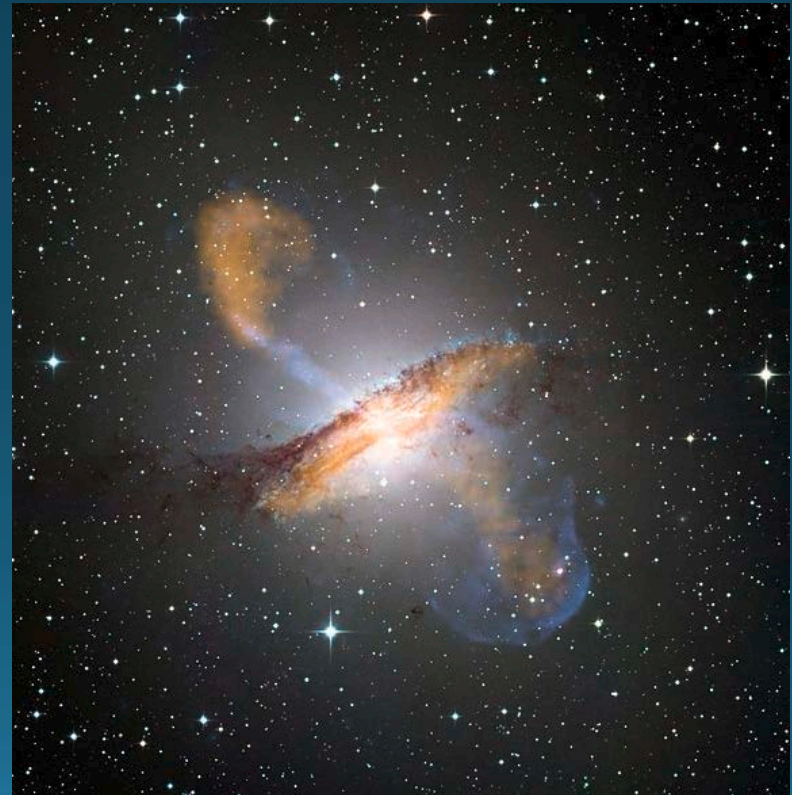


Physics of Galaxies, 2015

10 credits

Lecture 1: Introduction



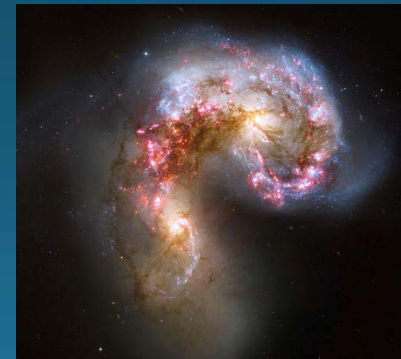
Outline for today I

- 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 (hp), Spring 2015

Literature: 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 Astrophysics I is required.

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

Teacher: Erik Zackrisson, erik.zackrisson(at)physics.uu.se, phone: 018-471 5975

Time: 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 session/ Seminar | Topics | To read | To turn in/prepare |
|----------|-------|-------|--|---|---------------------------------|--------------------|
| April 14 | 15-17 | 12167 | Lecture 1 | Course introduction Historical background The extragalactic distance scale Galaxy classification | 1—1.4, 3—3.1.2, 3.9—3.9.6 | |
| April 17 | 10-12 | 11167 | Lecture 2 | The Milky Way The Local Group | 2.1—2.4.2, 6.1—6.1.3 | |
| | | | | | | |

Course literature

Extragalactic Astronomy and Cosmology

Peter Schneider

2014/2015, Springer

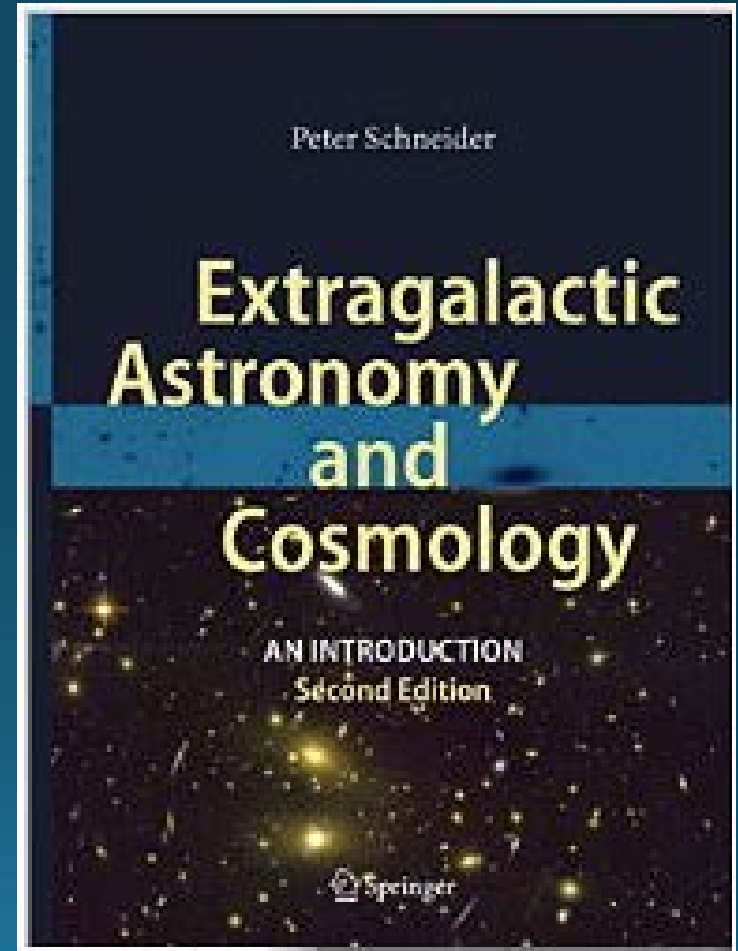
Hardback:

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 colours of unresolved stellar systems. Two stars in a close binary system have $m_B = 18.2$ and $m_B = 19.6$, respectively. The first star has a colour $B - V = -0.2$ and the second $B - V = 0.5$. If this system is observed in a telescope which cannot resolve the two components, what would the integrated m_B and $(B - V)$ of this object be?

Solution: At large distances, it becomes increasingly difficult to study the individual stars of stellar populations. There are basically two reasons for this:

1. The flux sensitivity 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 push them above the detection limit
2. Limitations in angular resolution of your telescope may blend 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.

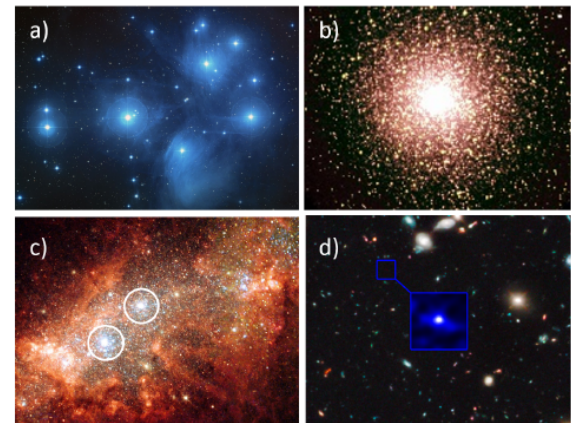


Figure 1: Resolved versus unresolved stellar populations. **a)** A nearby star cluster (the Pleiades, distance 440 ly) in which individual stars can be resolved; **b)** a Milky Way globular cluster (47 Tucanae, distance 17,000 ly) where many stars blend into a single, soft light in the center; **c)** Two

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!

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 two exercise sessions. In case you failed to participate in either of these, you should contact the teacher for additional problems to solve in order to pass the course. Hand-written solutions are quite acceptable, but submission via email is highly encouraged (and will allow for a swifter evaluation), so please consider scanning your solutions and submitting them 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 (O5, A0 and M0), all formed at the same time, and that the relative number of stars of each type is given by the Salpeter IMF.

- a) What is the (B-V) colour and M/L_V ratio of this population at an age of 1 Myr?
- b) Assuming that the population has aged sufficiently for all the O stars to die (and no longer contribute to the light emitted), what is the (B-V) colour and the M/L_V ratio (where M is defined as $M = M_{\text{stars}} + M_{\text{gas}} + M_{\text{remnants}}$)?

Table 1: Stellar parameters

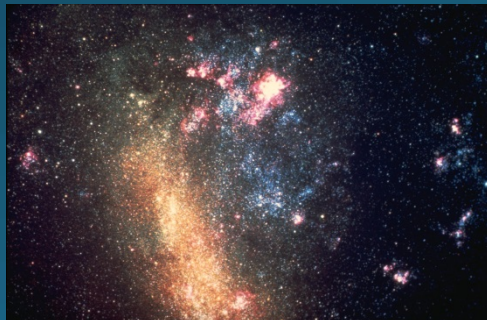
| Stellar type | Mass (M_{\odot}) | Luminosity in V ($L_{\odot,V}$) | (B-V) | Main sequence lifetime (yr) |
|--------------|-------------------------|--------------------------------------|-------|--------------------------------|
| O5 | 40 | 2.5×10^5 | -0.35 | 1.6×10^6 |
| A0 | 4 | 80 | 0.00 | 5.0×10^8 |
| M0 | 0.5 | 0.06 | 1.45 | 7.9×10^{10} |

2. *Surface brightness.* Derive an expression which converts surface brightness in units of mag arcsec^{-2} to $L_{\odot} \text{ pc}^{-2}$ and show that surface brightness is independent of distance (as long as redshift dimming is neglected).

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

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

Seminar I: Tidal dwarf galaxies

General instructions

This document provides preparation instructions for the first of the two seminars forming part of the examination for the course *Galaxies, AS7007* in 2012. The topic of this seminar is *Tidal dwarf galaxies*. While the existence of these objects has been known for quite some time, their properties remain puzzling and potentially at odds with our current picture of how dark matter should behave on subgalactic scales. The point of this exercise is to:

- Practice reading technical research papers (as opposed to popular articles, review papers or textbooks). As a professional astronomer most of the stuff you will read is likely to be of this variety.
- Practice critical thinking (for this purpose, speculative and controversial seminar topics have deliberately been chosen).
- Practice creativity. The answers you need may not be in the suggested literature – or in *any* publication for that matter. You may simply have to come up with a solution on your own.
- Practice information retrieval (learning not to waste time reading off-topic papers is an invaluable skill).
- Practice presenting material in front of an audience.

In preparing for the seminar, you should try to:

- Develop some insight into the field of tidal dwarf galaxies by studying the relevant literature. In doing so, the seminar questions listed may serve as guidance as to what you should focus on.
- Prepare to explain and discuss various concepts and recent results relevant to this field in front of the class. The use of computer, whiteboard or projector is highly encouraged.
- Analyze the enclosed tidal dwarf galaxy data set and prepare to present your findings to the class (using e.g. computer screen, whiteboard or transparencies).

You are perfectly welcome to collaborate with your classmates when preparing for the seminar, but once there – everyone is on their own. This means that you are not supposed to rely on the calculation, notes, viewgraphs etc. of others.

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
- May 19, 10—12
- May 21, 10—12



**Beatriz' lecture + introduction
to computer exercise**

- 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

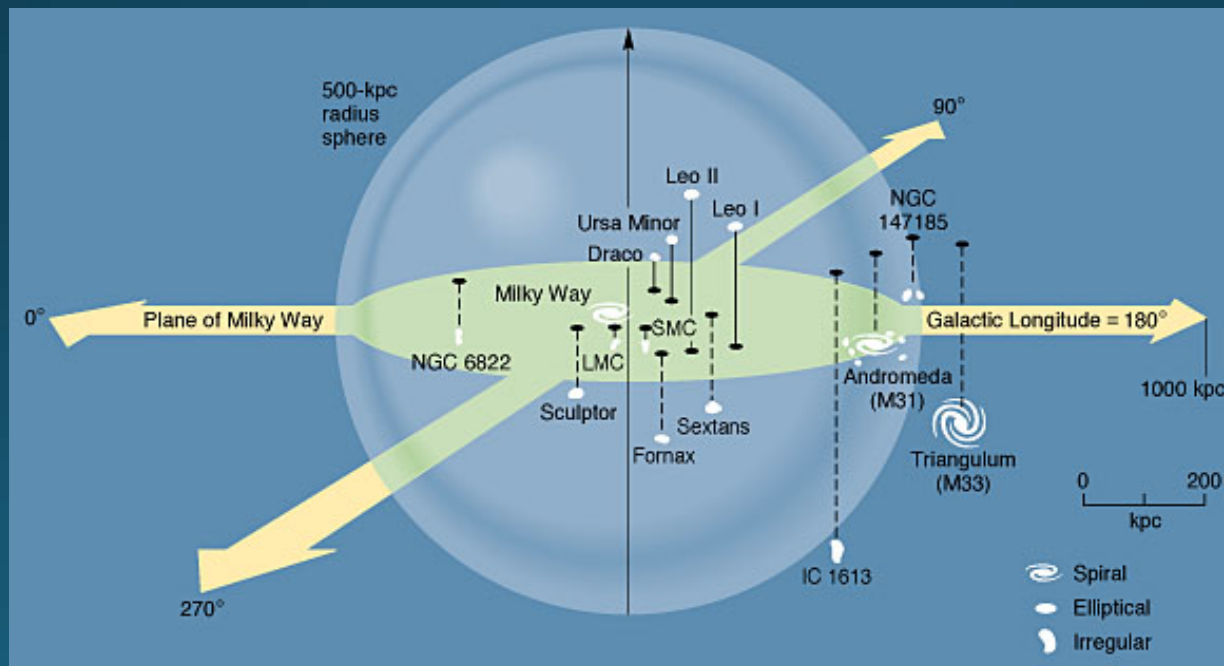
Course Outline

- 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

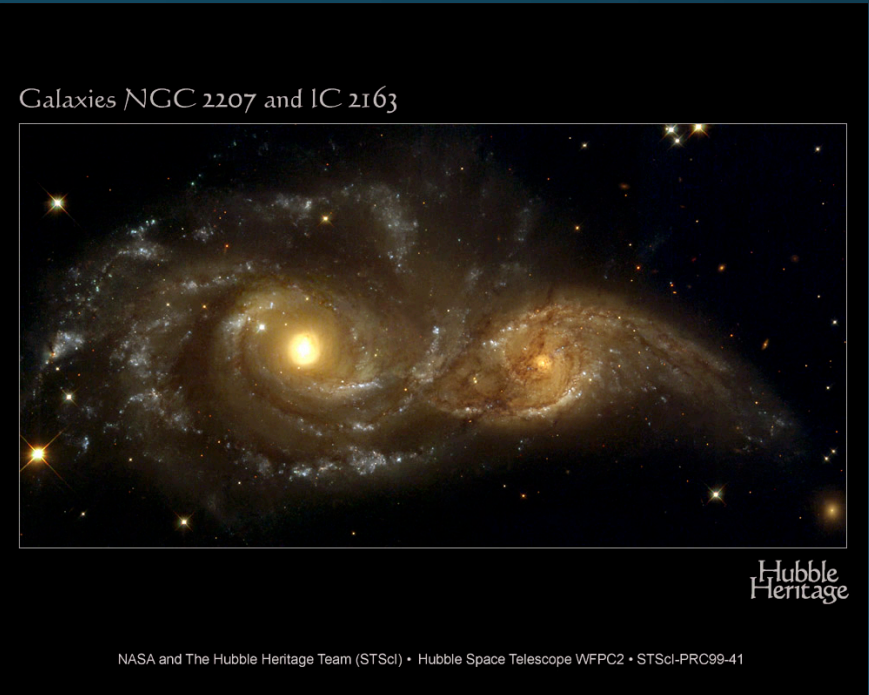
- Lecture 4:
 - Disk galaxies
 - Elliptical galaxies



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

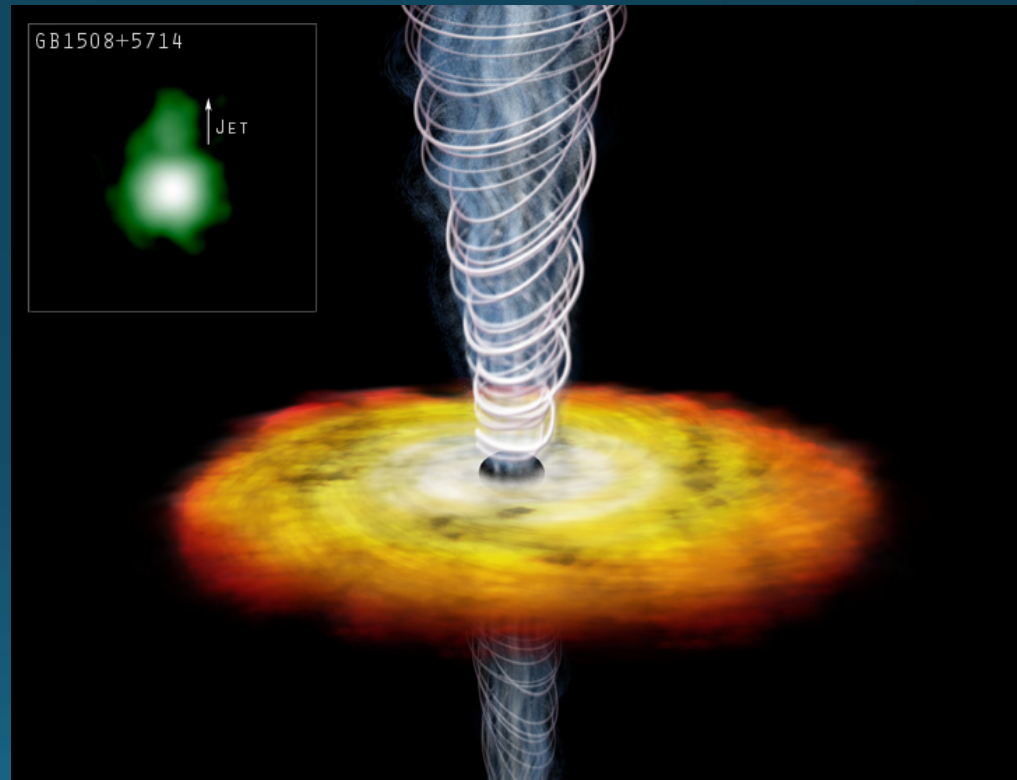
Course Outline

- 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



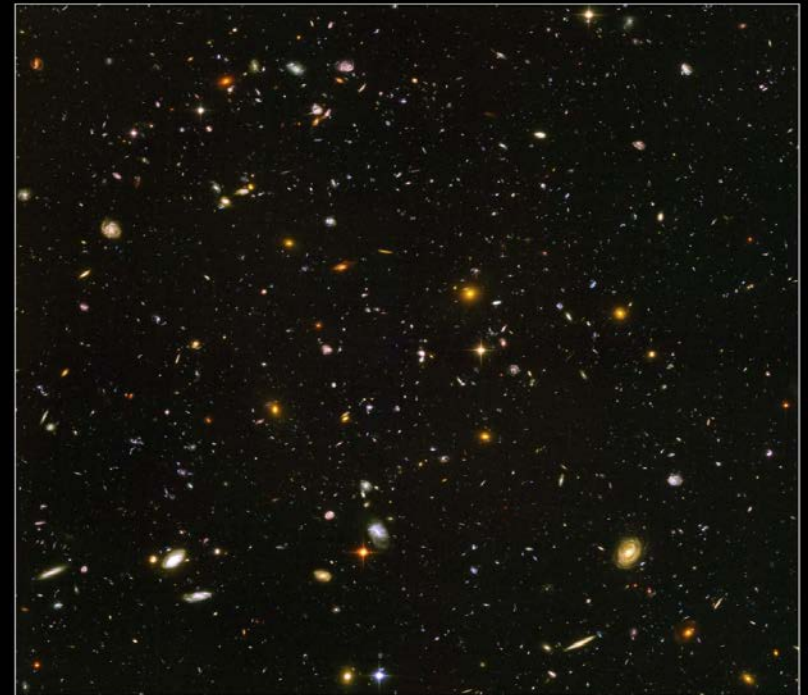
Course Outline

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



Course Outline

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



Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team

STScI-PRC04-07a

The Anatomy of Galaxies

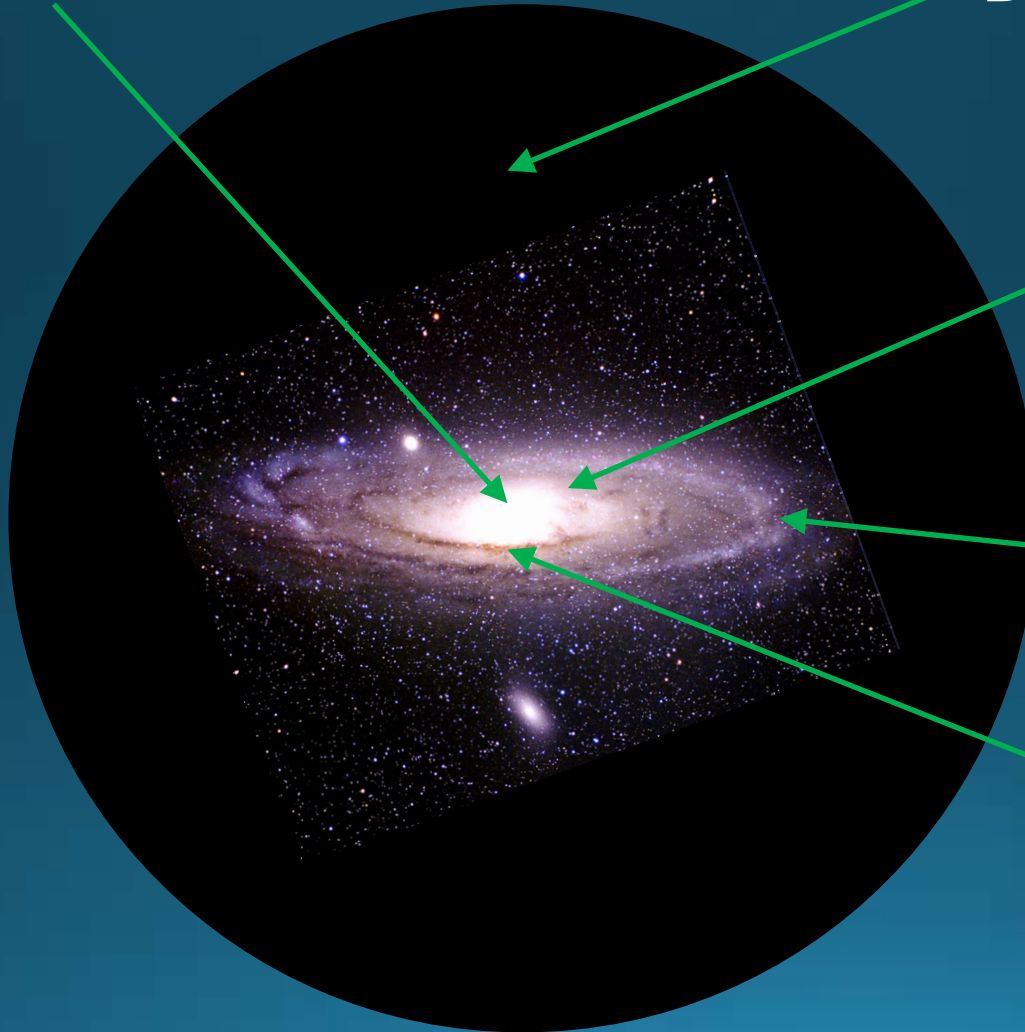
Supermassive black hole

Dark Matter

Stars

Gas

Dust



Intermission: What are you looking at?



Gas, dust or stars?

Intermission: What are you looking at?



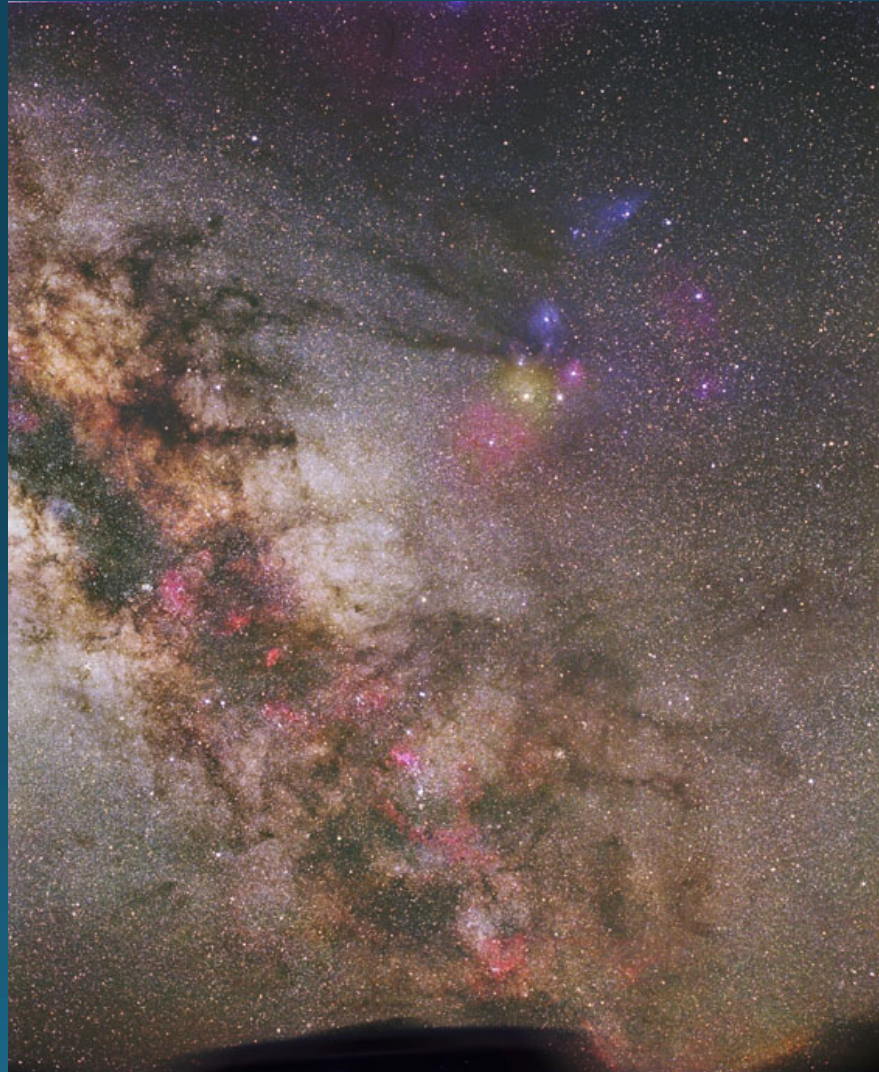
Gas, dust or stars?

Intermission: What are you looking at?

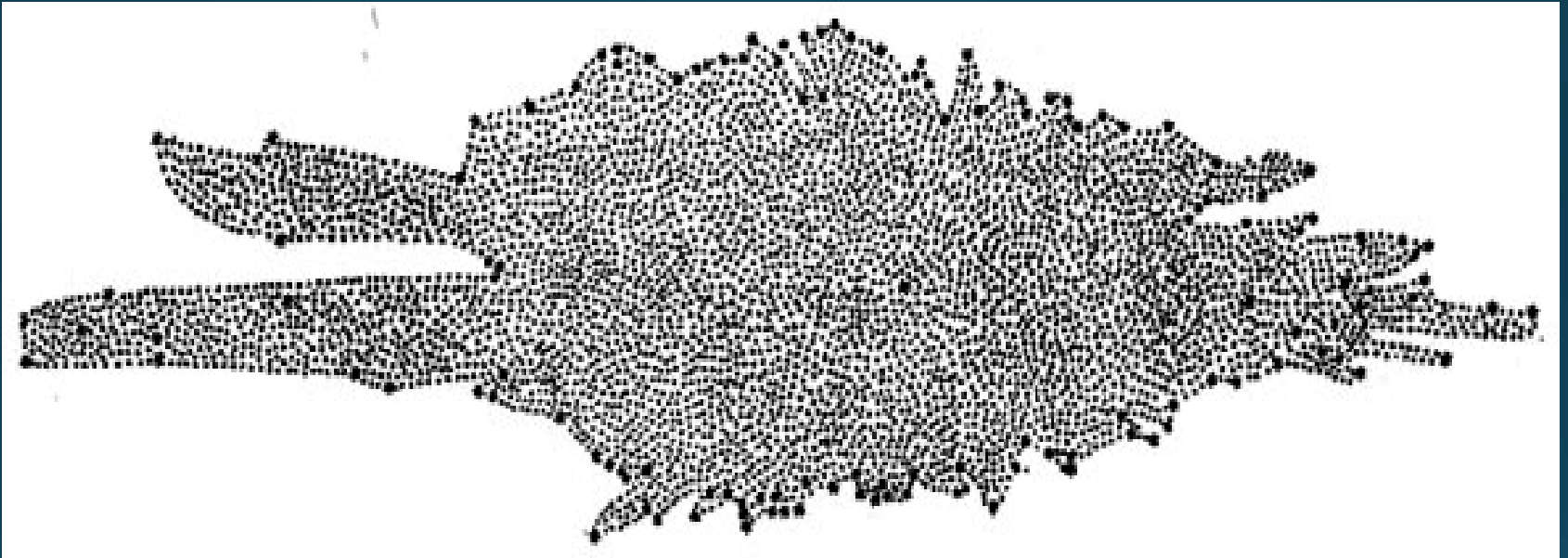


Gas, dust or stars?

Historical Background: The Milky Way



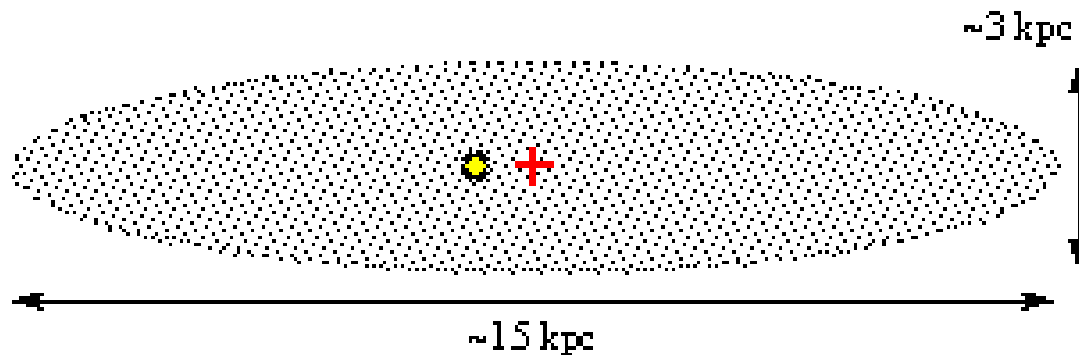
Historical Background: The Milky Way



- 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)



kpc = kiloparsec = 1000 pc

- 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

Galaxy NGC 7742



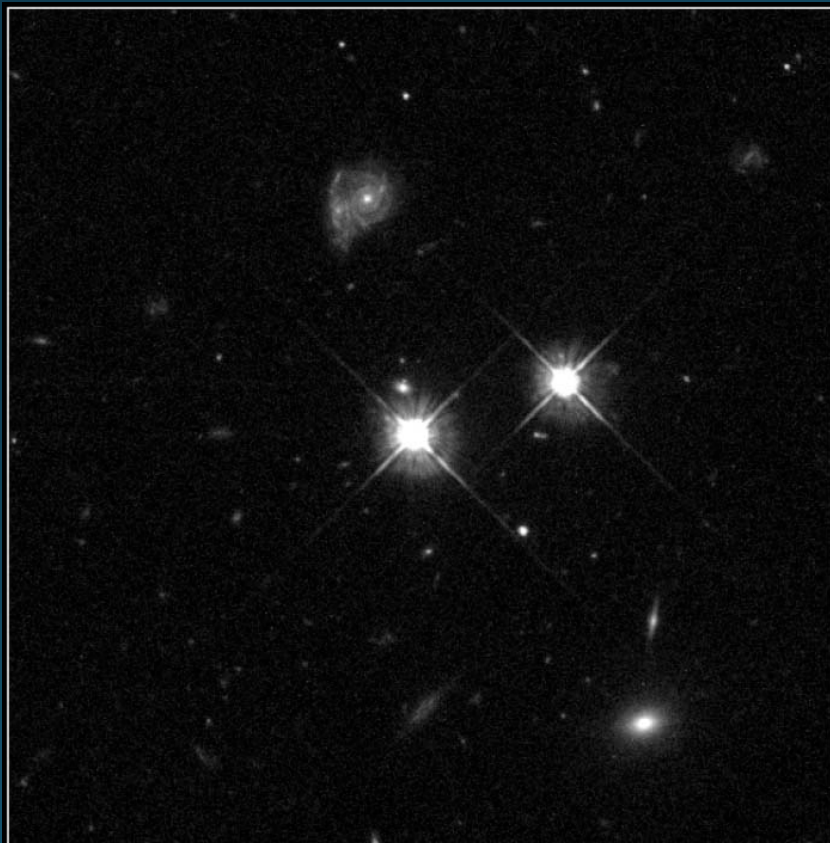
Hubble
Heritage

PRC98-28 • Space Telescope Science Institute • Hubble Heritage Team

- 1943 - Seyfert Galaxies

Historical Background: Quasars/QSO

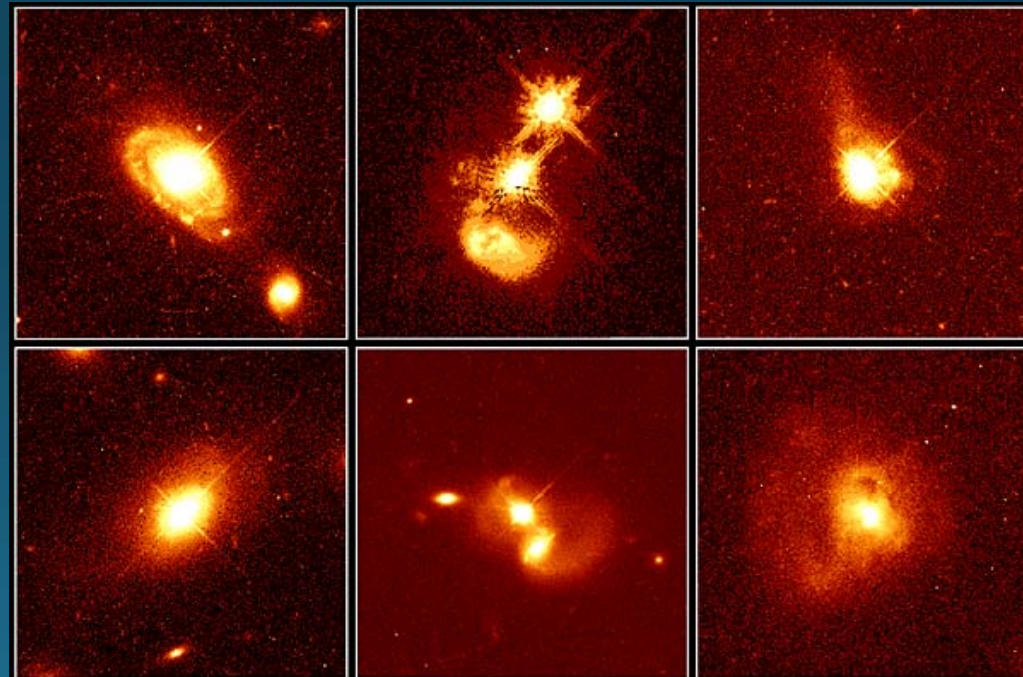
- 1960s – Radio Galaxies, Quasars
- Quasi-Stellar Object: QSO, Quasar



HST's 100,000th Observation

HST • WFPC2

PRC96-25 • ST ScI OPO • July 10, 1996 • C. Steidel (CalTech), NASA



Quasar Host Galaxies

HST • WFPC2

PRC96-35a • ST ScI OPO • November 19, 1996

J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA

Intermission: What are you looking at?

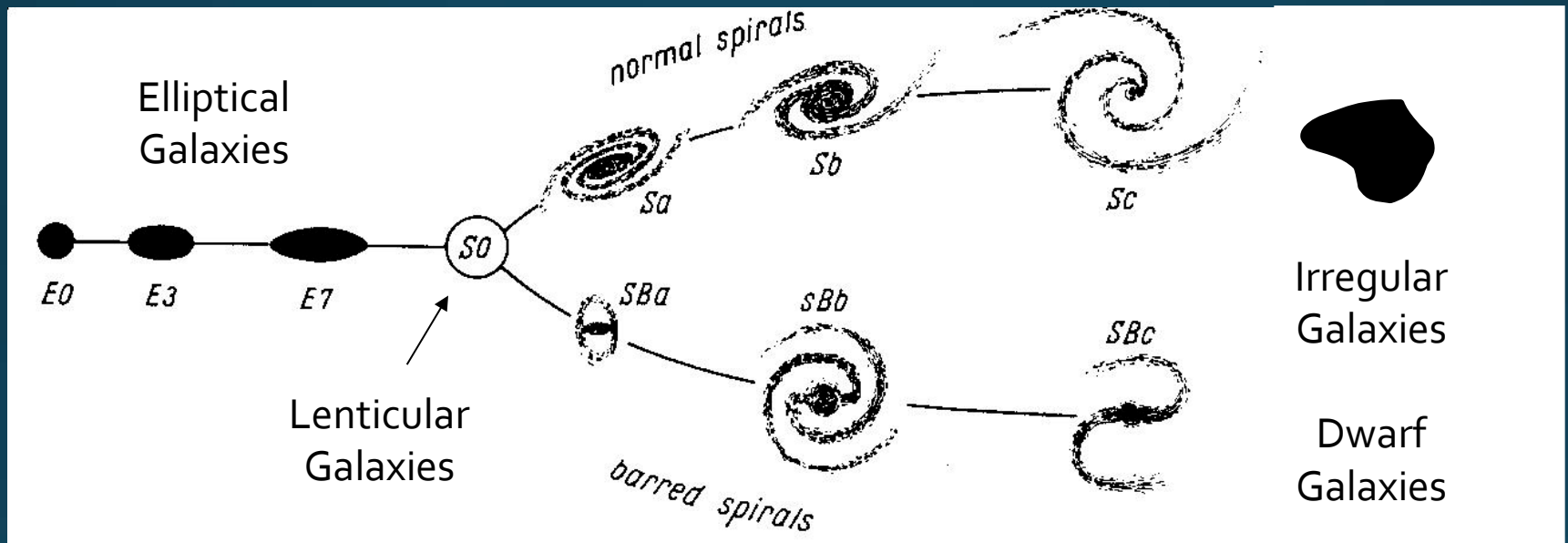


Intermission: What are you looking at?



Galaxy Classification

The Hubble Tuning Fork



Other famous classification schemes:

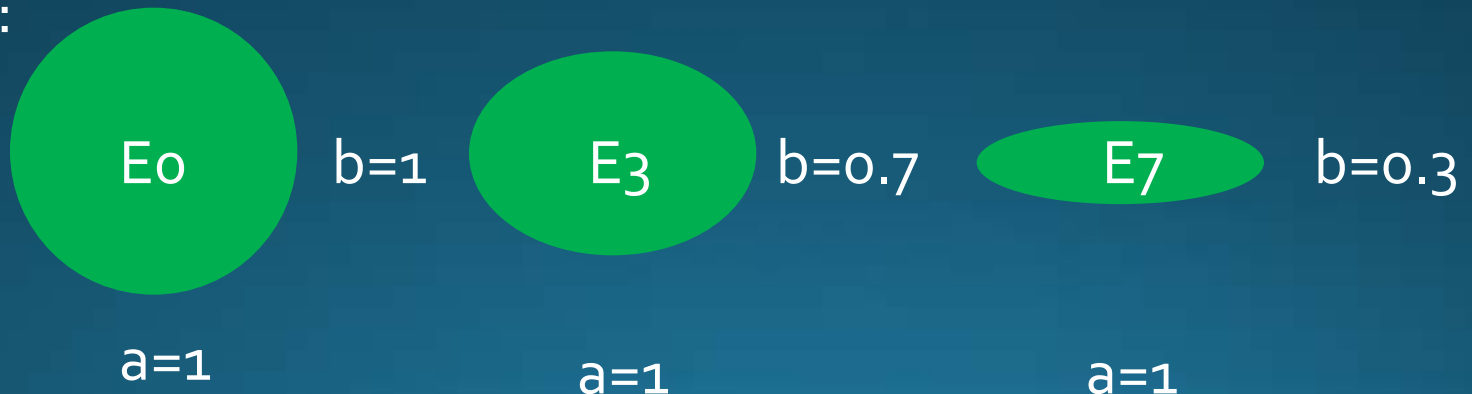
- de Vaucouleur
- van den Bergh
- Vorontsov-Velyaminov

Galaxy Classification

Elliptical galaxies

- Type: E_n , $n = 10(a - b) / a$.
- Major and minor axes: a and b
- \rightarrow E_0 circular, E_7 galaxies the most flattened.

Examples:

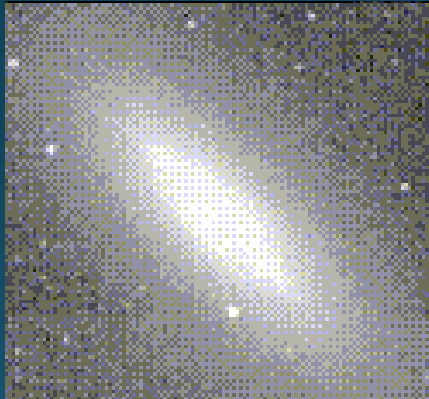


Galaxy Classification

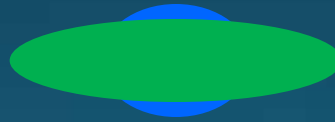
Lenticular galaxies

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

Examples:



S0



Edge-on



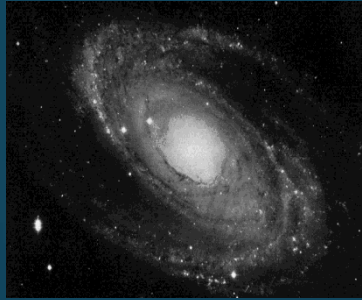
Face-on

Galaxy Classification

Normal Spirals



Sa



Sb

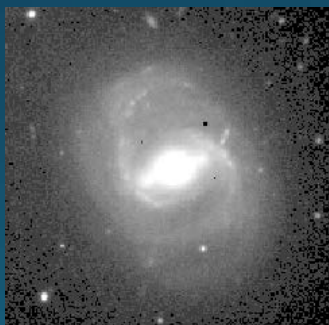


Sc

Barred Spirals



SBa



SBb



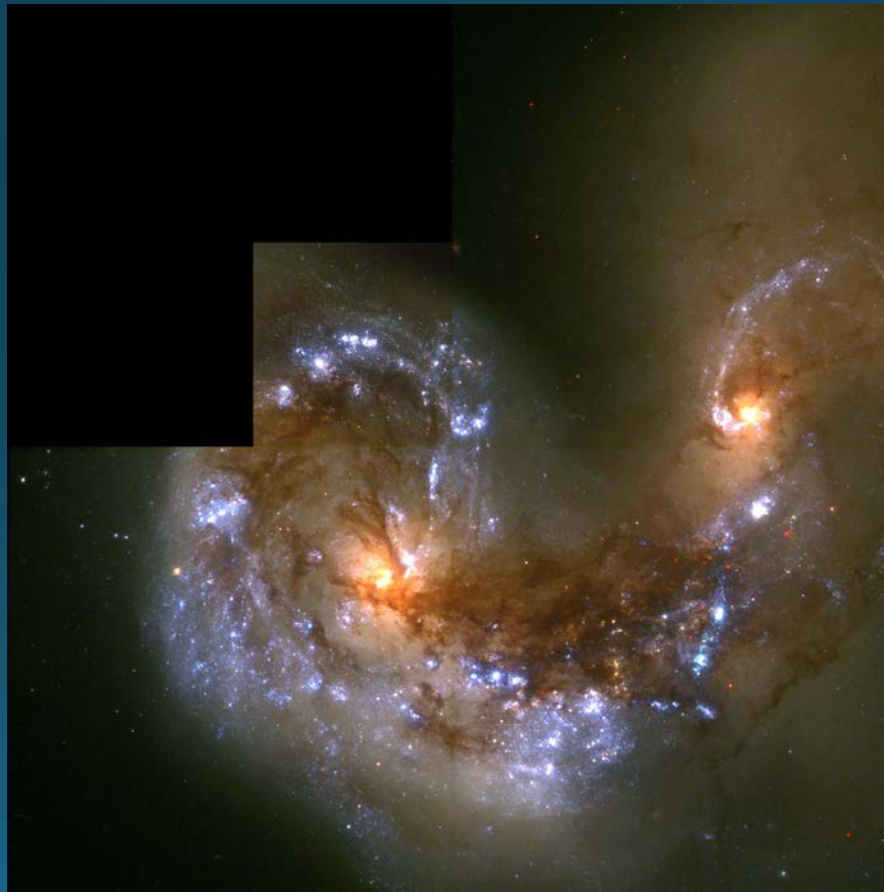
SBc

-
- 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

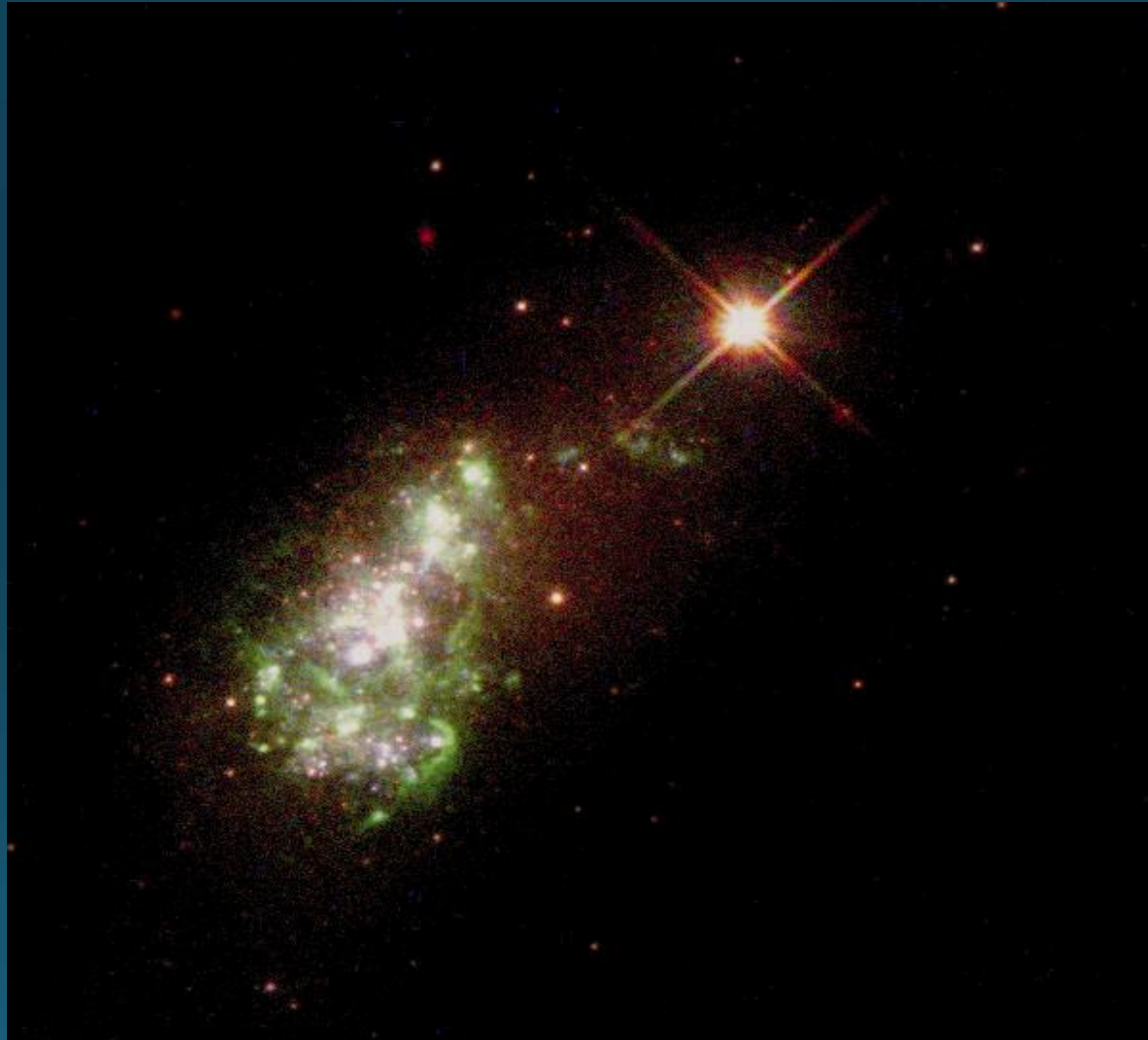
Dwarf galaxies
(dE, dSph, dI...) –
Low-luminosity
objects



Morphological Type?



Morphological Type?

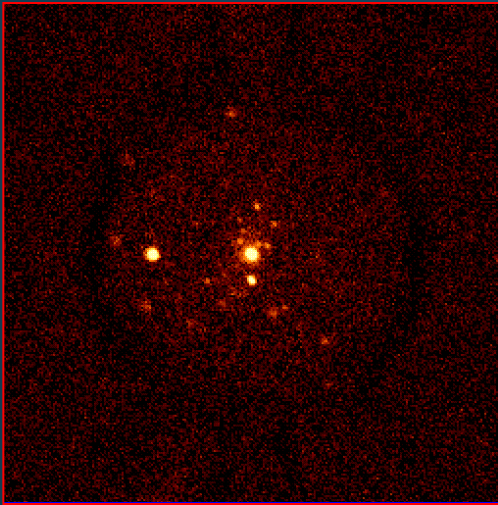


What is the Point of Morphological Classification?

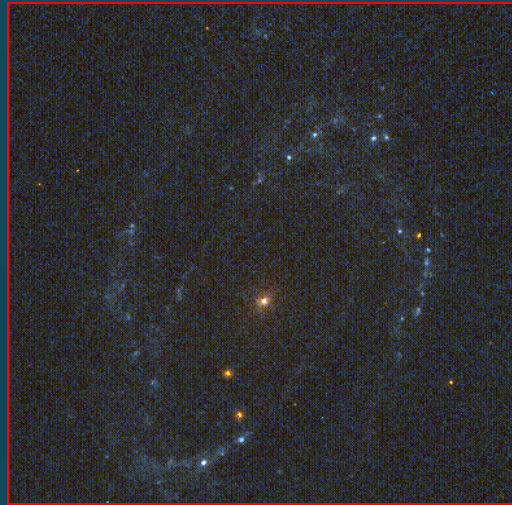
Hubble class correlates with:

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

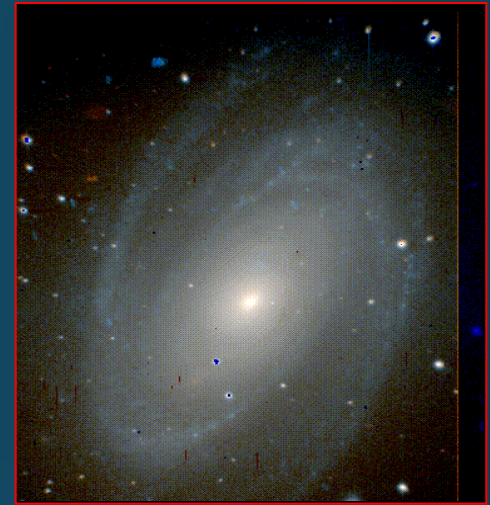
Morphological Complications



X-rays



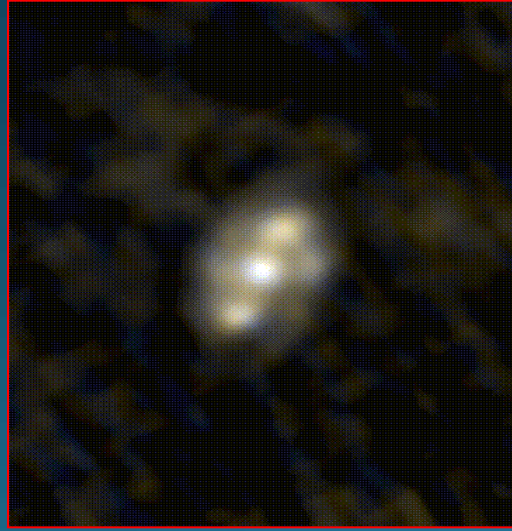
UV



Optical



Near-IR



Far-IR

Same galaxy (M81)
at different
wavelengths!

Morphological Complications

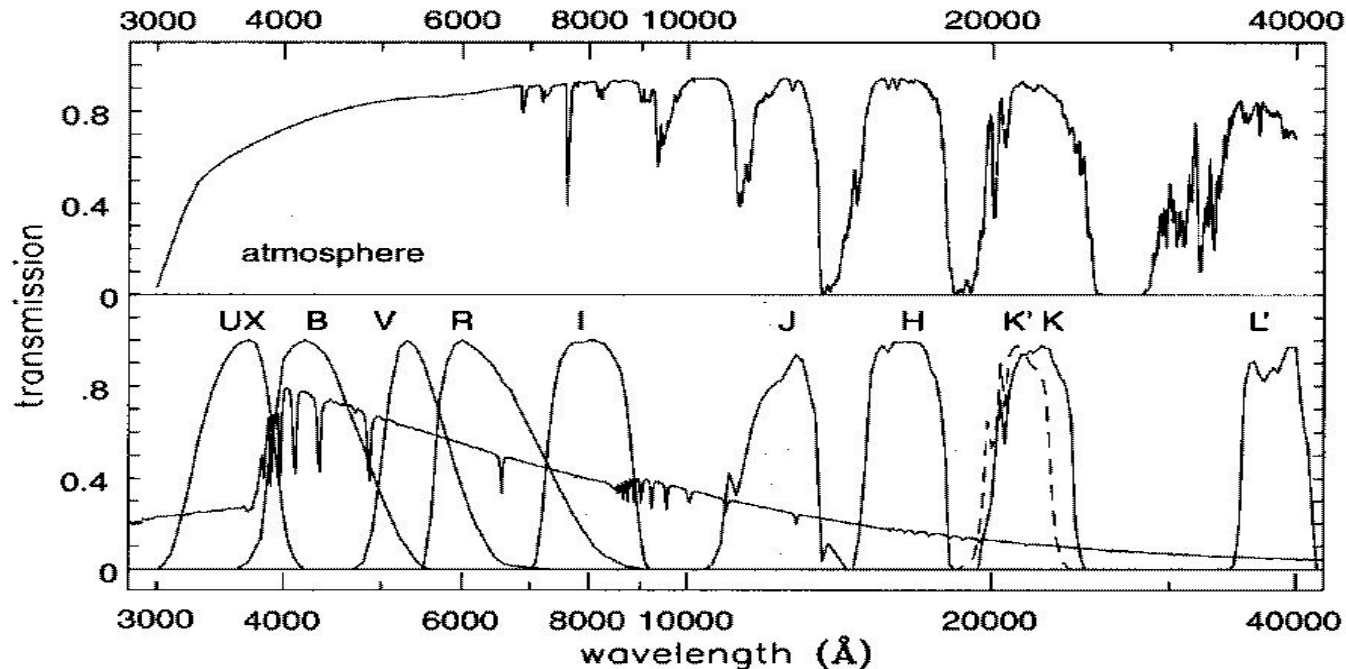
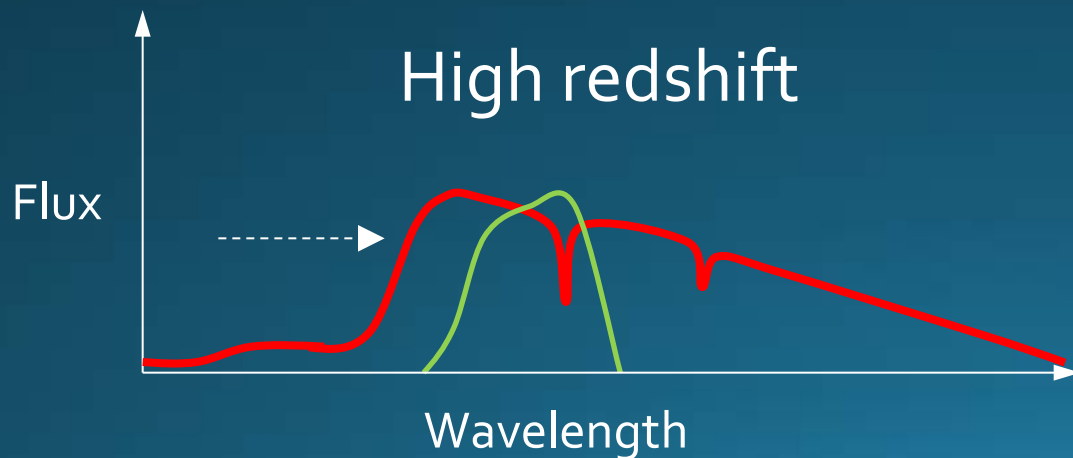
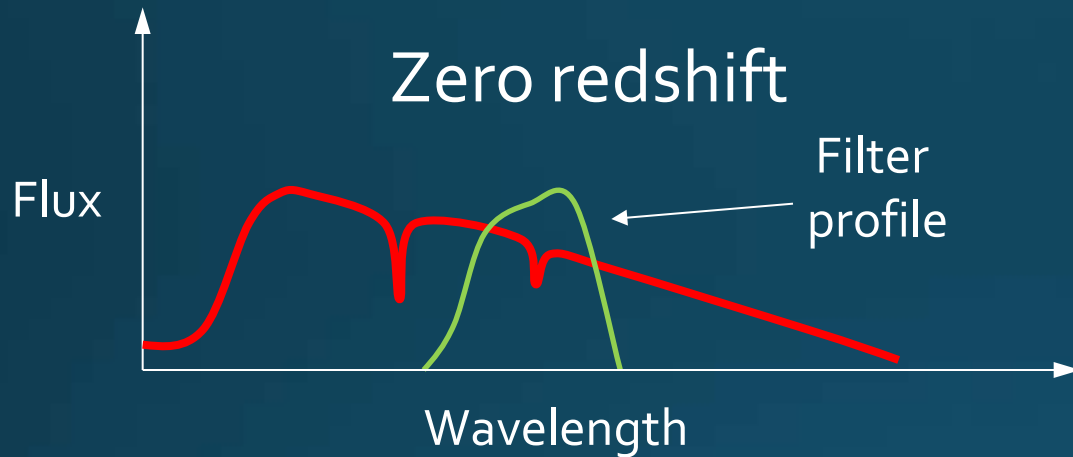


Figure 1.7 Above, atmospheric transmission in the optical and near-infrared. Below, flux F_λ of a model A0 star, with transmission curves $T(\lambda)$ for standard filters from Bessell, PASP 102, 1181; 1990. UX is a version of the U filter that takes account of atmospheric absorption. For JHK'KL', $T(\lambda)$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

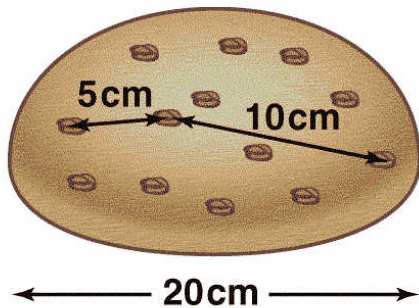
Intermission: What are you looking at?



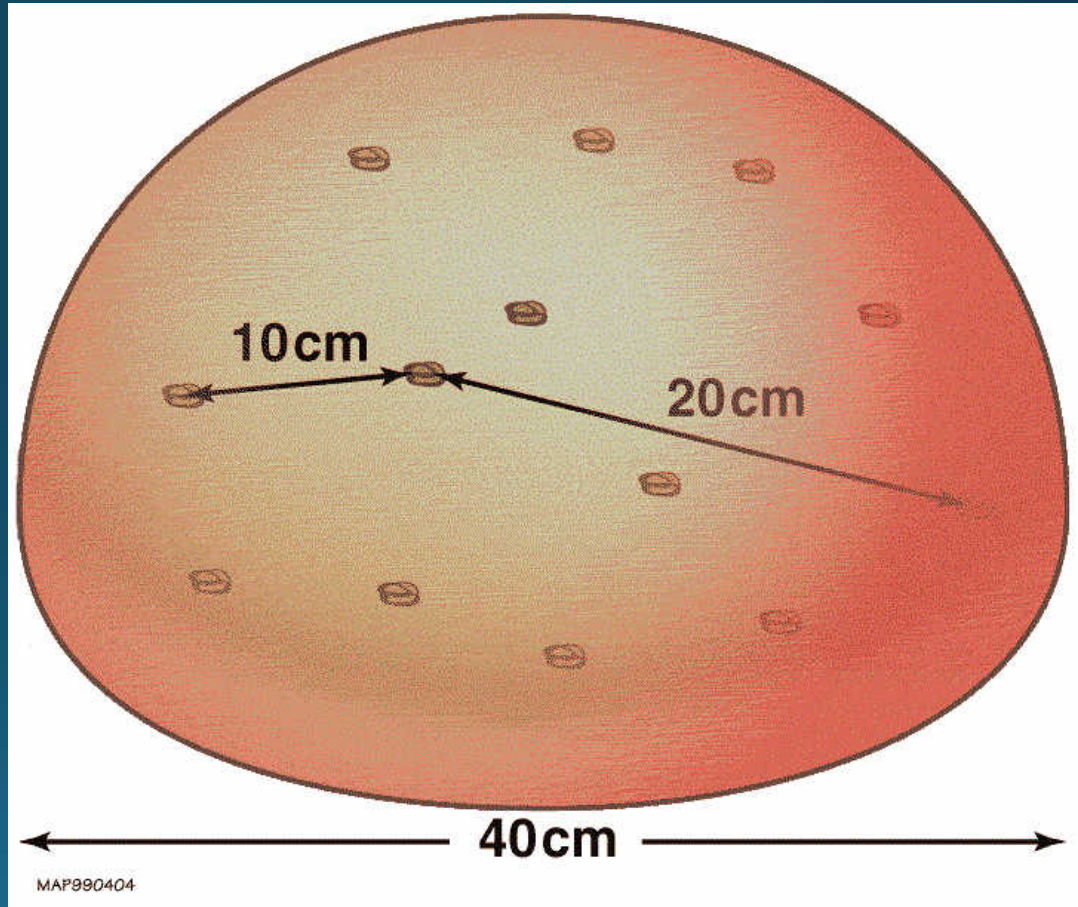
Intermission: What are you looking at?



The Cosmological Framework I



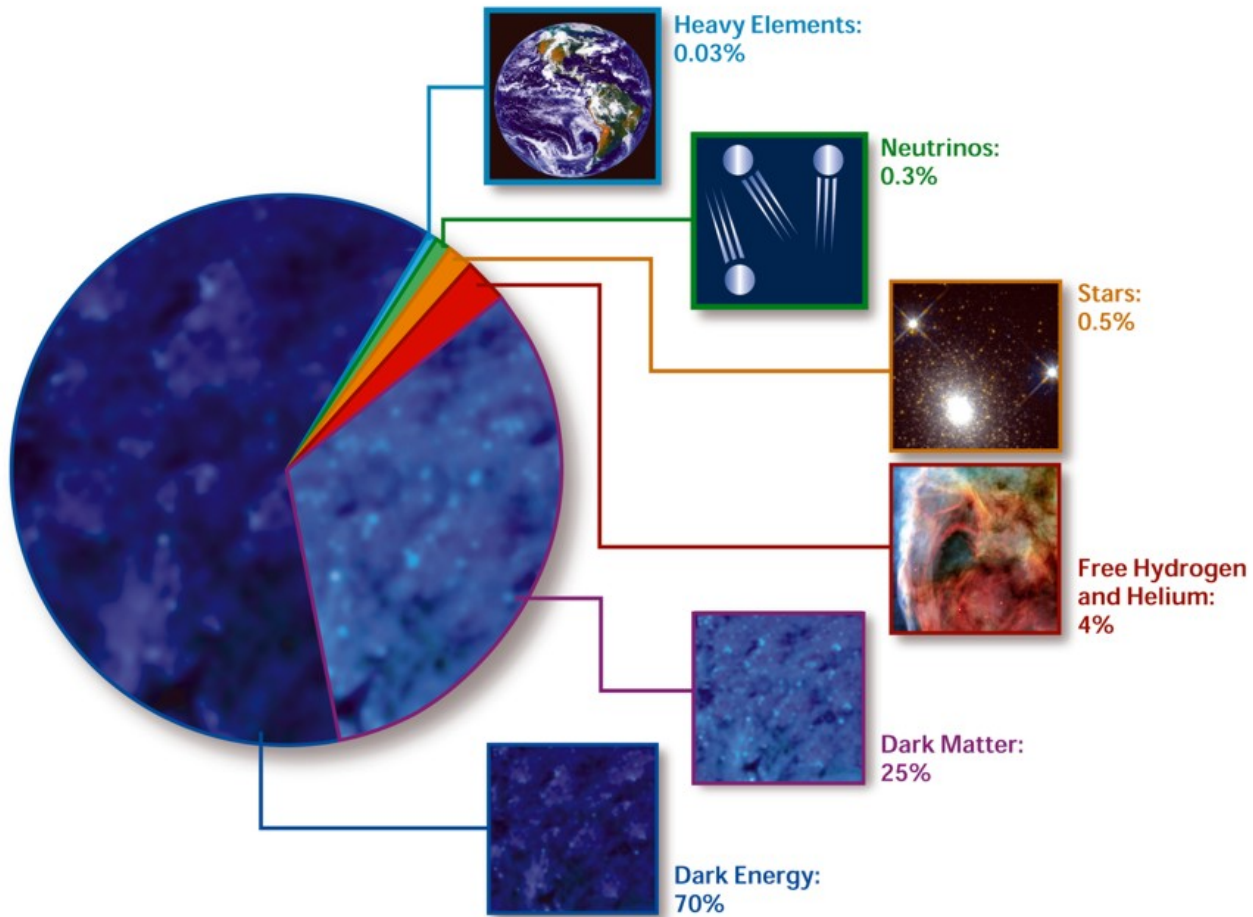
MAP990404



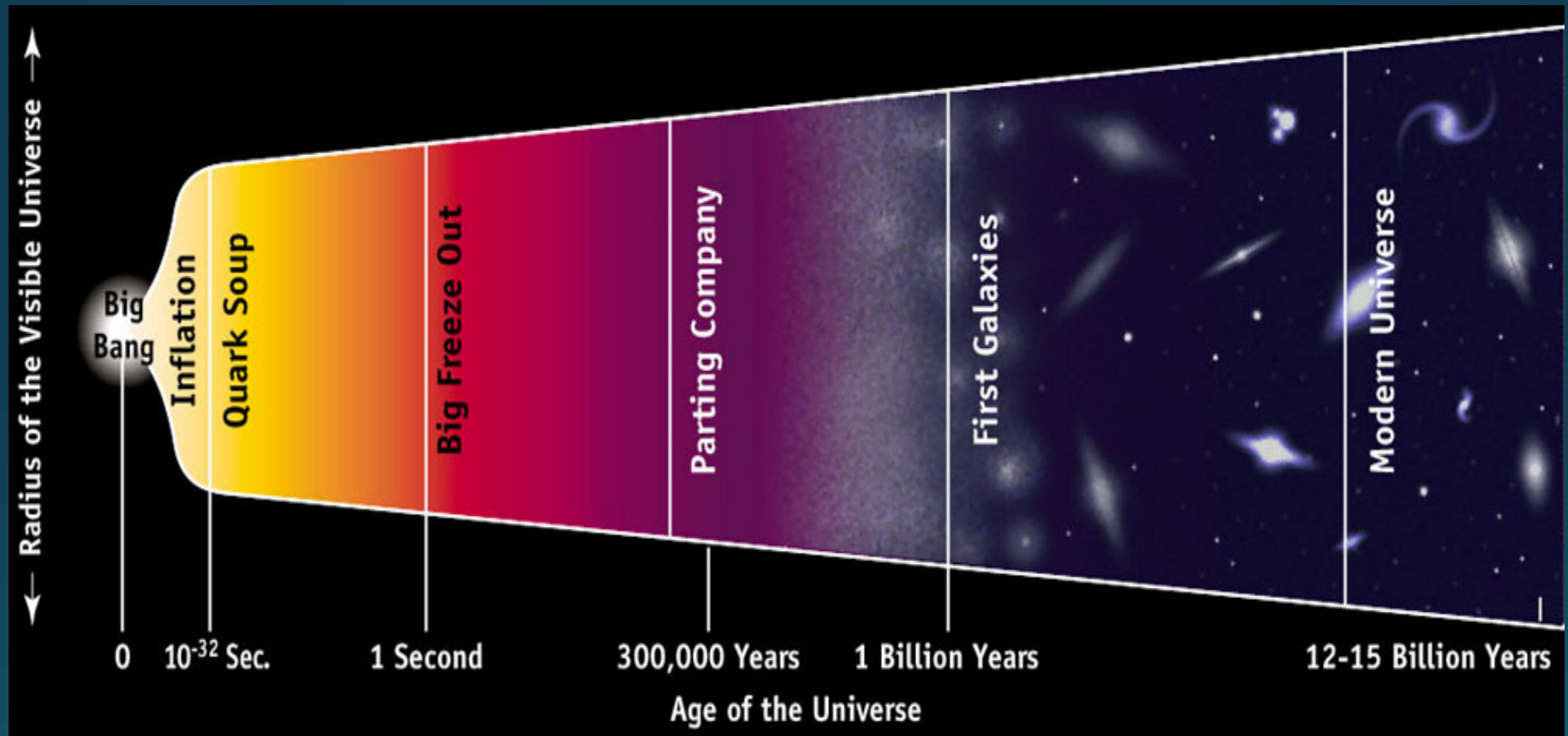
MAP990404

The Cosmological Framework II

COMPOSITION OF THE COSMOS



The Cosmological Framework III



The Cosmological Framework IV

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