study galaxies without some knowledge of stars) and general astronomy stuff and then in pgs 27-49 an eclectic overview of galaxies.
- I will try and present a summary of all of this material in quasi-coherent fashion in the next 3 lectures

Read MBW- please take a look at B&T and S&G

I will often refer to these 2 other books ; copies in the library

The field is changing rapidly and even MBW is getting outdated. **I will often use figures from recent papers**... Its necessary to read and know the literature. There were > 400 papers per month in the last year about galaxies.

Reading

- *Please read Chapter 1, 2.1-2.3 of MWB by next week*
- *Please develop 1 question from this reading and prepare to discuss next **Tuesday**.*
- First HW assigned Thursday next week
- Web page up by this Thursday
- I will 'assign' reading of a recent paper each week, each student will have to present a summary of a research paper twice during the semester – I will ask for volunteers (!)
- Student contributions should summarize the methods and results from the journal/review article and explain the importance of the work and its relevance to broader research on galaxies. The presentations should be pedagogical — focus on explaining rather than summarizing

Exams+ Other Info- Academic calendar

http://www.provost.umd.edu/calendar/15.cfm

- One mid-term, likely Oct 13
- Final exam
- Project/term paper due *next to last week* of semester (Dec 3)
- In event of a REAL EMERGENCY which forces you to miss an exam
    - Contact me prior to the exam- or as soon as possible
    - Document the emergency
- See http://www.registrar.umd.edu/deadlines.html for deadlines
- Thanksgiving November 26-29 (Thursday-Sunday)
    - Religious Holidays
        - Rosh Hashanah 9/13-15
        - Yom Kippur 9/23

Emergencies
Based on University Policy

- Regular attendance and participation in this class is best. However, if a class must be missed due to an illness, or other valid reason, the policy is:
    - For every necessary absence from class, a reasonable effort should be made to notify me in advance of the class. When returning to class, students must e-mail me or bring a note identifying the date of and reason for the absence.
- If a student is absent more than 5 time(s), documentation signed by a health care professional may be requested.
- If a student is absent on days when **tests are scheduled**, they should notify me in advance (if possible), and upon returning to class, bring documentation of the illness or personal reason.
- Please inform me of any other issue requiring special attention
- **None of this should be necessary in a graduate school class**

Homework

- Homework assigned approx. once every two weeks
- HW is collected *at the start of class* on the due date (~a week later)
  - **Please hand in on time**, or document the valid reason why it is late.
  - No credit after the day on which it is due, unless there is a justifiable reason.

Academic integrity

- **Always:**
  - Present your own thoughts in your own words
  - Cite any references that you use
- **Never**:
  - Copy from another student
  - Directly quote any published article unless you also give full credit to that article.
  - Allow other students to copy from you.
- Per campus policy, please write the honor pledge on each assignment

Topics we will cover

- Broad description of galaxies
- Stellar populations/star formation
- Gas and Dust in galaxies
- Milky Way as a detailed example of a galaxy
- Galactic dynamics/need for dark matter
- Spiral galaxies
- Elliptical galaxies
- Galactic evolution/formation and cosmological implications
- Active Galactic nuclei -galactic centers
- This is an **enormous** range of material; the level of detail will vary greatly from section to section

- I will focus on 'recent' research – to the detriment of 'classical' galaxy material (mostly dynamics of the Milkyway)
- The goal is that, if you wish, you can understand the recent research literature and start research projects of interest.

Where is the Material

- We will cover sections of MBW chapters
  - 1-2 Introduction and Observational facts
  - 8 Formation and Evolution of Gaseous Halos (only a small part)
  - 9 Star Formation in Galaxies
  - 10 Stellar Populations and Chemical Evolution
  - 11 Disk Galaxies
  - 13 Elliptical Galaxies
  - 14 Active Galaxies
  - 15 Statistical Properties of the Galaxy Population

This is an enormous amount of material and the depth of coverage will vary a lot.

We will not cover the material in the same order as the chapters in MBW (e.g. we will discuss Stellar Populations before Star Formation)

Lectures for the Semester

- Lecture 1 Introduction: Some Galaxy Properties
- Lecture 2 Introduction (continued): Some Galaxy Properties
- Lecture 3 Introduction (continued): Some Galaxy Properties
- Lecture 4 Basic Galaxy Properties
- Lecture 5 Properties of Stars Lec 1
- Lecture 6 Properties of Stars Lec 2
- Lecture 7 Gas in Galaxies Lec 1
- Lecture 8 Gas in Galaxies Lec 2
- Lecture 9 Dust in Galaxies
- Lecture 10-11 Milky Way Lec
- Lecture 12 Galactic Rotation
- Lecture 13 Dynamics I
- Lecture 14 Dynamics II
- Lecture 15 Dynamics III
- Lectures 16,17 Local group
- Lecture 18 Chemical Evolution
- Lecture 19 Star Formation
- Lecture 20-21-22 Spiral Galaxies
- Lecture 23-24-25 Elliptical galaxies
- Lecture 26 AGN 1
- Lecture 27-28 AGN 2-3

Some 'Recent' Reviews: There is a long list on the web page

Physical Properties and Environments of Nearby Galaxies
ARA&A 47: 159 M Blanton and J Moustakas

Physical Properties of Galaxies from z = 2–4 ARA&A 49: 525 2011
Alice E. Shapley

Physical Parameters Along the Hubble Sequence: M Roberts and M. Haynes
ARA&A Vol. 32 (1994): 115-15

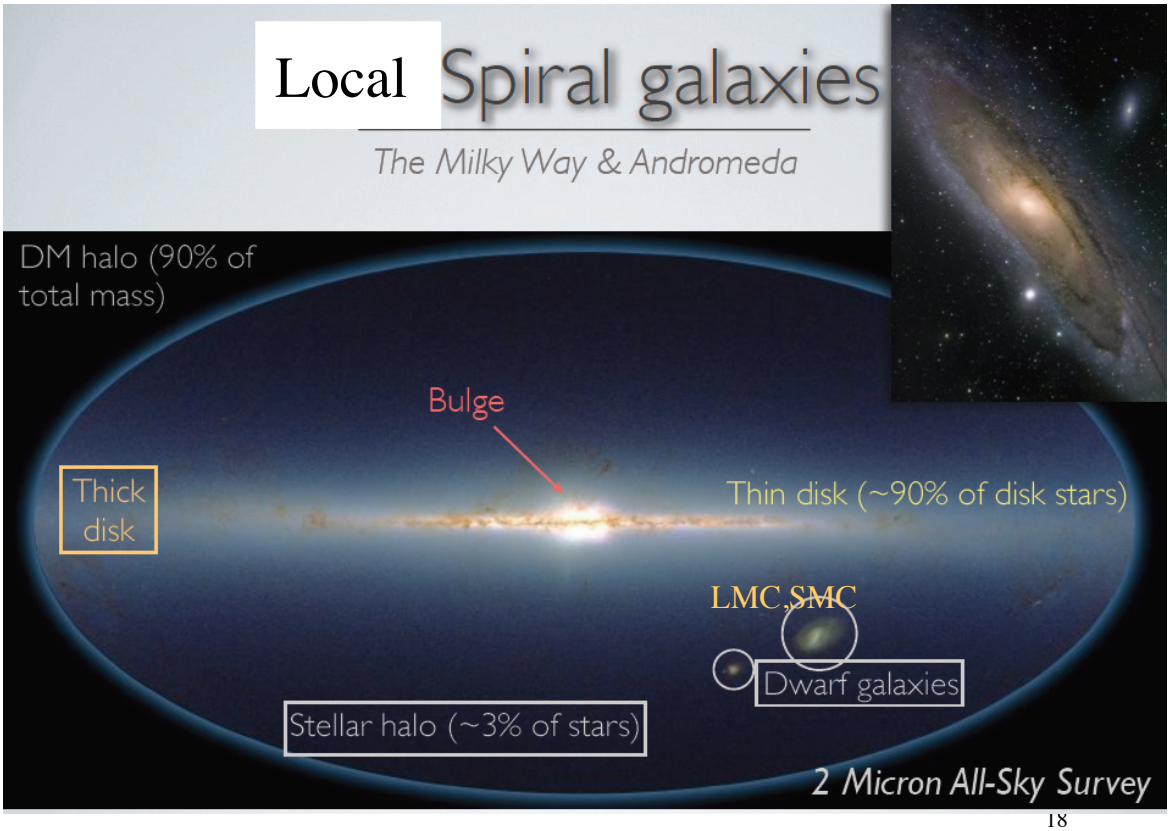
Star Formation In Galaxies Along The Hubble Sequence R. Kennicutt, Jr.
ARA&A Vol. 36 (1998): 189 – 231

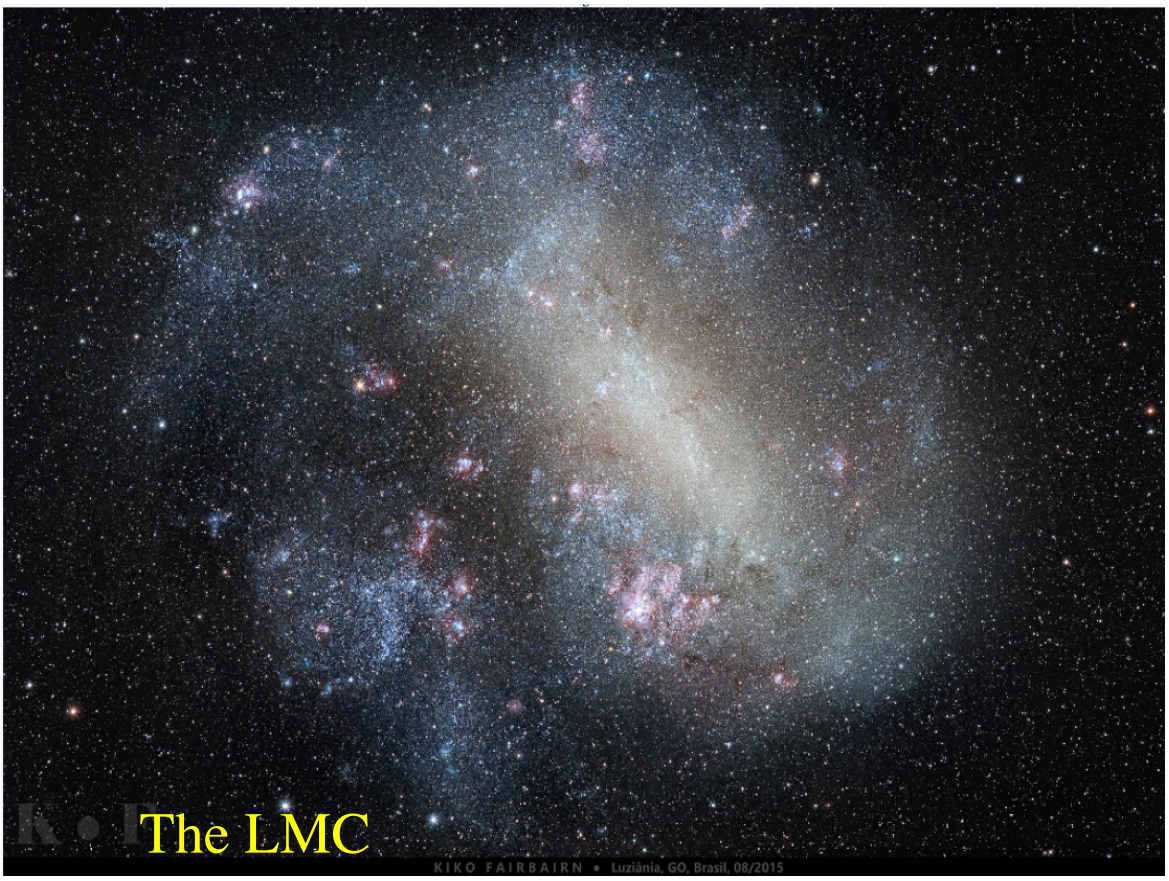
Galaxy Formation: Where Do We Stand? Christopher J. Conselice arXiv:1212.5641

Modeling the Panchromatic Spectral Energy Distributions of Galaxies
Charlie Conroy ARA&A 2013. 51:393–455

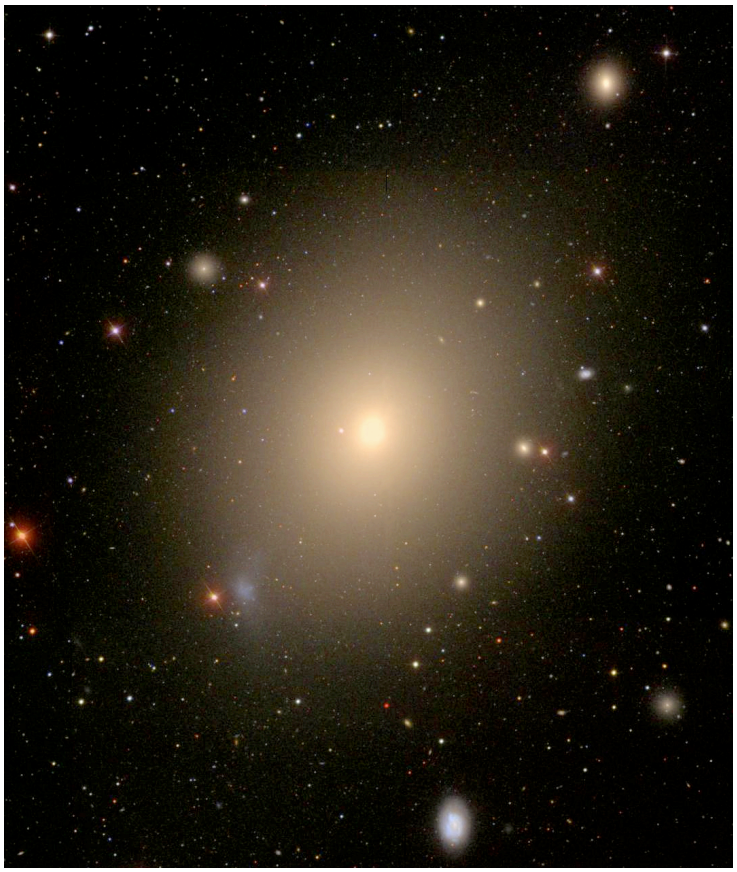
While I do not expect you to read ALL the reviews in DETAIL, they are good refreshers for the material I will present and are a good introduction to the scientific literature- Something you all will need to learn to read and understand... no time like the present.


Jens Hackman, Milky Way over Weikersheim, http://epod.usra.edu/archive/epodviewer.php3?oid=322784
The Galaxy
Andromeda

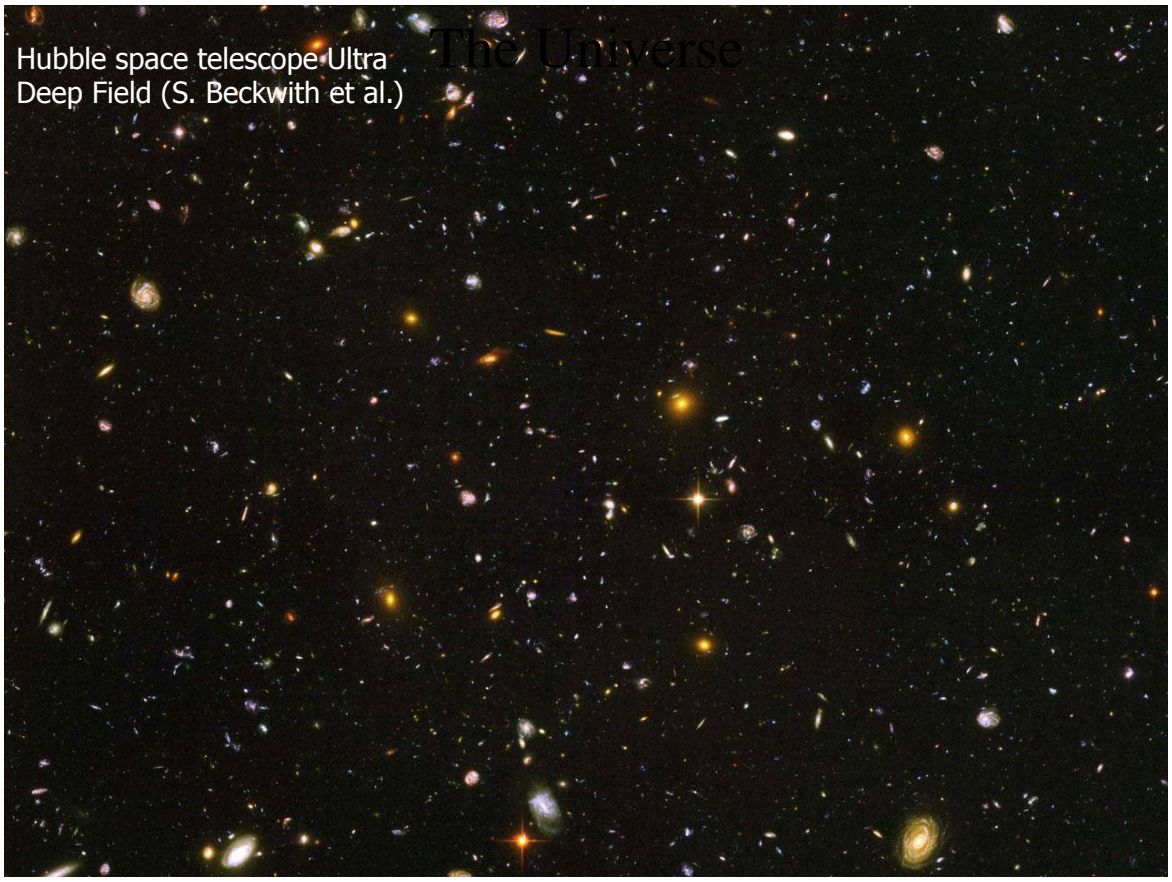

Local Spiral galaxies
The Milky Way & Andromeda
DM halo (90% of total mass)
Bulge
Thick disk
Thin disk (~90% of disk stars)
LMC, SMC
Dwarf galaxies
Stellar halo (~3% of stars)
2 Micron All-Sky Survey



NGC 4472 in the Virgo Cluster



Sloan Digital Sky Survey



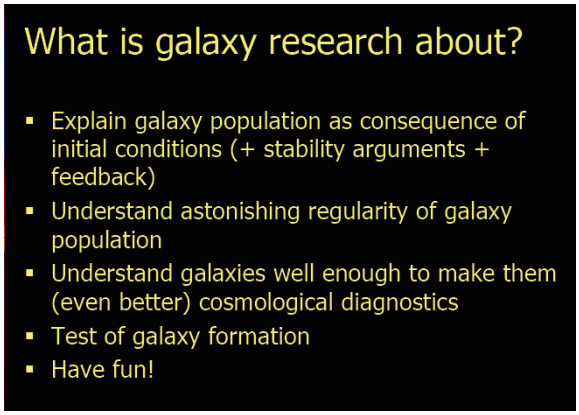
The BIG Picture

- Essentially, all research on galaxies aims at answering how galaxies form and evolve (MBW 1.4.5)
- Steps include understanding the role of the different galactic structural components in this history (baryons (gas, stars and dust), black holes and dark matter), and how they relate with each other.
- We need to link structural analysis, kinematics and dynamics, stellar population properties and evolution, multi-wavelength observations, ample redshift coverage, and theory.
- It is only with such a holistic approach that the physics can be obtained (adapted from Gadotti 2012)

- From a theoretical point of view Galaxies reside in dark matter halos, but, are biased tracers of the underlying matter distribution (MBW sec 1.4.4): that is the observable galaxy properties such as luminosity are not *simple* tracers of dark matter.
- Different kinds of galaxies reside in different mass halos and massive halos can host *multiple* galaxies (pairs, groups, clusters)

Modern galaxy research

- Explain the observed galaxy population and its changes over cosmic time
- Understand why galaxies show the extreme regularity of various parameters
- Try to use galaxies to understand cosmology and vv.
- Cosmic laboratories for all the details of astrophysics
  - star formation
  - interaction of baryons with dark matter
  - formation of the chemical elements
  - the relationship of black holes to their host galaxies
  - nature of dark matter and its distribution



The Evolution of Galaxy Structure Over Cosmic Time
Christopher J. Conselice
ARA&A. 52 (2014): 291-337

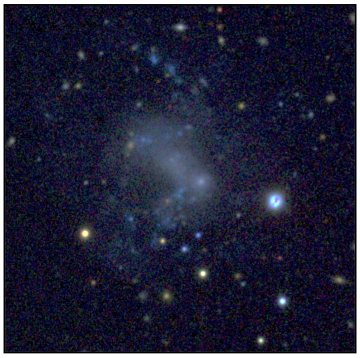
A Brief History

- Discovery of 'nebulae' in late 1700's (Messier) and their cataloging in the late 1800's (NGC catalog)
- Realization (Hubble etc) that the nebular were outside the Milky Way- island universes(originally due to Kant) (for historical interest see 'The Great Debate' http://apod.nasa.gov/diamond_jubilee/debate20.html
- Expansion of the universe 1920's (Hubble)
- Dark matter- Zwicky 1930's Rubin 1970's
- Cosmic Microwave Background and Big Bang Nucleosynthesis established the Big Bang
- 1980's - the development of Cold Dark Matter (CDM) and post 1998- ΛCDM
- 1990's The mass function of galaxies (#/volume)

See **http://www.astr.ua.edu/keel/galaxies** for a nice observationally oriented introduction to the subject

- realization that the distribution of dark matter and baryons is complex and time dependent

Galaxies: From J. Dalcanton



Ellipticals

$M_{halo}>10^{11}M_{\odot}$

V~350km/s

Highly Clustered

Old stars

little star formation

now

Spirals

$M_{halo}>10^{10}\,M_{\odot}$

V~200km/s

wide range of stellar ages

star forming

Dwarfs

$M_{halo}>10^{8}M_{\odot}$

V~30km/s

Weakly Clustered

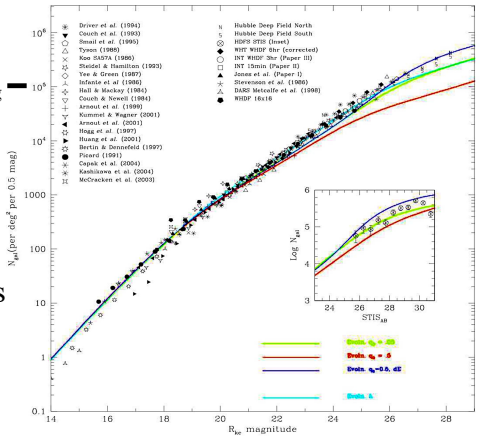
Young stars

Numerous

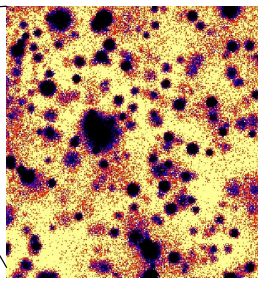
How Many Galaxies are There

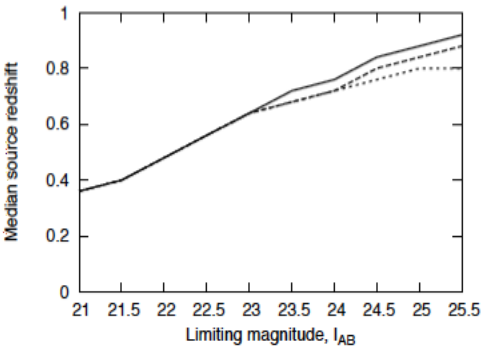
- There are ~50 galaxies/sq arc min at 10^5/deg^2/0.5mag m~25.5, rising slowly to ~175 at m~29

The median redshift at a given magnitude increases slowly

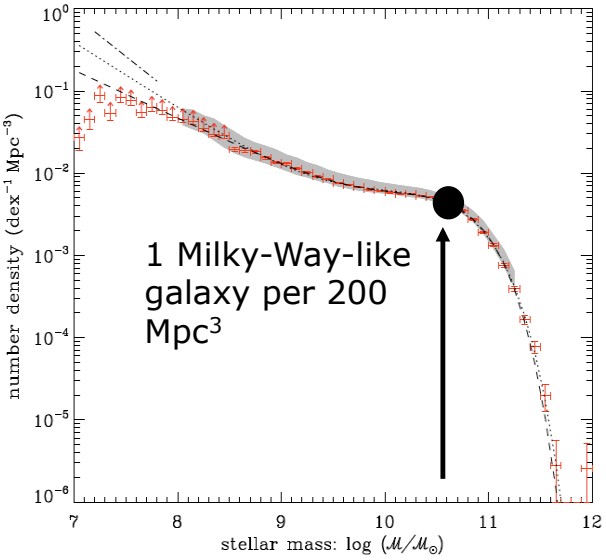


~40% of stellar mass in ellipticals (at z=0) but only 5% by number

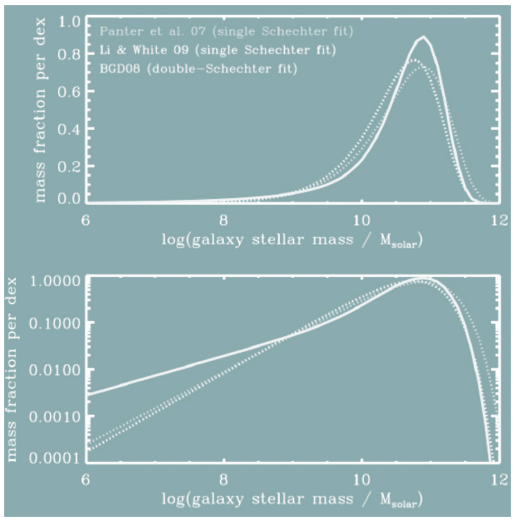




How Many Galaxies are There



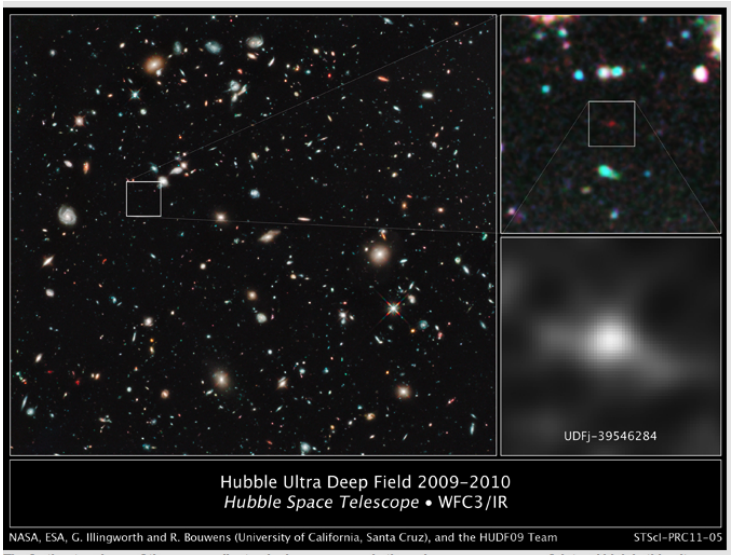
(Rix 2009)



where is the mass-narrow distribution around log M~10.5$M_\odot$.
In mass MW is typical

How Old are Galaxies

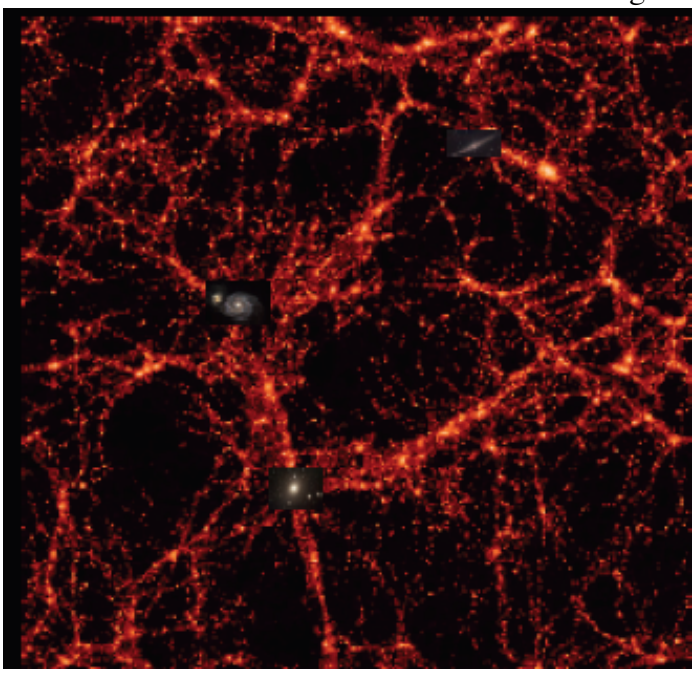
- Direct imaging by HST has shown the existence of galaxies at z~8 (13Gyrs ago, for an age of the universe model of 13.7Gyrs)
- Stellar ages: in the MW oldest stars are ~13.2Gyrs old (error of +/-2 Gyrs) (Physics Today, vol. 65, issue 4, p. 49)
- However galaxies have changed enormously over cosmic time
- The present day pattern of galaxies emerged at z~1



The farthest and one of the very earliest galaxies ever seen in the universe appears as a faint red blob in this ultra-deep-field exposure taken with NASA's Hubble Space Telescope. This is the deepest infrared image taken of the universe. Based on the object's color, astronomers believe it is 13.2 billion light-years away. (Credit: NASA, ESA, G. Illingworth (University of California, Santa Cruz), R. Bouwens (University of California, Santa Cruz, and Leiden University), and the HUDF09 Team)

Galaxies Do Not Live Alone

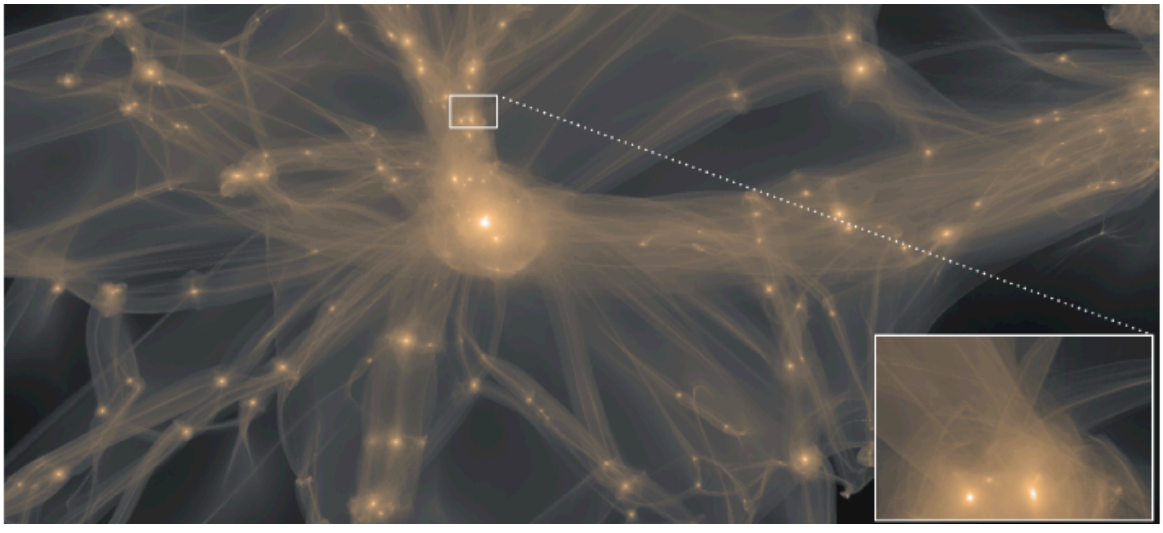
- Galaxies are part of the 'cosmic web'- representing overdense regions of both baryons and dark matter
- The effective size of the dark matter is much larger than the apparent stellar size



The cosmic web has structure at all scales but eventually becomes homogenous at R>70Mpc

Eric Bell

Cosmic Web



In this rendering the large scale sheets and filaments are more easily seen- galaxies tend to reside in these *sheets* and *filaments* and are rare in voids.