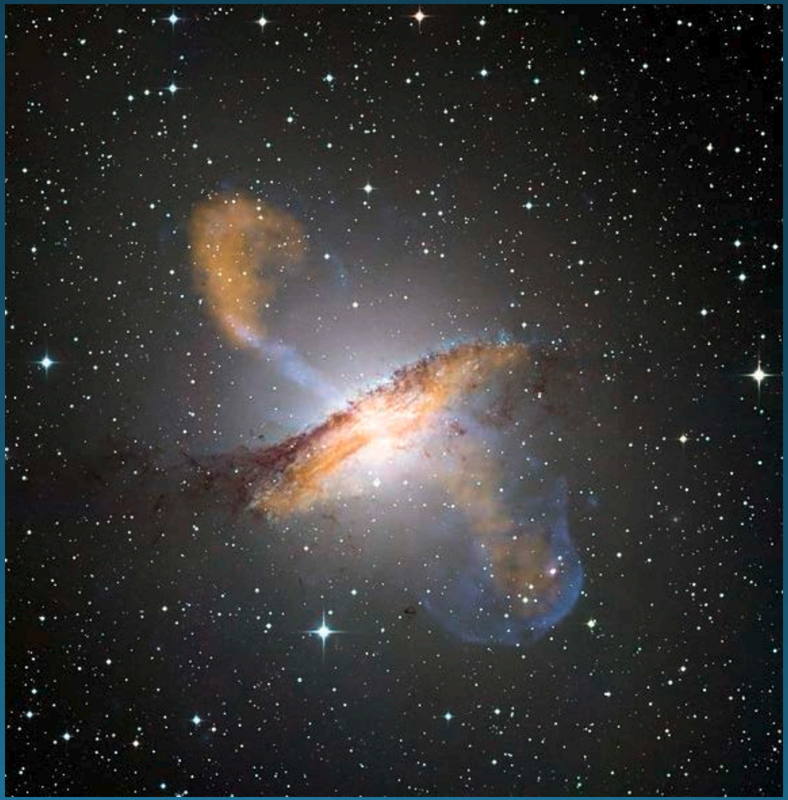
Physics of Galaxies 2016
Lecture 1: Introduction

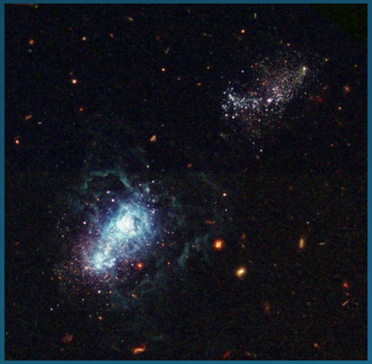


Outline for today I

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

Outline for today II

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



Teacher

- Erik Zackrisson
  - Email: erik.zackrisson@physics.uu.se
  - Room 63103
    In astronomy corridor on floor 3 in house 6 – just ring the bell to get in!

Course homepage

- Link: www.astro.uu.se/~ez/kurs/Galaxies16.html

The Physics of Galaxies, 10 ECTS (hp), Spring 2016

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 properties, evolution and origin 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
Time: April-June 2016

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

Schedule

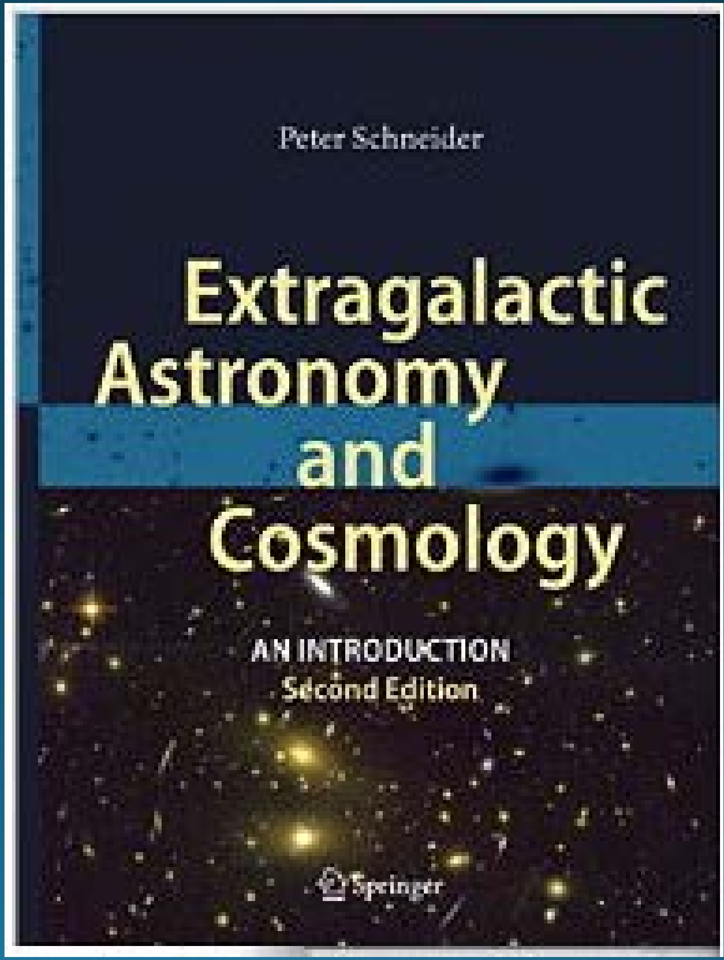
Recent changes are marked in red

Date	Time	Room	Lecture/ Exercise session/ Seminar	Topics	To read	To turn in/prepare
April 12	10-12	Å80115	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 14	13-15	Å2003	Lecture 2	The Milky Way The Local Group	2.1—2.4.2, 6.1—6.1.3	
April 19	15-17	Å80109	Lecture 3	Dark matter in galaxies	2.4.3, 3.3.4, 4.4.6, 7.6—7.6.3, 7.8, 8.2.2—8.2.3	

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



Intermission: What are you looking at?

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:** April 27, 10-12
- **Session 2:** May 19, 13-15
- **Objective:** Solve problems *together* in class

Exercise sessions

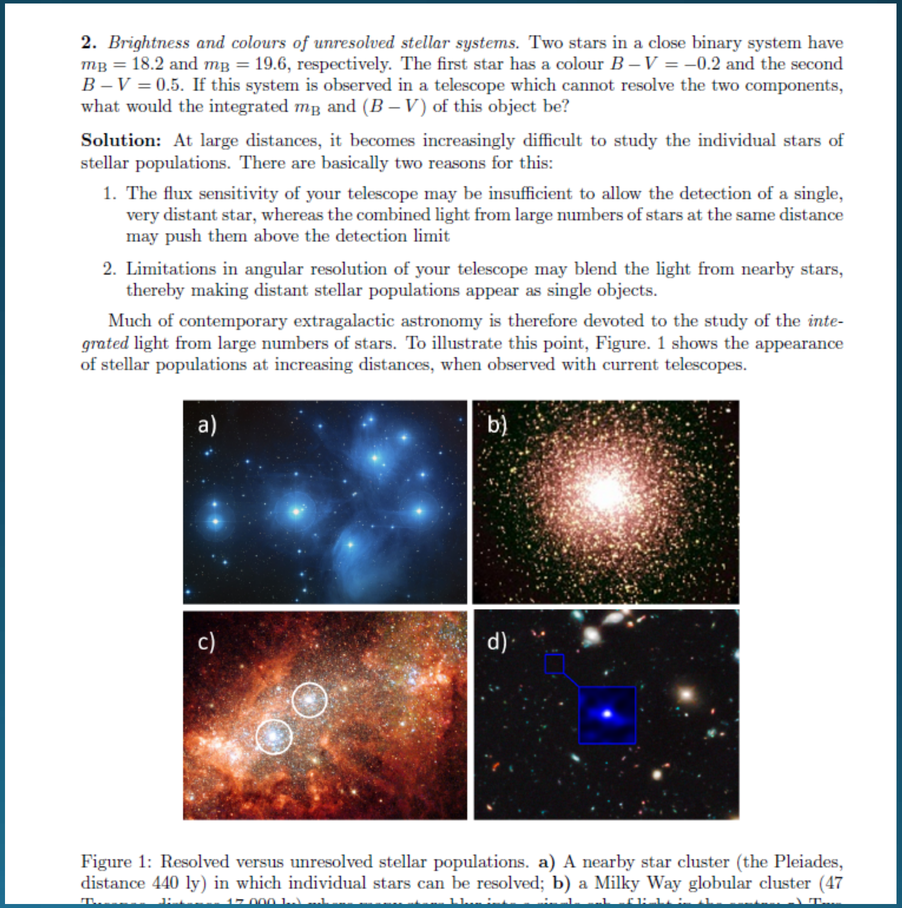
- **Preparation:**
  - Study exercises and solutions posted on course homepage
  - Bring pen, paper, calculator/computer, textbook
- **Grade:** Pass/Fail

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

Hand-in exercises

- 2 exercises downloadable from the course homepage
- Submit by email
  Deadline: June 14
- **Grade:** Fail, 3, 4, 5
- 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 $M = M_{\rm stars} + M_{\rm gas} + M_{\rm remnants}$)?

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 $L_\odot$ 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

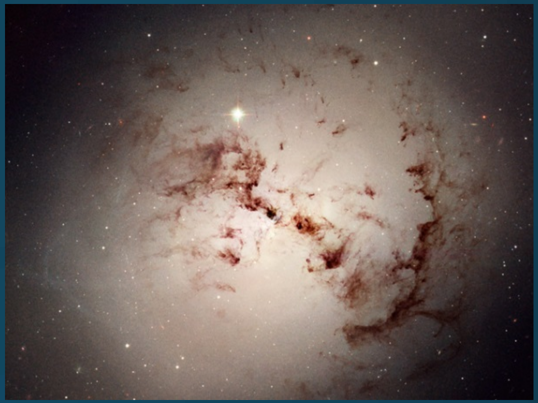
Intermission: What are you looking at?

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 26
  - **Grade:** Fail, 3, 4, 5
- Oral presentation (≈ 10 minutes), May 31
  - **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 the work of a scientist is really like
- Two seminars:
  - 1. May 12, 13-16 (Note: 3 hours!)
  - 2. May 24, 13-15 (group 1), 15-17 (group 2)
- Instructions available from course homepage

Seminars

- Purpose:
  - Practice finding and reading relevant research papers
  - Practice critical thinking
  - Practice analyzing astronomical data
  - Practice scientific creativity
  - Practice communication skills
- What if you cannot attend the seminars?
  - Have to present results in written report

  (→ more work!)

Seminar I

- **Grade:** Pass/fail
- Role-playing exercise
- Preparation:
  - Study the two scenarios in the instructions
  - Read the additional material available in the student portal

Seminar I

General instructions

This document provides preparation instructions for the first of the two seminars forming part of the examination for the course *Physics of Galaxies* in 2016. This is a role-playing exercise that will cast you into situations that scientists (and especially astronomers) frequently encounter, yet in general tend to be rather poorly prepared for.

The point of this exercise is to:

- Practice reading research papers, press releases or other scientific texts in the field of extragalactic astronomy
- Practice critical thinking
- Practice interacting with the public and with journalists in a professional manner, and also to get some feeling for what it may feel like to be on the other end of this conversation

Seminar II

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

Seminar II: The most distant galaxies

General instructions

This document provides preparation instructions for the second of the two seminars forming part of the examination for the course *Physics of Galaxies* in 2015. The topic of this seminar is *The most distant galaxies*. Galaxies are being detected at ever-increasing redshifts, and as of 2015, a number of photometric galaxy candidates have been claimed at $z \approx 10$–12, i.e. at about 300-500 Myr after the Big Bang. None of these candidates have so far been confirmed through spectroscopy – the spectroscopic redshift record is still held by an object at $z \approx 7.7$, but the race to detect emission lines from from even more distant galaxies is on.

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.

Database exercise (“lab”)

- Introduction to exercise in lecture 6
- Complete individually and hand in report no later than June 7
- **Grade:** Fail, 3, 4, 5

Intermission: What are you looking at?

Schedule I

Complete schedule on course homepage!

- 8 Lectures:
  - April 12, 10—12
  - April 14, 13—15
  - April 19, 15—17
  - April 21, 15—17
  - April 26, 13-15
  - May 3, 10—12 ← **Includes introduction to database exercise**
  - May 10, 10—12
  - May 17, 10—12

- 2 Exercise sessions:
  - April 27, 10—12
  - May 19, 13—15

Schedule II

- 2 seminars:
  - May 12, 13—16
  - May 24, 13-15 (group 1) & 15-17 (group 2)

- Oral presentations of literature exercises
  - May 31, 13—15 + additional date?

Grades

- Final grade will be the mean grade from:
  - Seminar 2
  - Written report on literature exercise
  - Oral presentation of literature exercise
  - Report from database exercise
  - Hand-in exercises

- No final grade will be computed until you have a reached a passing grade (3 or higher) for each of these
- Please note that you also need a passing grade from the two exercise sessions and seminar 1 to complete the course

Grades – example

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

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

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

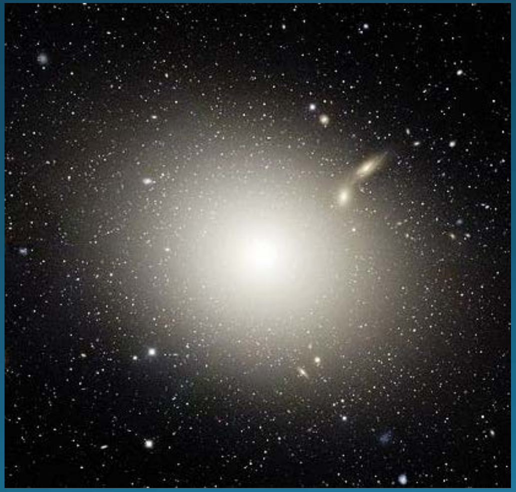
My estimates:

- 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

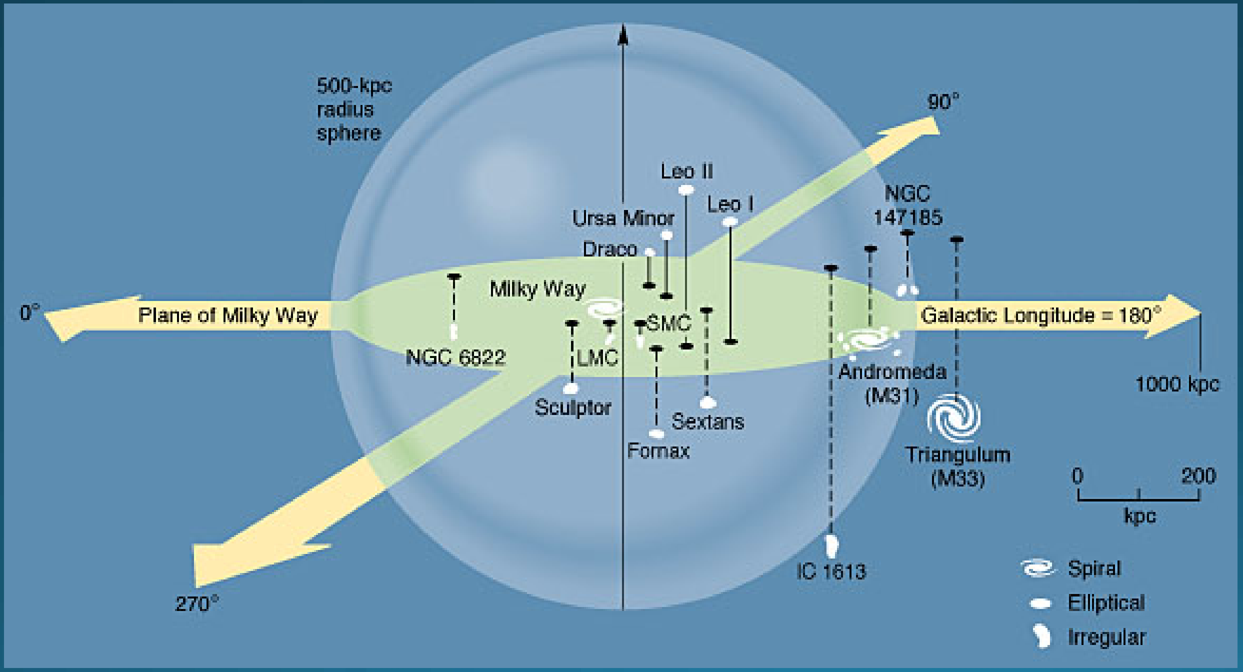
Course Outline

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


Course Outline

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

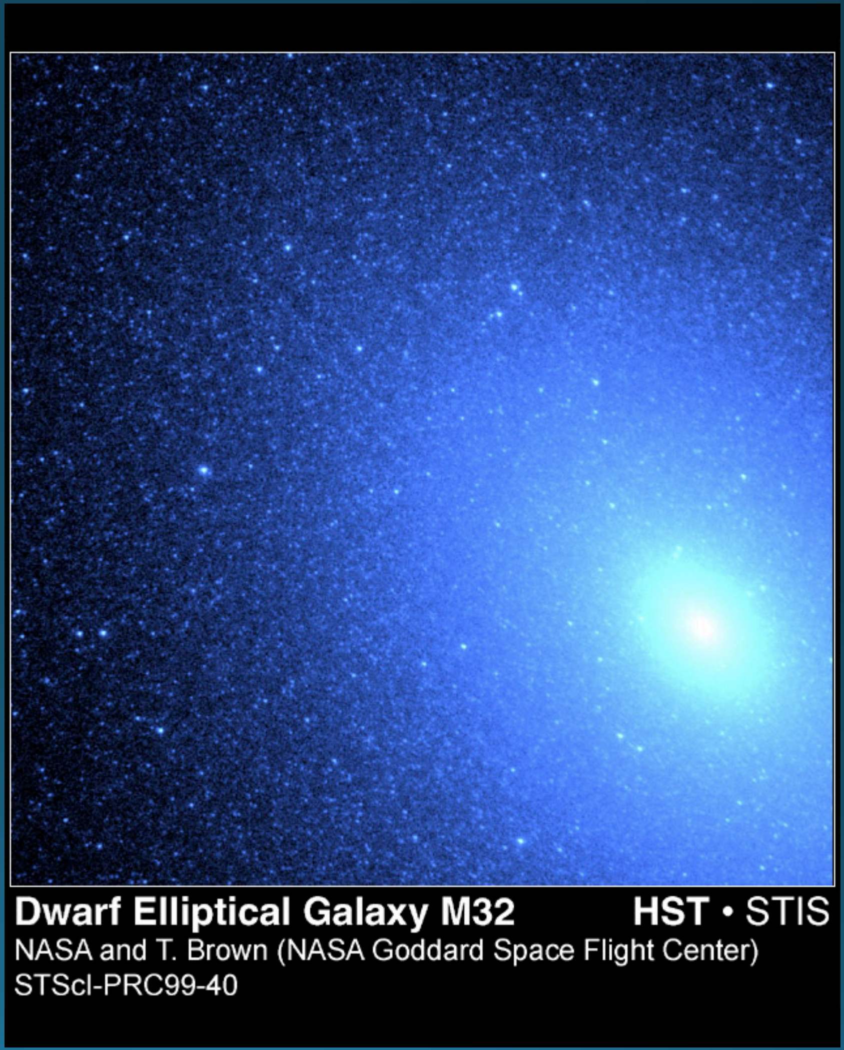


Course Outline

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

Course Outline

- Lecture 4:
  - Disk galaxies
  - Elliptical galaxies

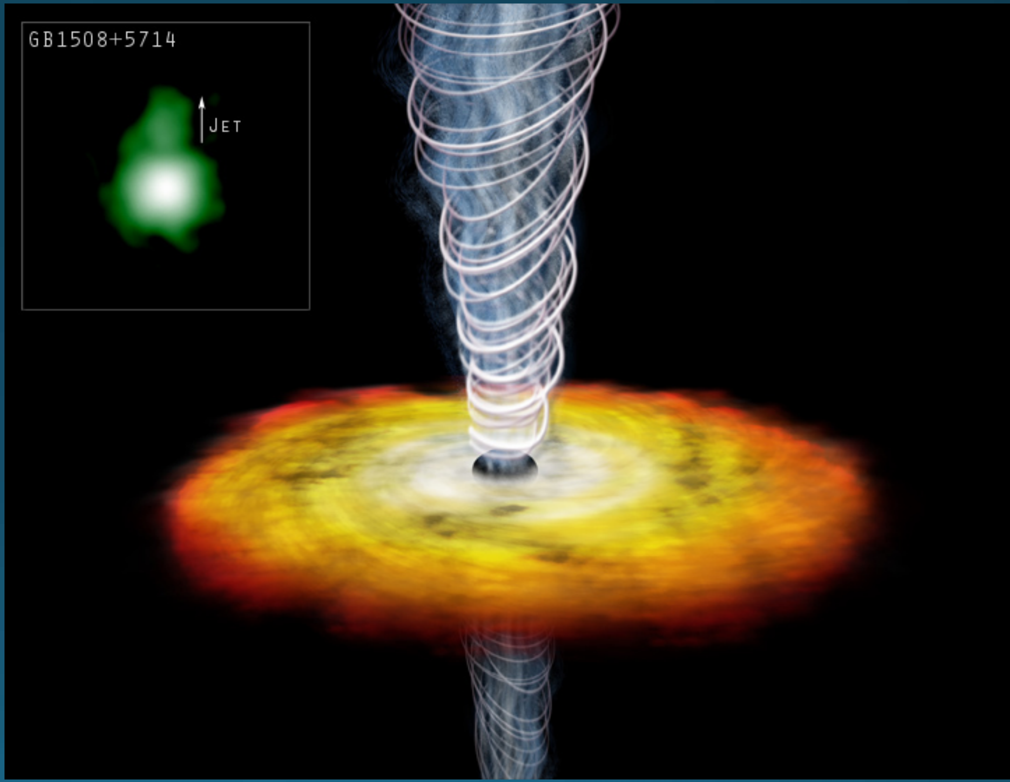


Course Outline

- Lecture 5:
  - Star formation
  - Population synthesis
  - Galaxy spectra
  - The interstellar medium
  - The cosmic star formation history

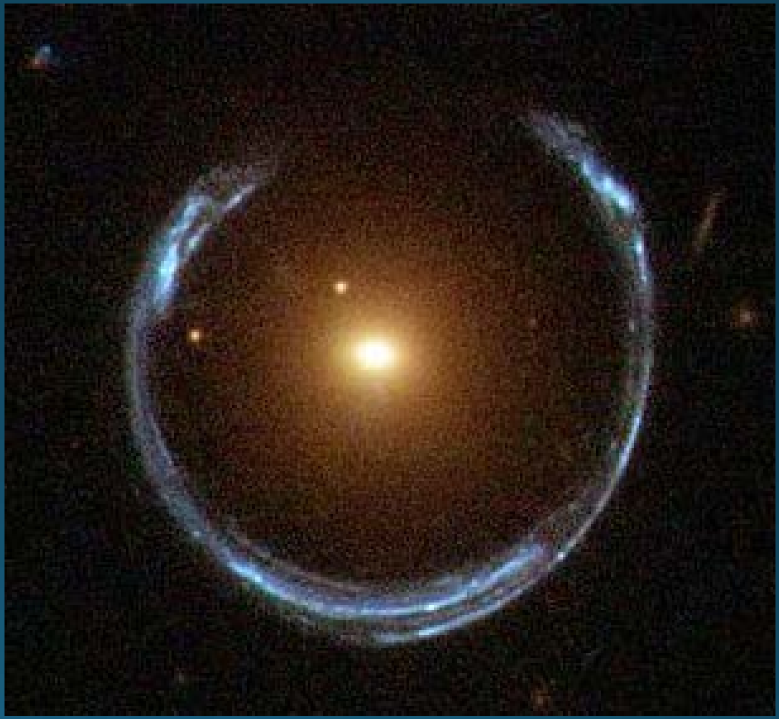
Course Outline

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



Course Outline

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

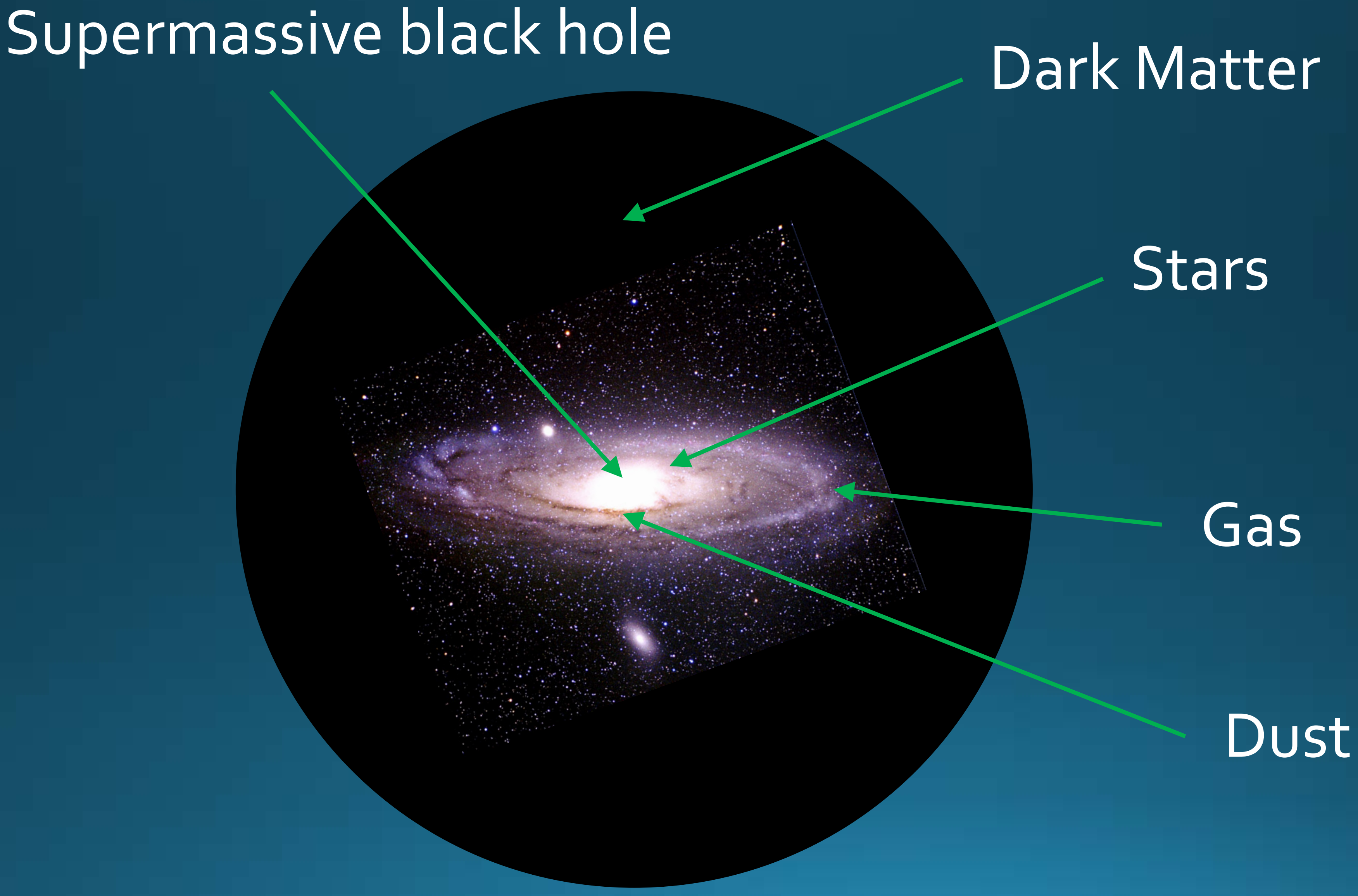


Course Outline

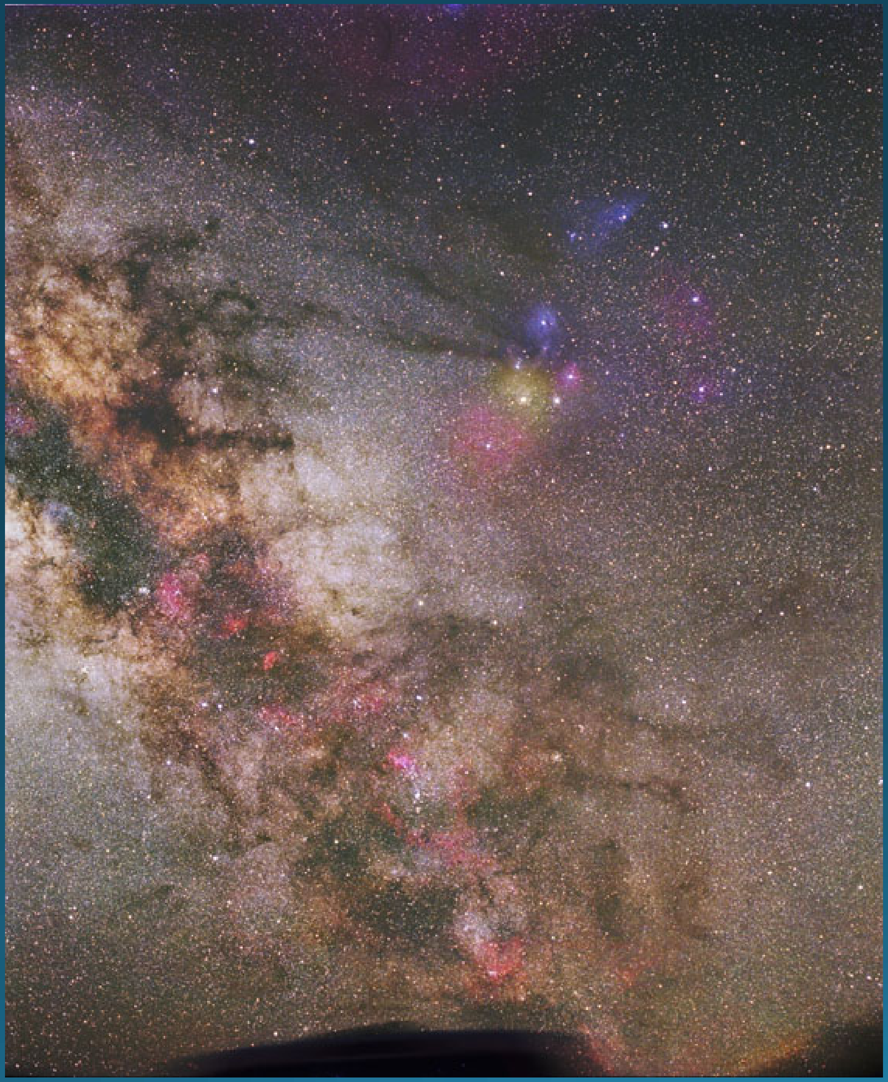
- Lecture 8:
  - The high-redshift Universe
  - Cosmic reionization
  - The first stars and galaxies

Intermission: What are you looking at?

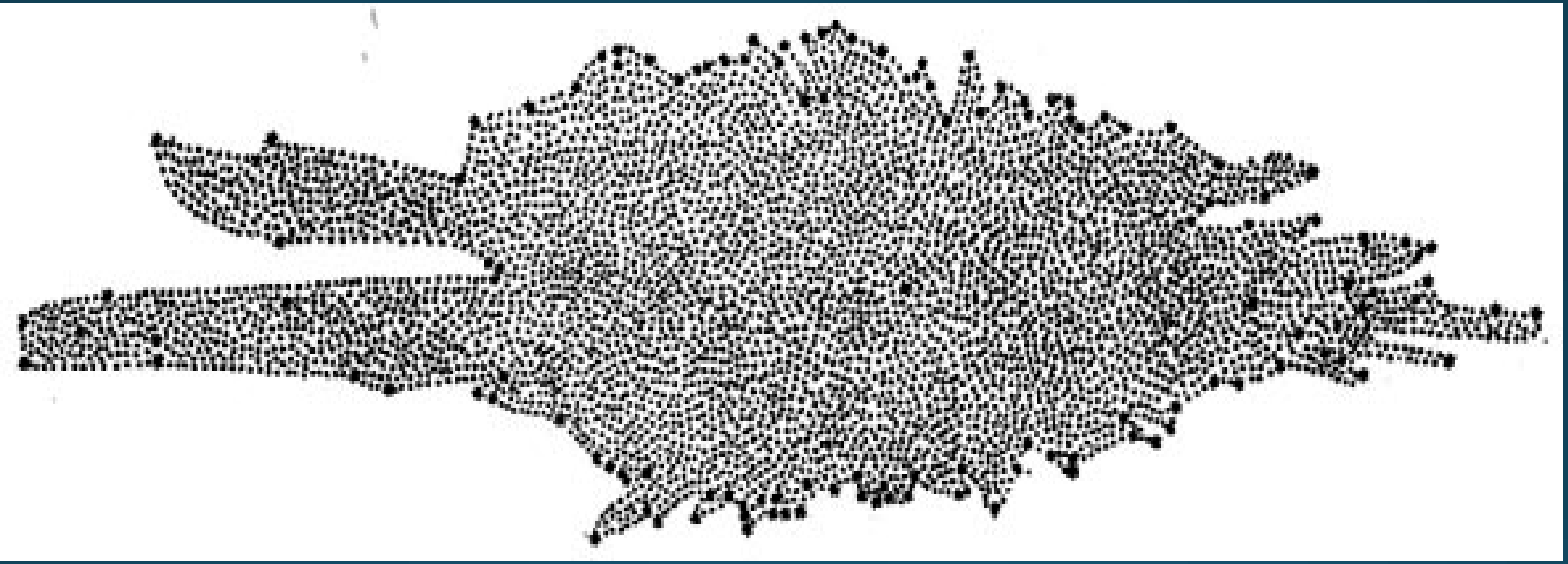
The Anatomy of Galaxies



Historical Background: The Milky Way

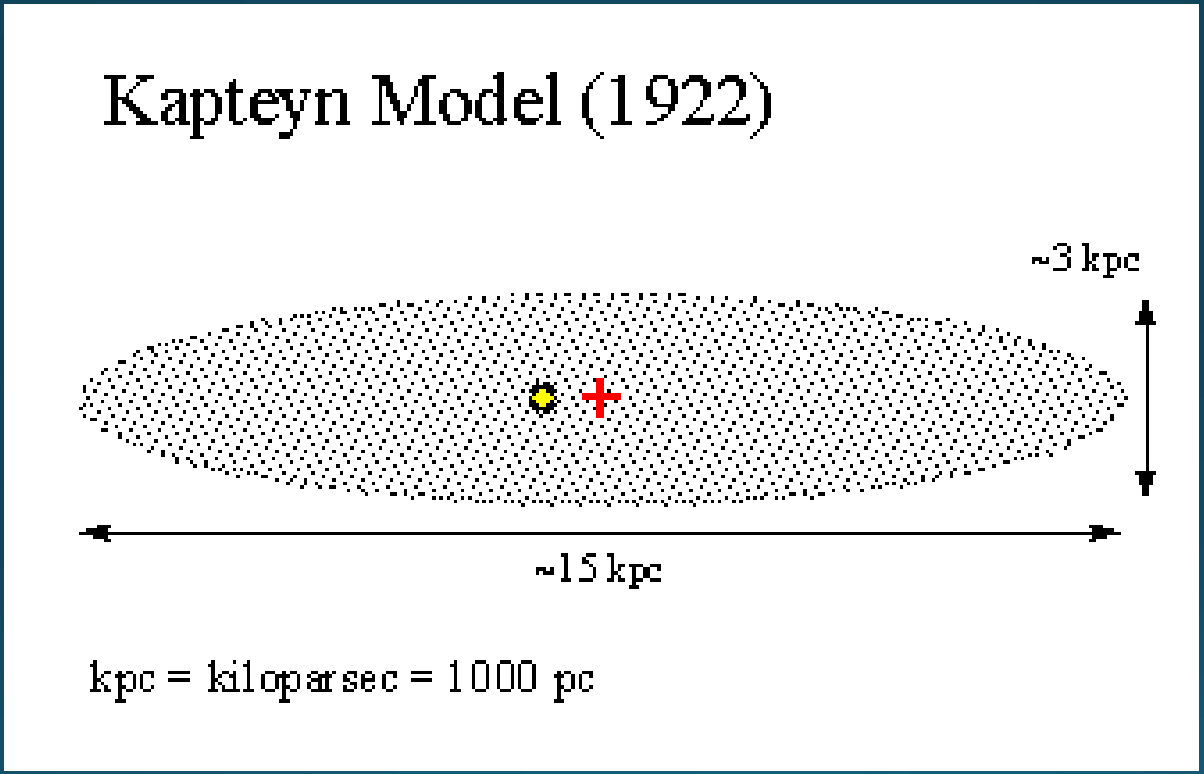


Historical Background: The Milky Way



- 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

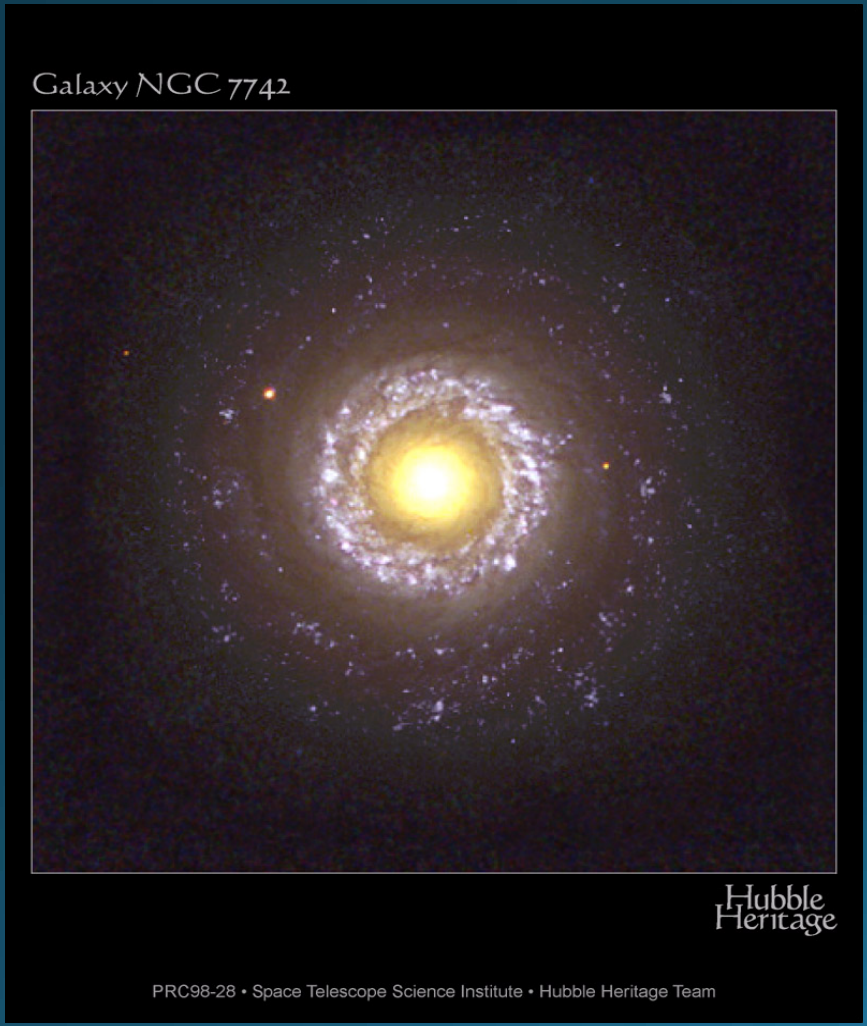


- Sun offset from centre
- Dust obscuration still not accounted for → wrong scale

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)

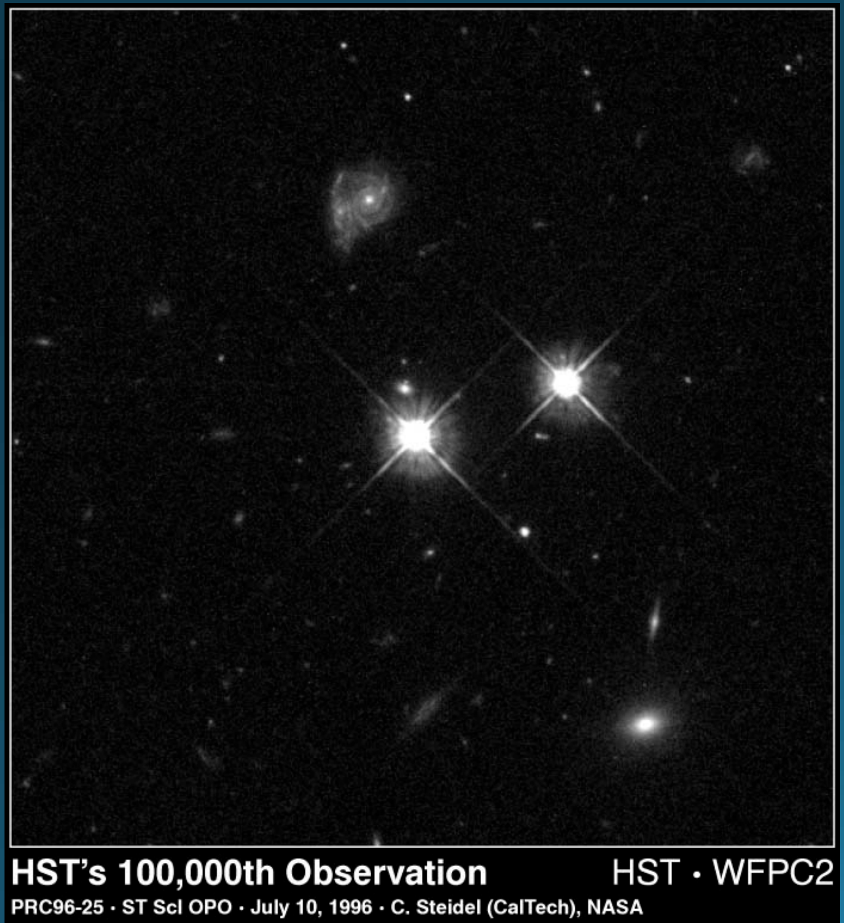
Historical Background: Active Galaxies

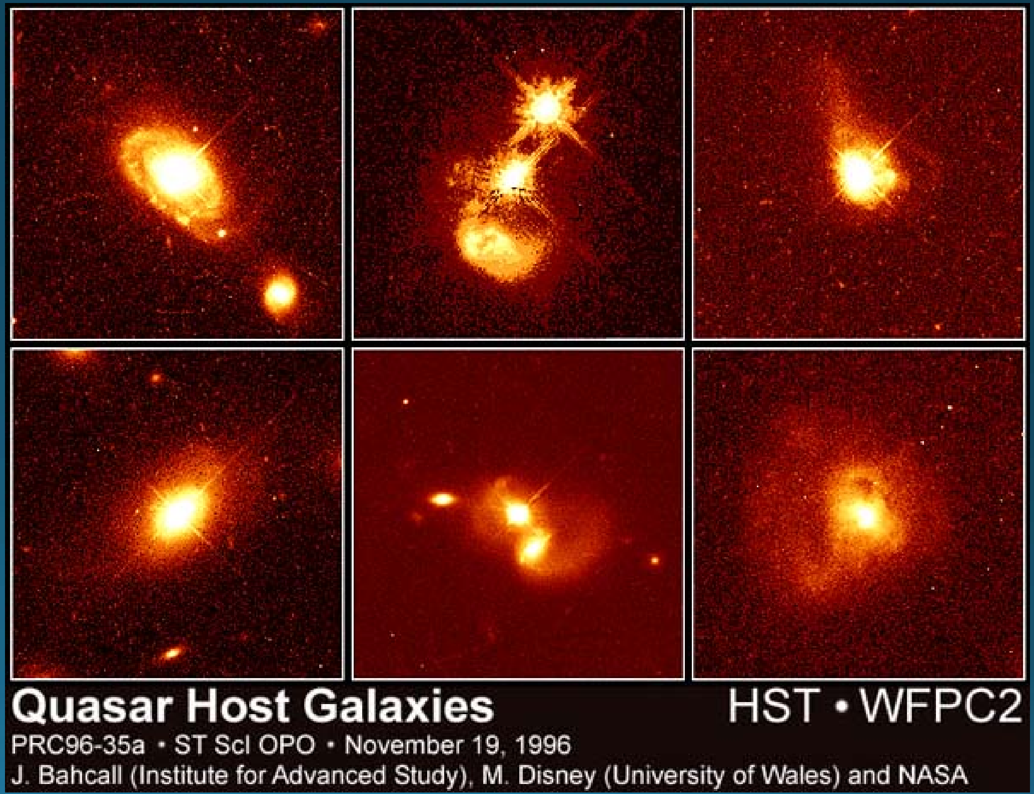


- 1943 - Seyfert Galaxies

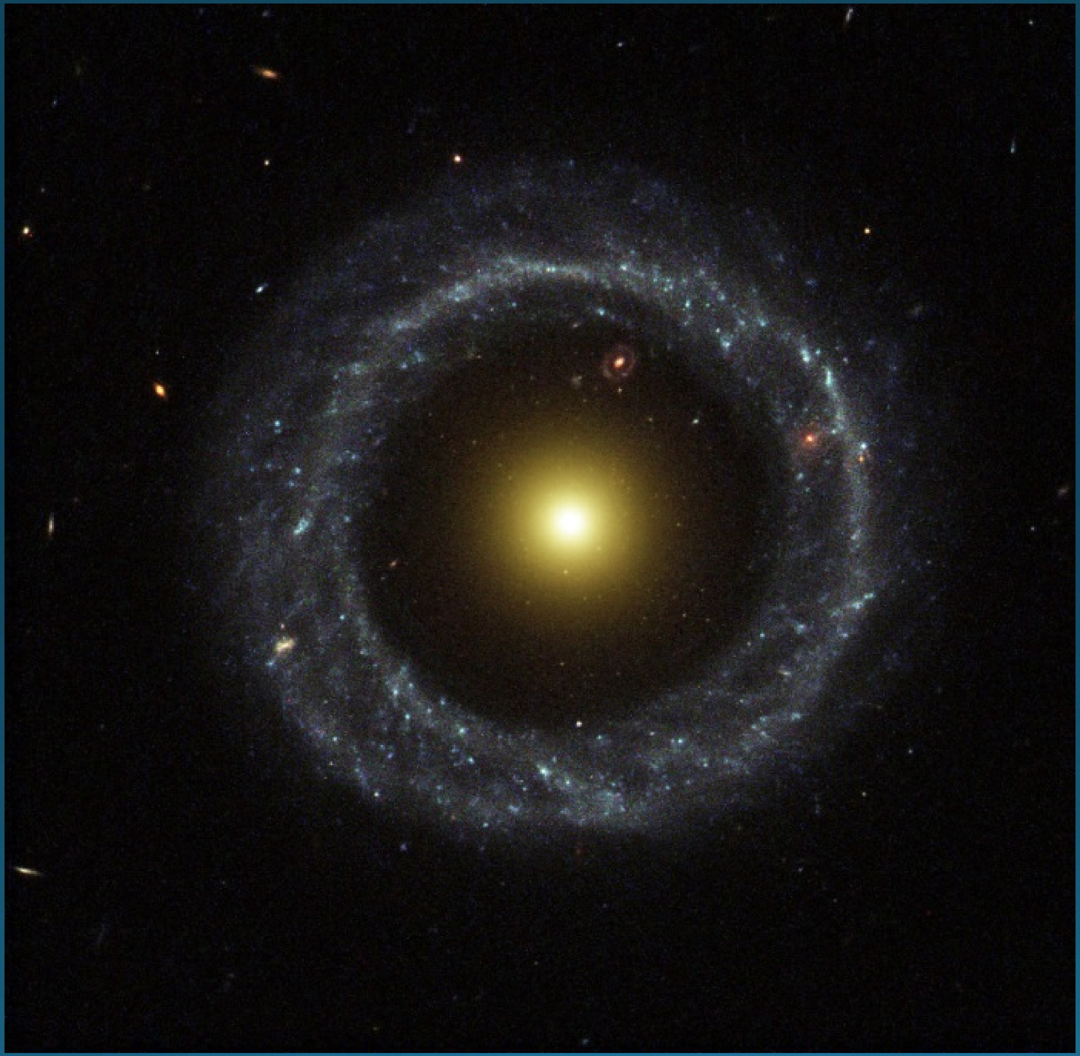
Historical Background: Quasars/QSO

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

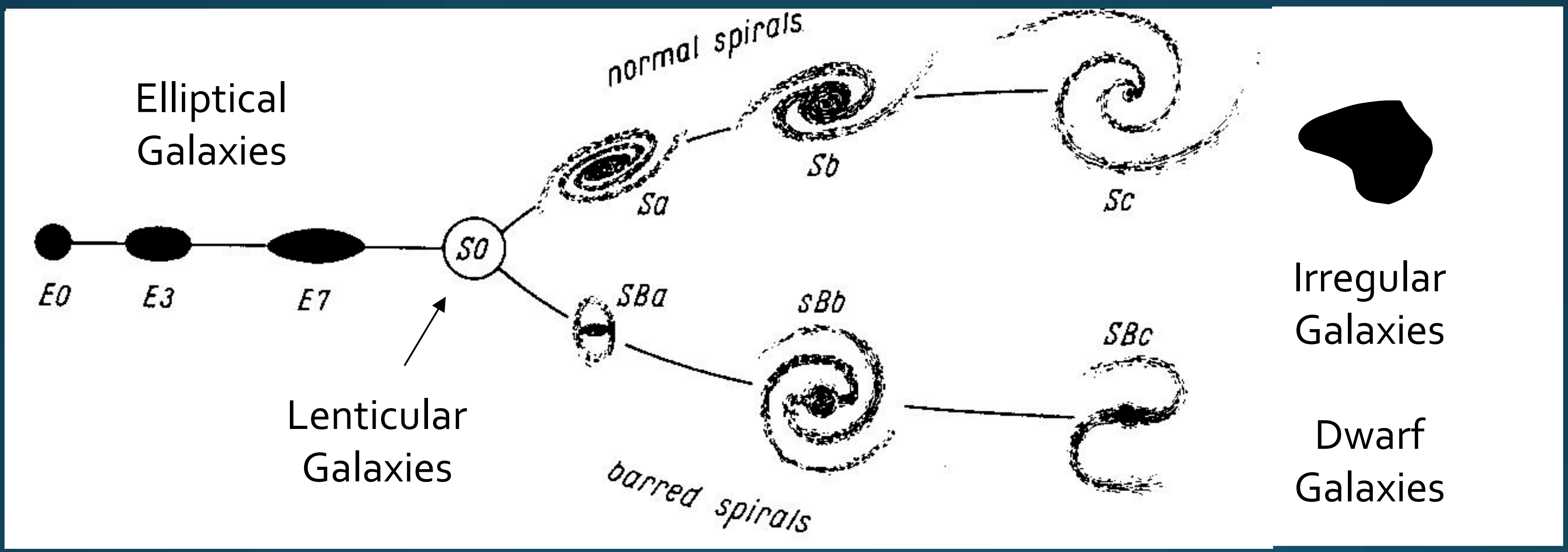




Intermission: What are you looking at?



Galaxy Classification
The Hubble Tuning Fork



Other famous classification schemes:

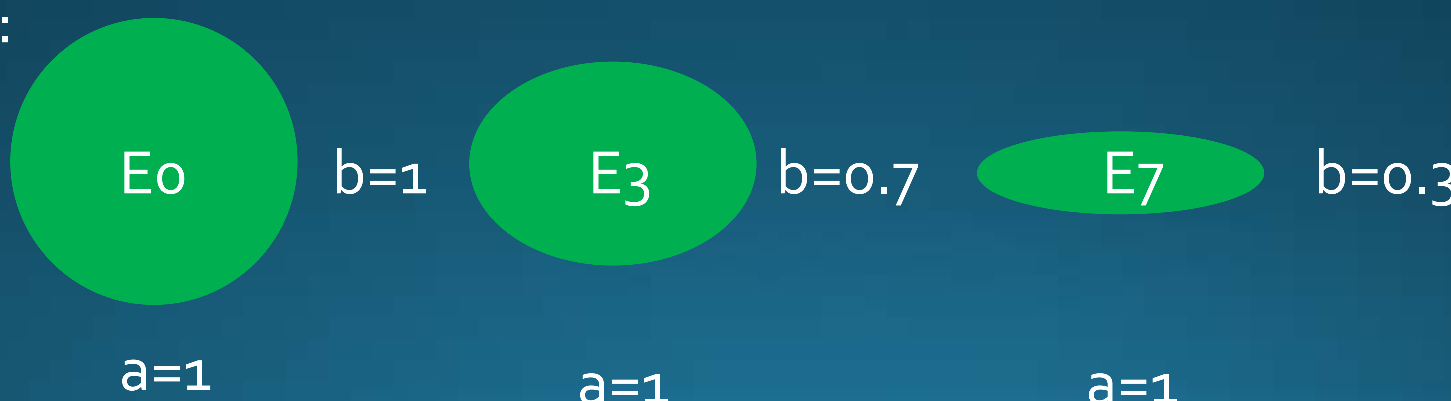
- de Vaucoleur
- van den Bergh
- Vorontsov-Velyaminov

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:

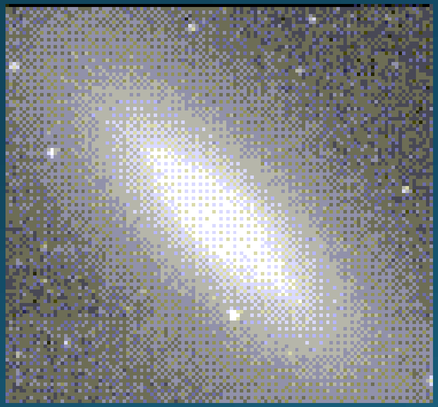


Galaxy Classification

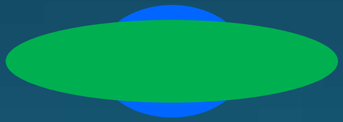
Lenticular galaxies

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

Examples:



So



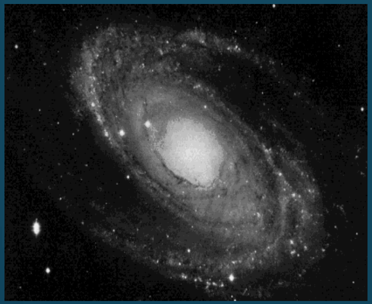
Edge-on

Face-on

Galaxy Classification

Normal Spirals

Sa

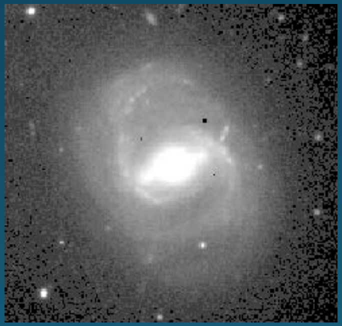


Sb

Sc

Barred Spirals

SBa



SBb

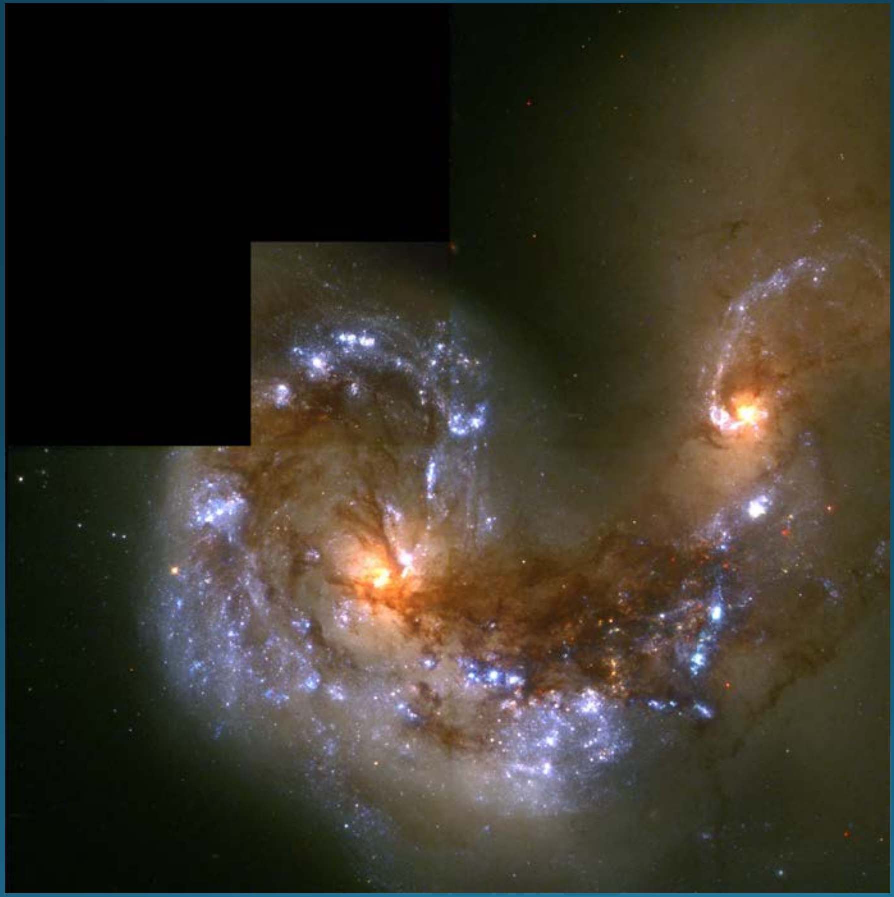
SBc

- 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

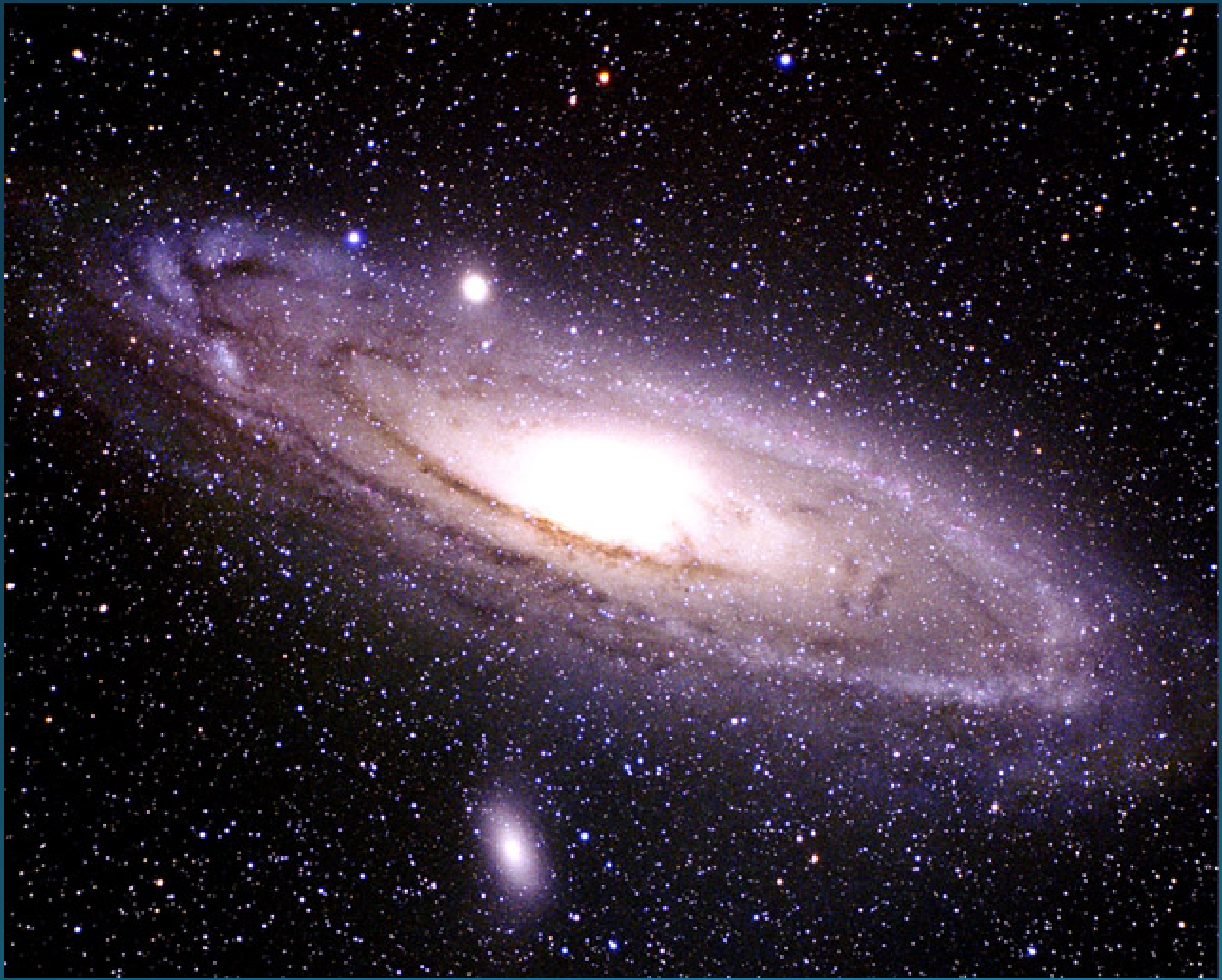
Irregular galaxies (I)



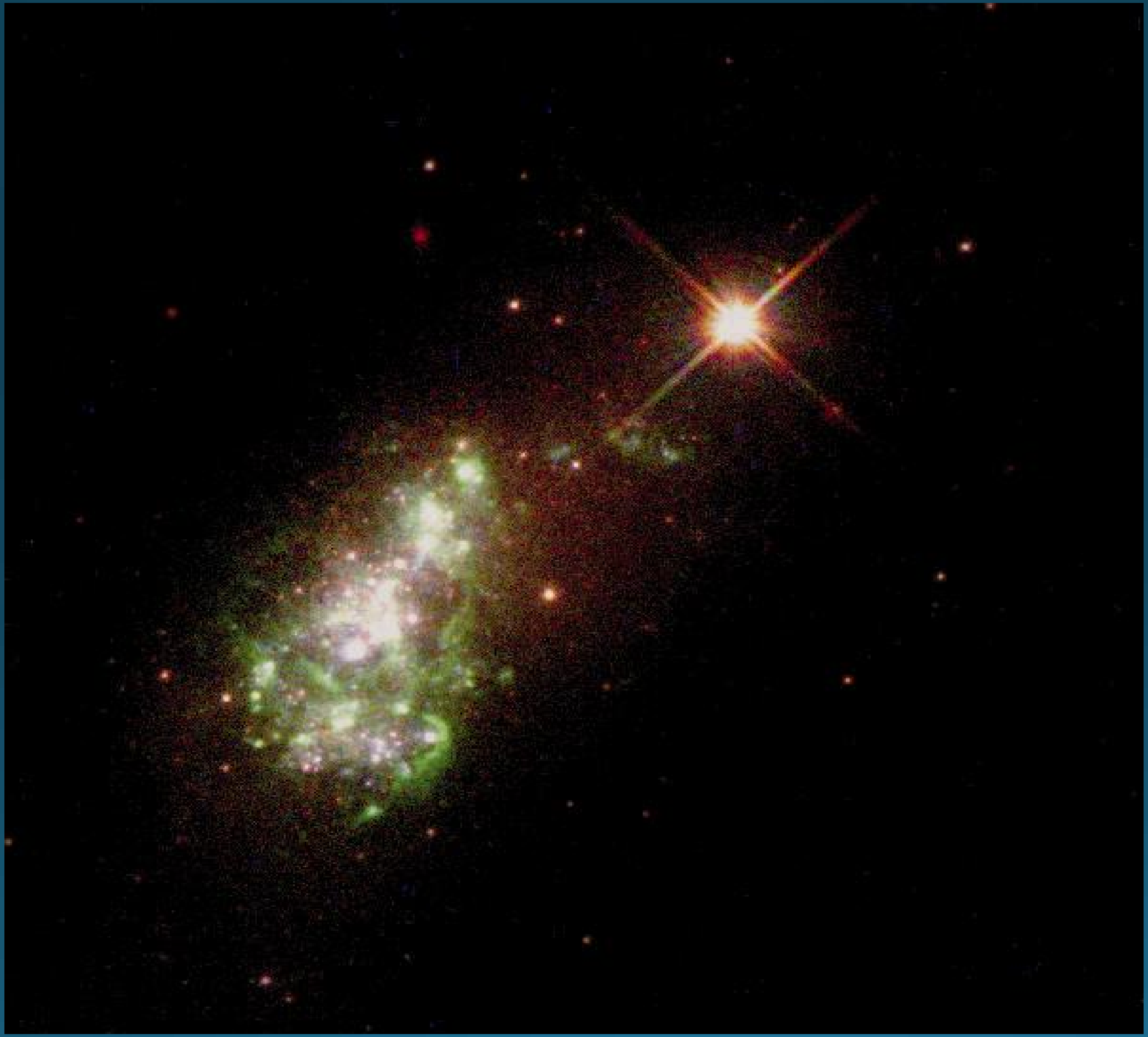
Galaxy Classification

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

Morphological Type?



Morphological Type?

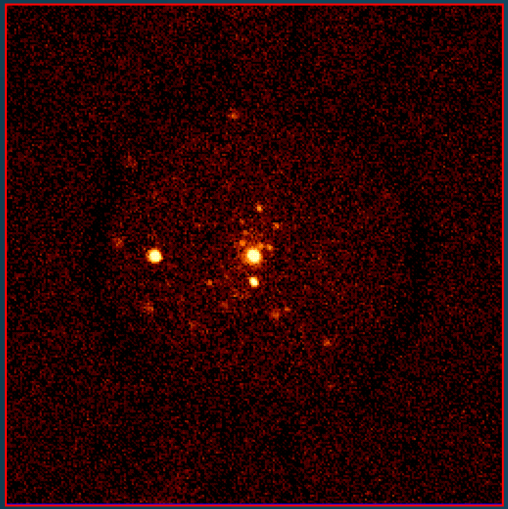


What is the Point of Morphological Classification?

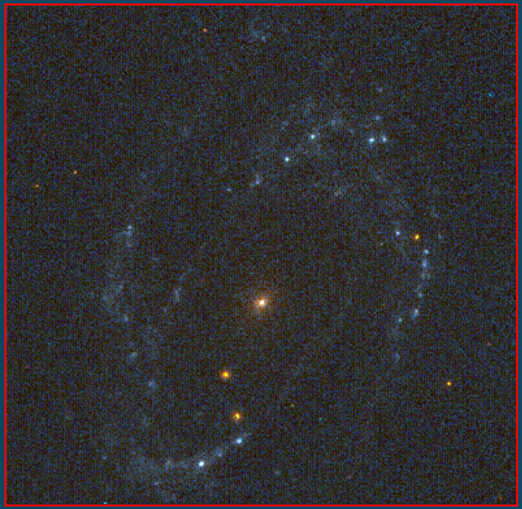
Hubble class correlates with:

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

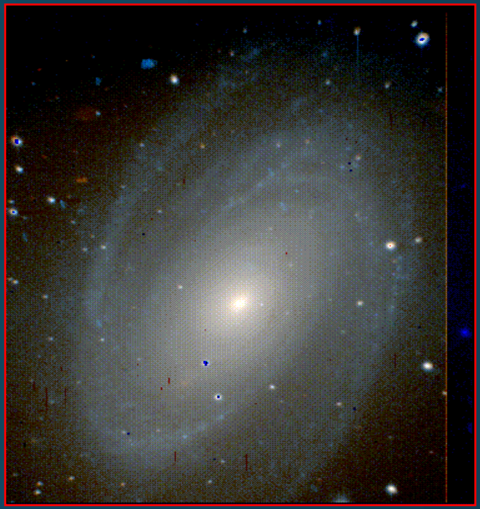
Morphological Complications



X-rays

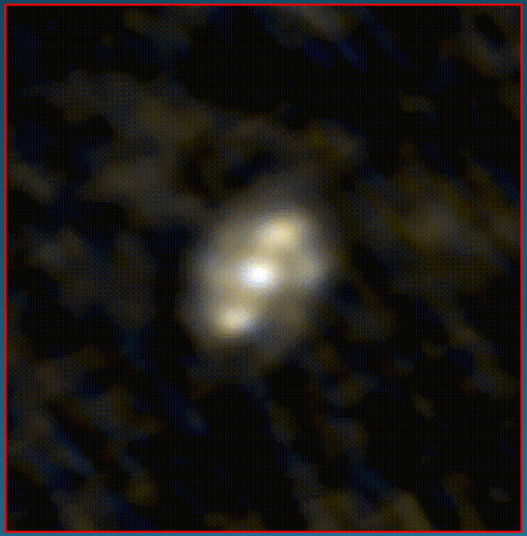


UV



Optical

Near-IR



Far-IR

Same galaxy (M81) at different wavelengths!

Morphological Complications

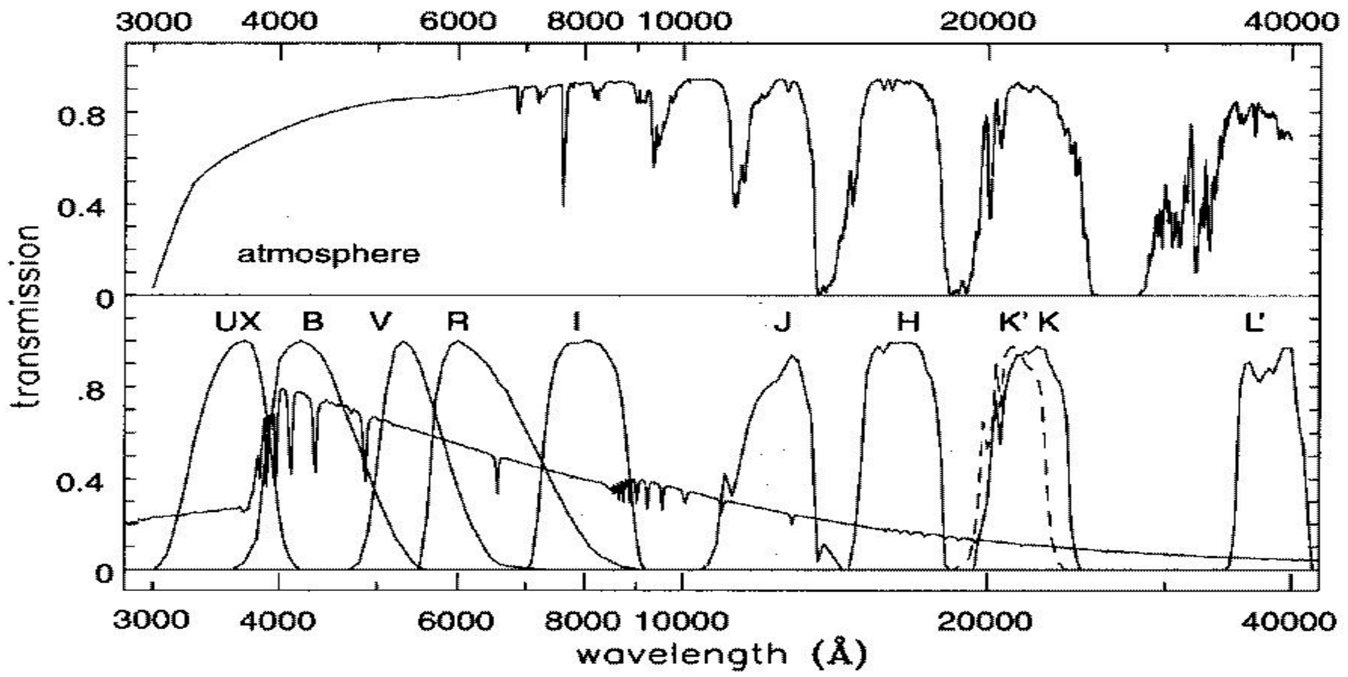
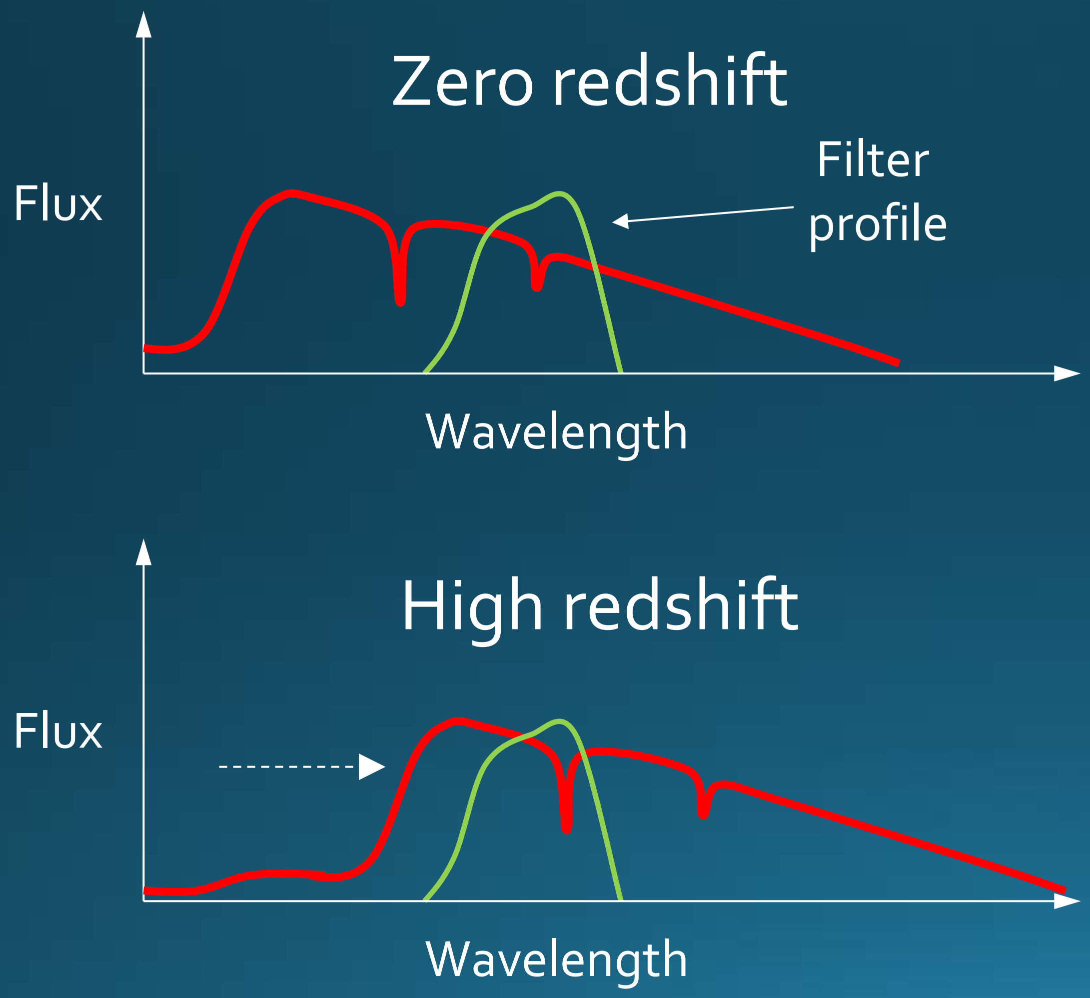


Figure 1.7 Above, atmospheric transmission in the optical and near-infrared. Below, flux F_λ of a model A0 star, with transmission curves $\mathcal{T}(\lambda)$ for standard filters from Bessell, PASP 102, 1181; 1990. UX is a version of the U filter that takes account of atmospheric absorption. For $JHK'KL'$,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

Morphological Complications

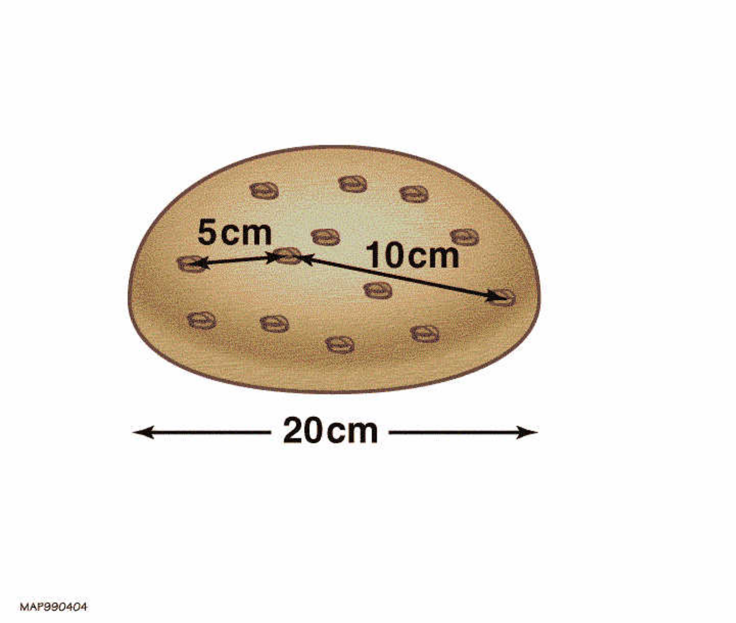


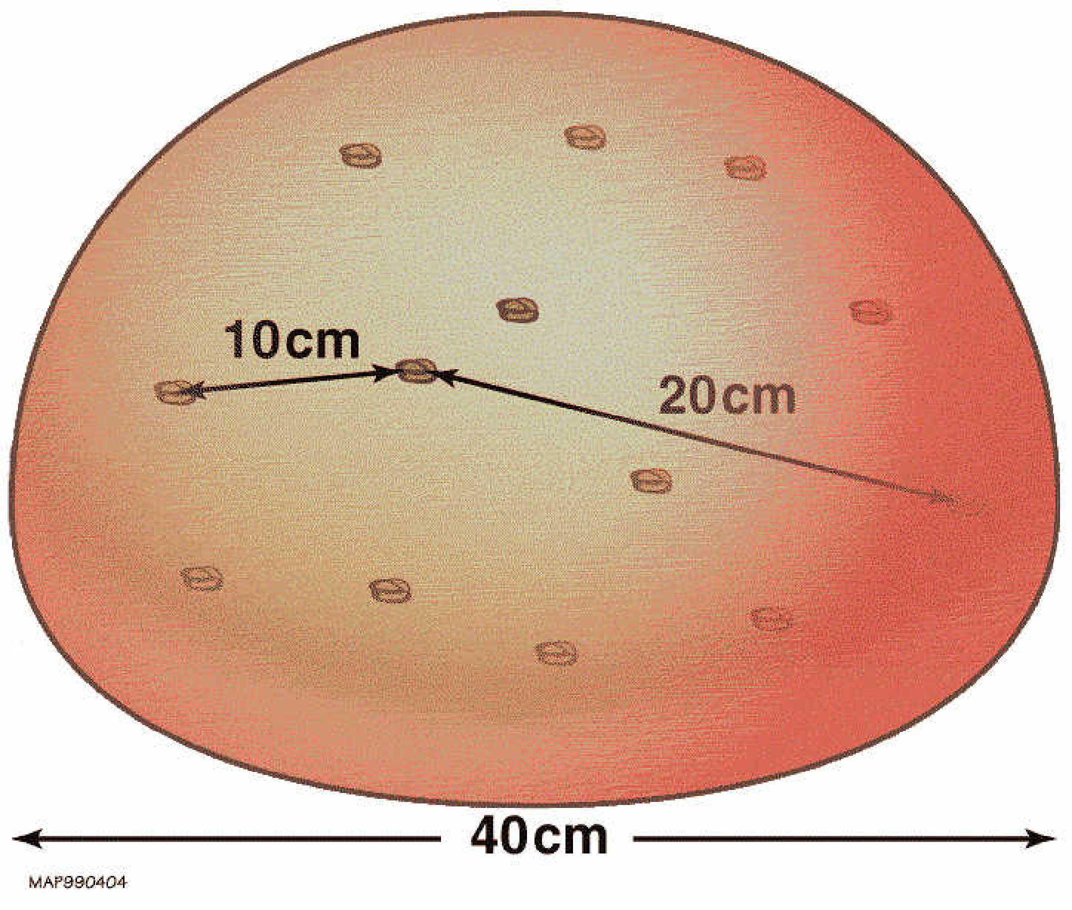
- Same filter probe different parts of spectrum at high and low redshifts
- Two galaxies with identical morphologies at a given rest wavelength may appear to have different morphologies

Intermission: What are you looking at?

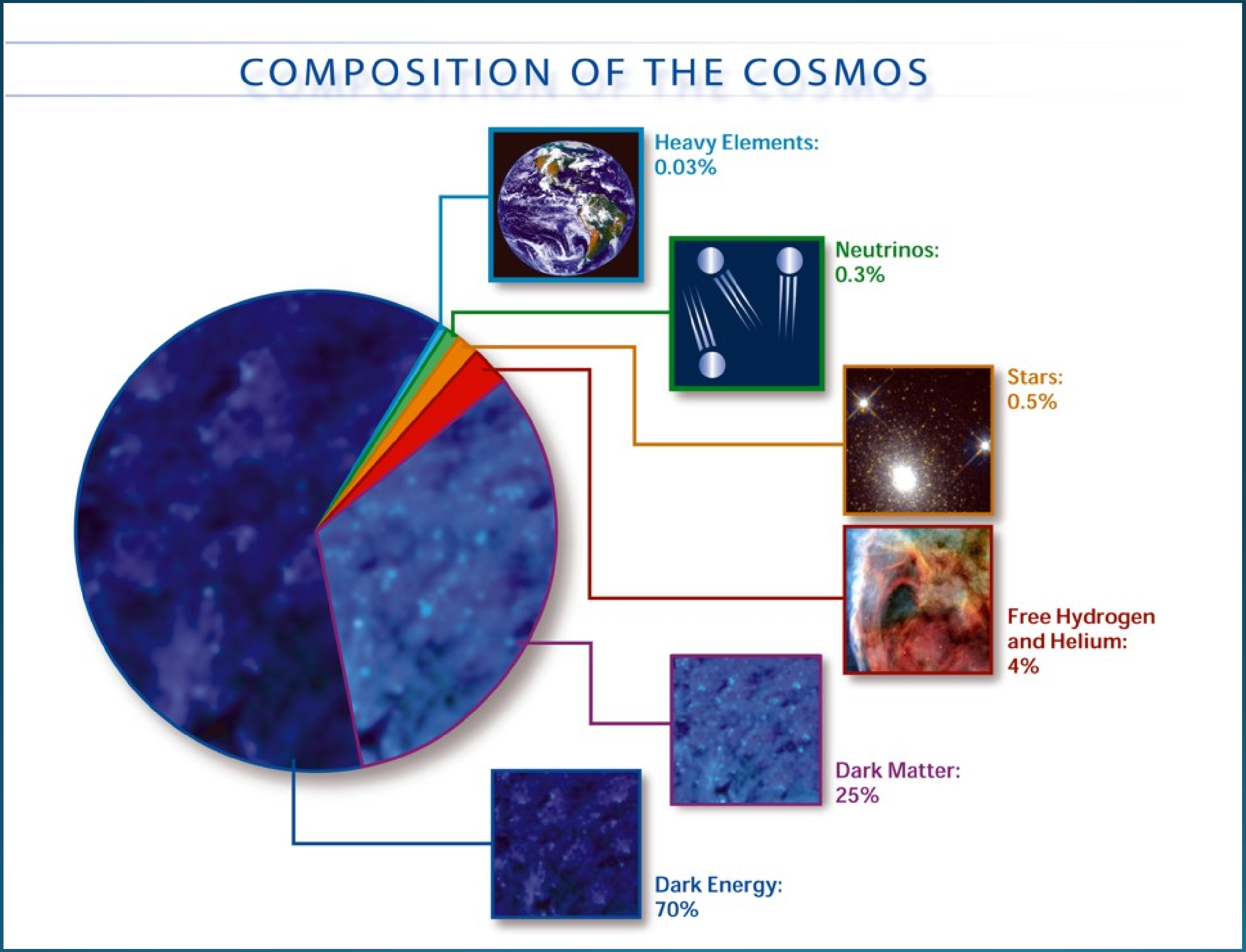
Intermission: What are you looking at?

The Cosmological Framework I

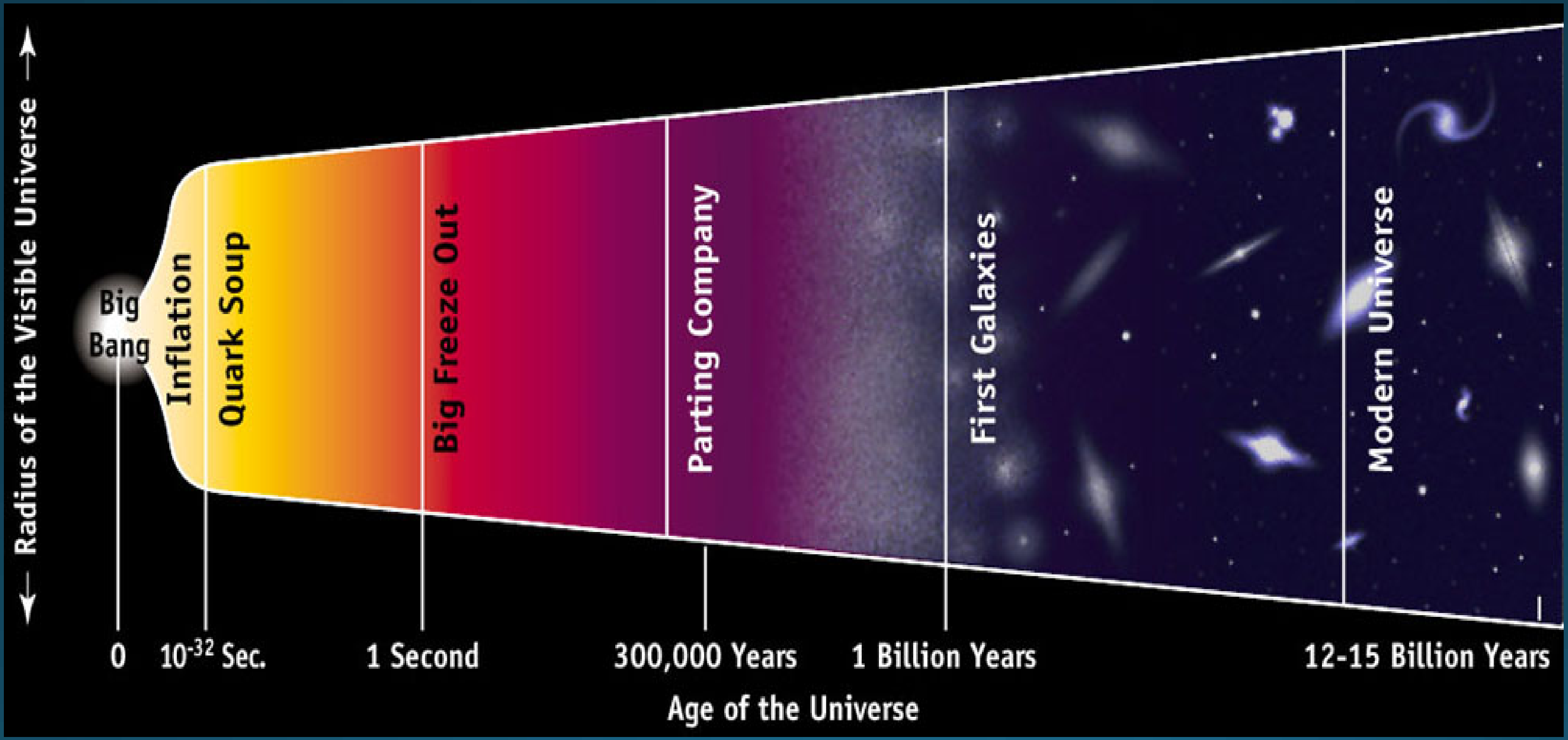




The Cosmological Framework II



The Cosmological Framework III



The Cosmological Framework IV

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