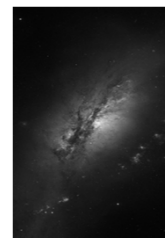


Physics of Galaxies, 2015 10 credits Lecture 1: Introduction



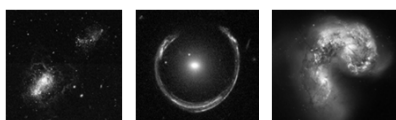
Outline for today I

- Formal Stuff:
 - Course literature
 - Examination
 - Schedule
- Course outline



Outline for today II

- What is a Galaxy?
- Historical Background
- Galaxy Classification
- The Cosmological Framework



Teachers

- Main teacher
 - Erik Zackrisson
 - erik.zackrisson@physics.uu.se
- Guest teacher
(lecture 6 + computer lab)
 - Beatriz Villarroel
 - beatriz.villarroel@physics.uu.se



We're in the astronomy corridor on floor 3 in house 6
– just ring the bell to get in!

Course homepage

- Link:
www.astro.uu.se/~ez/kurs/Galaxies15.html

The Physics of Galaxies, 10 credits (6p), Spring 2015

Lecturer: Peter Schneider, 2015, "Extragalactic Astronomy and Cosmology", Springer, ISBN 978-3-642-54082-0 (hardback) or 978-3-642-54083-7 (ebook)

Contents: Extragalactic astronomy, with emphasis on the origin and evolution of galaxies.

Prerequisites: Knowledge corresponding to a Bachelor's degree in physics, or similar. In addition, basic knowledge about spectra, stellar physics, galaxies and cosmology corresponding to the course "Astronomy 1" is required.

Examination: Seminars, literature report, hand-in exercises, laboratory exercises

Teacher: Erik Zackrisson, erik.zackrisson@physics.uu.se, phone: 018-471 3915

Year: April-June 2015

If you are interested in participating, please notify Erik Zackrisson as soon as possible!

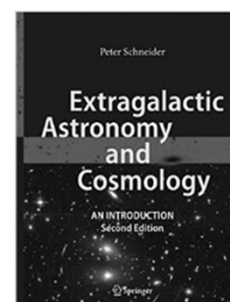
Schedule
Recent changes are marked in red

Date	Time	Room	Lecture Exercise seminar Number	Topics	To read	To write in progress
April 14	15-17	12187	Lecture 1	Course introduction Historical background The extragalactic distance scale Galaxy classification	1-2.4, 3-3.2.2, 3.8-3.9.6	
April 17	16-18	11187	Lecture 2	The Milky Way The Local Group	2.1-2.4.2, 3.1-3.1.3	

Course literature

**Extragalactic Astronomy
and Cosmology**
Peter Schneider
2014/2015, Springer
Hardback:
ISBN 978-3-642-54082-0
eBook:
ISBN 978-3-642-54083-7

Around 700 SEK



Examination

- Two exercise sessions
- Hand-in exercises
- Two seminars
- One computer/laboratory exercise
- Written essay (minimum 3 pages) + oral presentation (10 minutes)

But no written test!

Exercise sessions

- **Session 1:** May 5, 15-17
- **Session 2:** May 26, 13-15
- **Objective:** Solve problems *together* in class



Exercise sessions

- **Preparation:**
 - Study exercises and solutions posted on course homepage
 - Bring pen, paper, calculator/computer, textbook
 - **Grade:** Pass/Fail
- No-show or not actively participating →
Need to complete more hand-in exercises

Exercises and solutions on the course homepage

Make sure you understand the solutions before coming to the exercise session!

The problems we solve in class will be similar.

2. Brightness and colors of unresolved stellar systems. Two stars in a close binary system have mag. 15.2 and mag. = 15.6, respectively. The first star has a color $B - V = -0.2$ and the second $B - V = 0.1$. If this system is observed in a filterband which passes neither the two components, what would the integrated mag. and $(B - V)$ of this object be?

Solution: At large distances, it becomes increasingly difficult to study the individual stars of stellar populations. These are basically too faint to see in this filterband.

1. The flux intensity of your telescope may be insufficient to allow the detection of a single, very distant star, whereas the combined light from large numbers of stars at the same distance may path from above the detection limit.

2. Limitations in angular resolution of your telescope may limit the light from nearby stars, thereby making distant stellar populations appear as single objects.

Much of contemporary extragalactic astronomy is therefore devoted to the study of the integrated light from large numbers of stars. To illustrate this point, Figure 1 shows the appearance of stellar populations at increasing distances, when observed with current telescopes.

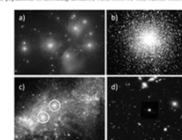


Figure 1: Resolved versus unresolved stellar populations. At a nearby star cluster (the Pleiades, distance 440 ly) in which individual stars can be resolved, by a Hubble Wide field-of-view camera (cf. Figure 1a), the stars appear as distinct points of light.

Hand-in exercises

- 2 exercises downloadable from the course homepage
- Submit by email
- **Deadline:** June 12
- **Grade:** Pass / fail
- Collaboration OK, but please don't turn in identical solutions!

Note: If you didn't actively participate in the exercise sessions, you need to hand in additional exercises – please contact me if this situation should arise

Physics of Galaxies
Hand-in exercises 2015

Instructions: These are the two problems you need to solve to pass the course if you have already actively participated in the exercise sessions. If you are unable to participate in either of them, you should contact the teacher for additional problems to solve to obtain to pass the course. Handwritten solutions are quite acceptable, but submission via email is highly recommended (and will allow for a better evaluation, as your teacher will receive your solutions and comments back as a pdf file. The deadline for handing in solutions to these problems is June 12, 2015.

1. Population synthesis. Use the table of stellar parameters below to generate a simple population synthesis model. Assume that the stellar population of your model galaxy only consists of three types of stars (G, K, and M), all present at the same time, and that the relative number of stars of each type is given by the relative $H\beta$.

a) What is the $(B - V)$ color and $H\beta$ ratio of this population at an age of 1 Myr?

b) Assuming that the population has aged sufficiently so that all the O stars in the cloud no longer contribute to the light output, what is the $(B - V)$ color and the $H\beta$ ratio (where M is defined as $M = H\beta_{\text{G}} + H\beta_{\text{K}} + H\beta_{\text{M}}$)?

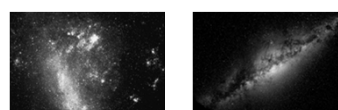
Table 1: Stellar parameters

Stellar type	Mass	Abundance in $H\beta$	Mass sequence lifetime
G	$1.0 M_{\odot}$	1.0×10^6	1.0×10^7 yr
K	$0.8 M_{\odot}$	0.8×10^6	1.0×10^8 yr
M	$0.5 M_{\odot}$	0.5×10^6	1.0×10^9 yr

2. Surface brightness. Define a surface brightness which accounts surface brightness in units of mag arcsec $^{-2}$ in $B - V$ and show that surface brightness is independent of distance (as long as you're not using a telescope).

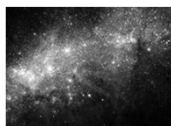
Literature exercise

- Choose subject individually
- Find suitable articles
 - Published papers (ADS abstract service) http://adsabs.harvard.edu/abstract_service.html
 - Preprints: <http://www.arxiv.org>
- Written report (≈ 3 pages), deadline May 29
 - **Grade:** Fail, 3, 4, 5
- Oral presentation (≈ 10 minutes), June 4
 - **Grade:** Fail, 3, 4, 5



Suggested topics

- The first stars
- Origin of supermassive black holes
- Galaxies and cosmic reionization
- Ultrafaint dwarfs
- Extragalactic background radiation
- Galactic archeology
- Magnetic fields in galaxies
- Science cases of future telescopes (pick one!):
 - James Webb Space Telescope
 - European Extremely Large Telescope
 - Square Kilometer Array
 - Gaia



But please feel free to suggest other topics!

Seminars

- Small “simulations” of what research is really like
- Two seminars:
 - 1. May 7, 13-15
 - 2. May 26, 13-15
- Instructions available from course homepage



Seminars

- **Grade:** Fail, 3, 4, 5 (one grade per seminar)
- **Preparation:**
 - Read suggested papers + others
 - Answer questions + analyze dataset
 - Prepare to present answers and results in class



Seminars

- Purpose:
 - Practice finding and reading relevant research papers
 - Practice analyzing astronomical data
 - Practice critical thinking
 - Practice scientific creativity
 - Practice discussing in front of audience
- What if you cannot attend the seminars?
 - Have to present results in written report (→ more work!)

Computer exercise ("lab")

- Beatriz in charge of this
- Introduction to exercise in lecture 6
- Complete individually and hand in report no later than June 9
- **Grade:** Fail, 3, 4, 5



Schedule I

Complete schedule on course homepage!

- 8 Lectures:
 - April 14, 15–17
 - April 17, 10–12
 - April 21, 10–12
 - April 24, 10–12
 - April 28, 13–15
 - May 8, 10–12 ← Beatriz' lecture + introduction to computer exercise
 - May 19, 10–12
 - May 21, 10–12
- 2 Exercise sessions:
 - May 5, 15–17
 - May 22, 13–15

Schedule II

- 2 seminars:
 - May 7, 13—15
 - May 26, 13-15
- Oral presentations of literature exercises
 - June 4, 10—12



Grades

- Final grade will be the mean grade from:
 - Seminar 1
 - Seminar 2
 - Written report on literature exercise
 - Oral presentation of literature exercise
 - Report from computer exercise
- No final grade will be computed until you have reached a passing grade (3 or higher) for each of these
- Please note that you also need a passing grade from the two exercise session and on your hand-in exercises to complete the course

Grades – example

- 1) Seminar 1
Grade: 3
- 2) Seminar 2
Grade: 4
- 3) Written report on literature exercise
Grade: 4
- 4) Oral presentation on literature exercise
Grade: 3
- 5) Report on computer exercise
Grade: 5

Calculate mean grade: $(3 + 4 + 4 + 3 + 5) / 5 = 3.8 \approx 4$
Final grade: 4:

How much time will I have to spend on this course?

My estimates:

- Attending lectures, exercise sessions, seminars etc. ≈ 0.6 week
- Reading the textbook ≈ 1.5 weeks
- Preparing for exercise sessions ≈ 0.4 week
- Preparing for seminars ≈ 1 week
- Computer exercise ≈ 1 week
- Literature exercise (written report + oral presentation) ≈ 1.5 weeks
- Hand-in problems ≈ 0.5 week

Sum: 6.5 weeks, i.e. ≈ 10 hp

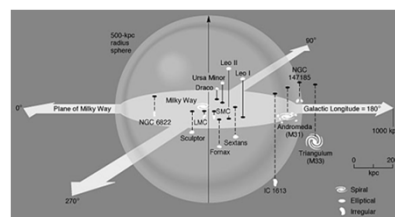
Course Outline

- Lecture 1:
 - Introduction
 - Historical Background
 - Galaxy Classification
 - The Cosmological Framework



Course Outline

- Lecture 2:
 - The Astronomical Distance Scale
 - The Milky Way
 - The Local Group



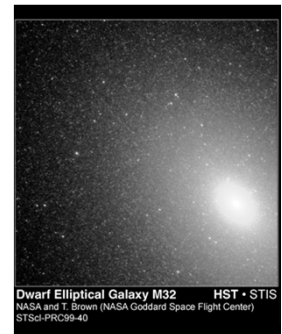
Course Outline

- Lecture 3:
 - Dark matter in galaxies
 - The dark halo
 - Subhalos
 - Mass-to-light ratios
 - Baryon fractions



Course Outline

- Lecture 4:
 - Disk galaxies
 - Elliptical galaxies



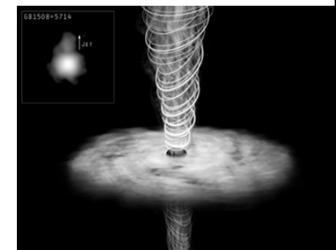
Course Outline

- Lecture 5:
 - Star formation
 - Population synthesis
 - Galaxy spectra
 - The interstellar medium
 - Chemical evolution
 - The galaxy luminosity function
 - Black holes in galaxies



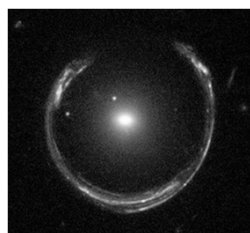
Course Outline

- Lecture 6:
 - Active galaxies:
 - Quasars
 - Blazars
 - Seyfert Galaxies
 - Radio Galaxies
 - Introduction to computer exercise



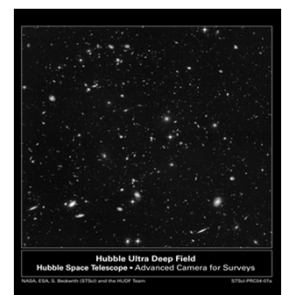
Course Outline

- Lecture 7:
 - Galaxy groups
 - Galaxy clusters
 - Gravitational lensing

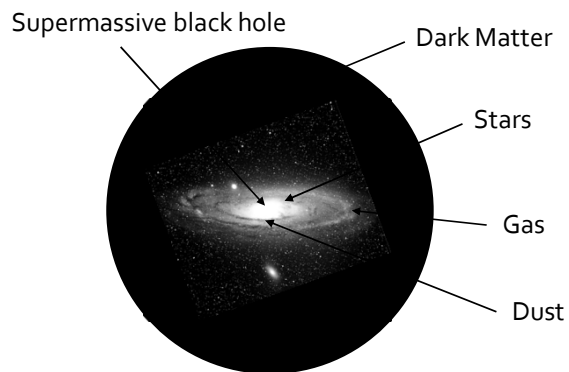


Course Outline

- Lecture 8:
 - The high-redshift Universe
 - Cosmic reionization
 - The first stars and galaxies



The Anatomy of Galaxies



Intermission: What are you looking at?



Intermission: What are you looking at?



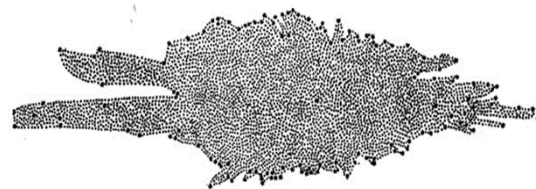
Intermission: What are you looking at?



Historical Background: The Milky Way



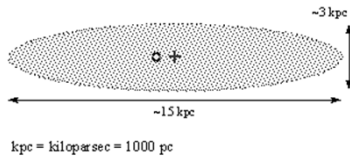
Historical Background: The Milky Way



- The "Herschel Universe" (late 1700s): Sun almost in the centre of Milky way
- Dust obscuration towards centre of the Milky Way (left side of figure) not accounted for

Historical Background: The Milky Way

Kapteyn Model (1922)

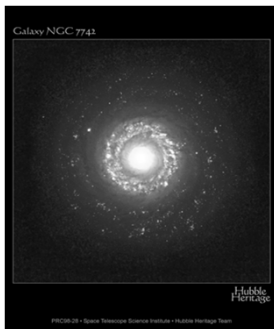


- Sun offset from centre
- Dust obscuration still not accounted for → wrong scale

Historical Background: Other Galaxies

- Mid-1800s: William Parsons (Lord Rosse) discovers spiral structure in nebulae
- 1912: Henrietta Leavitt discovers period-luminosity relation for Cepheids
- 1920s – The Great Debate
 - Shapley (local objects) VS Curtis (outside Milky Way)
 - Outcome: Spiral Nebulae are external galaxies
- 1929 – Expansion of the Universe (Hubble's law)

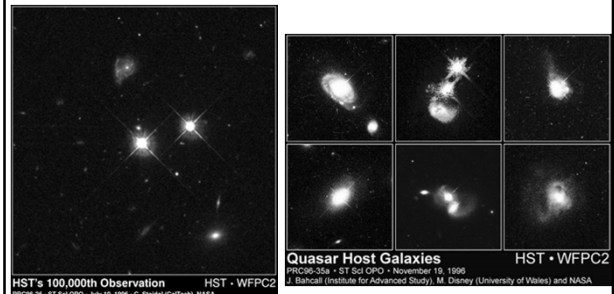
Historical Background: Active Galaxies



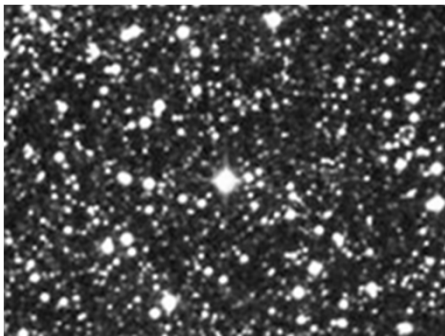
- 1943 - Seyfert Galaxies

Historical Background: Quasars/QSO

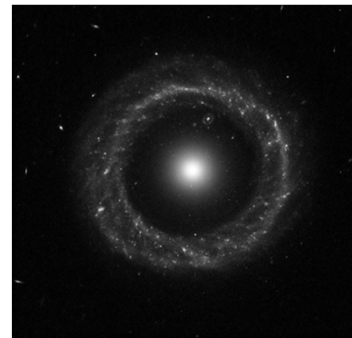
- 1960s – Radio Galaxies, Quasars
- Quasi-Stellar Object: QSO, Quasar



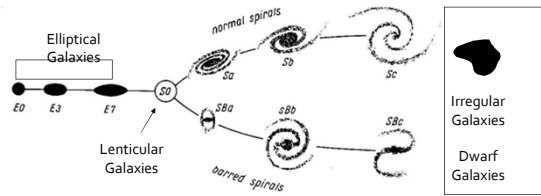
Intermission: What are you looking at?



Intermission: What are you looking at?



Galaxy Classification The Hubble Tuning Fork



Other famous classification schemes:

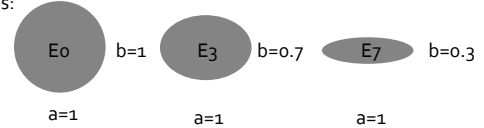
- de Vaucouleur
- van den Bergh
- Vorontsov-Velyaminov

Galaxy Classification

Elliptical galaxies

- Type: En , $n = 10(a - b) / a$.
- Major and minor axes: a and b
- \rightarrow E0 circular, E7 galaxies the most flattened.

Examples:

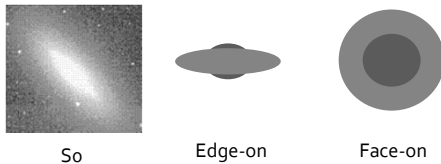


Galaxy Classification

Lenticular galaxies

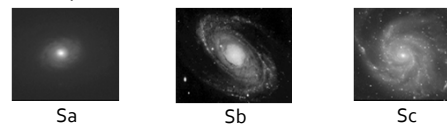
- Disk and central bulge, but no spiral arms
- SBo if barred, S0 otherwise

Examples:

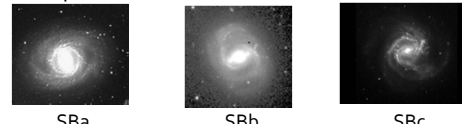


Galaxy Classification

Normal Spirals



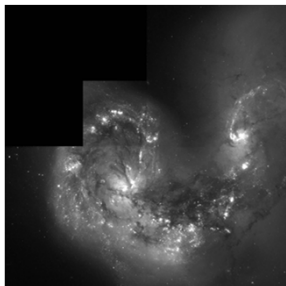
Barred Spirals



- Large bulges
- Tightly wound spiral arms
- Few star-forming regions in arms
- Small bulges
- Loosely wound spiral arms
- Many star-forming regions in arms

Galaxy Classification

Irregular galaxies (I)



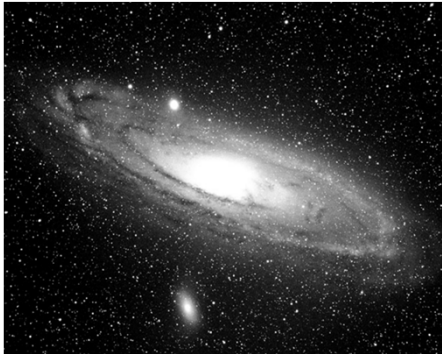
Galaxy Classification

Dwarf galaxies (dE, dSph, dl...) – Low-luminosity objects



Dwarf Elliptical Galaxy M32 HST • STIS
NASA and T. Brown (NASA Goddard Space Flight Center)
STScI-PRC99-40

Morphological Type?



Morphological Type?

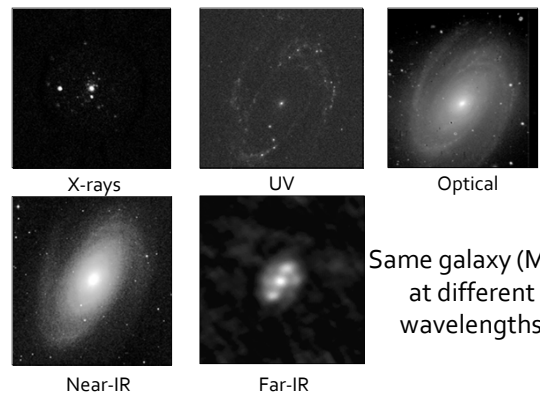


What is the Point of Morphological Classification?

Hubble class correlates with:

- Gas content
- Dust content
- Star-forming properties
- Spectrum
- Metallicity

Morphological Complications



Same galaxy (M81)
at different
wavelengths!

Morphological Complications

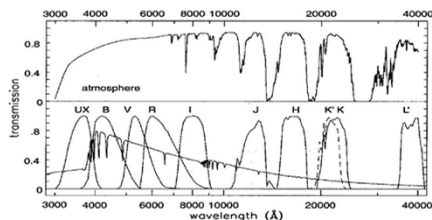
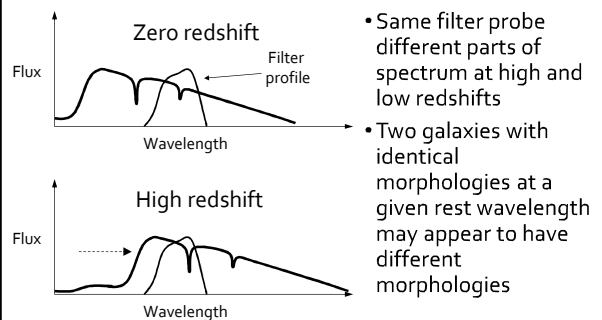


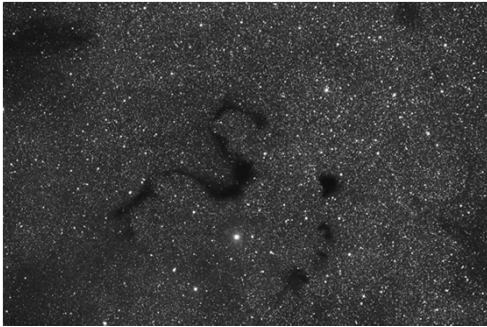
Figure 1.7 Above, atmospheric transmission in the optical and near-infrared. Below, flux F_λ of a model A0 star, with transmission curves $T(\lambda)$ for standard filters from Bessell, PASP 102, 1181; 1990. UX is a version of the U filter that takes account of atmospheric absorption. For $JHK'KL'$, $T(\lambda)$ is for transmission through the atmosphere and subsequently through the filter.

Morphological Complications

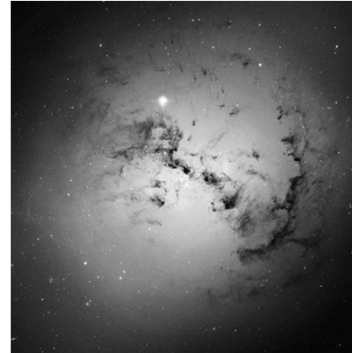


- Same filter probe different parts of spectrum at high and low redshifts
- Two galaxies with identical morphologies at a given rest wavelength may appear to have different morphologies

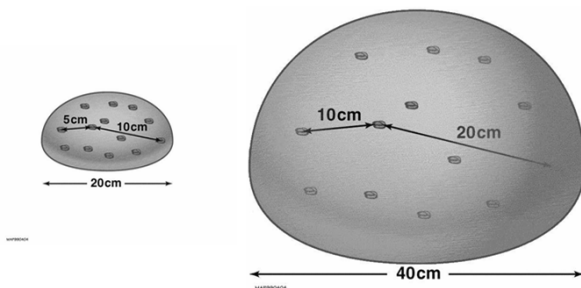
Intermission: What are you looking at?



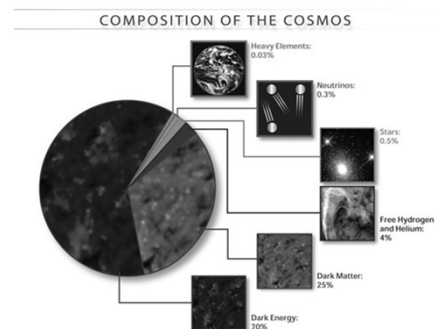
Intermission: What are you looking at?



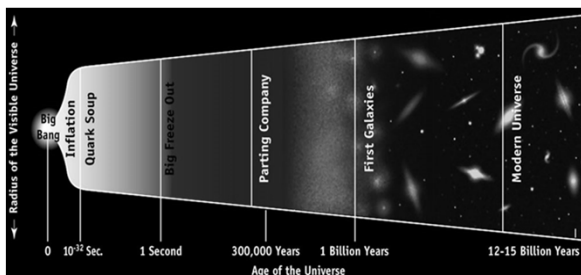
The Cosmological Framework I



The Cosmological Framework II



The Cosmological Framework III



The Cosmological Framework IV

- $\Omega_i = \rho_i / \rho_c$
- ρ_c = critical density of the Universe
- $\Omega_{\text{Tot}} \approx 1.0$
- $\Omega_{\text{Baryons}} \approx 0.04$
- $\Omega_M \approx 0.3$
- $\Omega_\Lambda \approx 0.7$