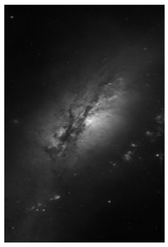
Physics of Galaxies, 2015
10 credits
Lecture 1: Introduction

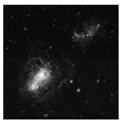
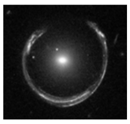
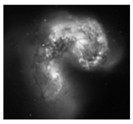

Outline for today I

- 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!

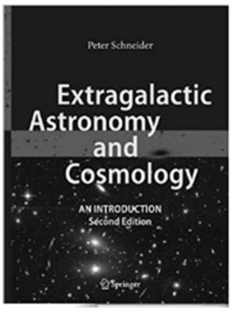
Schedule
Recent changes are marked in red

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.

Hand-in exercises

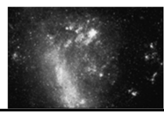
- 2 exercises downloadable from the course homepage
- Submit by email **Deadline:** June 12
- **Grade:** Pass / fail
- Collaboration OK, but please don't turn in identical solutions!


Physics of Galaxies
Hand-in exercises 2015

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

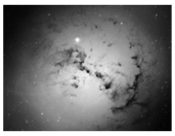
Literature exercise

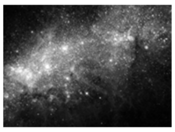
- Choose subject individually
- Find suitable articles
  - Published papers (ADS abstract service) http://adsabs.harvard.edu/abstract_service.html Preprints: http://www.arxiv.org
- Written report (≈ 3 pages), deadline May 29
  - **Grade:** Fail, 3, 4, 5
- Oral presentation (≈ 10 minutes), June 4
  -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

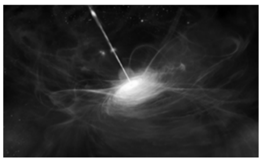
General instructions

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 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 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 ≈ 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

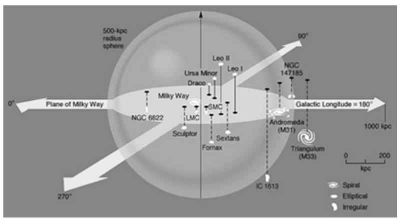
Sum: 6.5 weeks, i.e. ≈ 10 hp

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

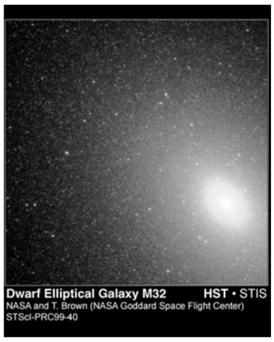


Course Outline

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

Course Outline

- Lecture 4:
  - Disk galaxies
  - Elliptical galaxies

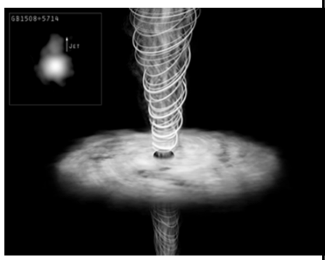


Course Outline

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

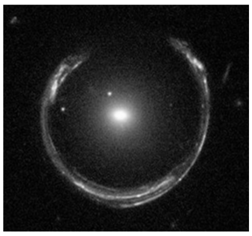
Course Outline

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



Course Outline

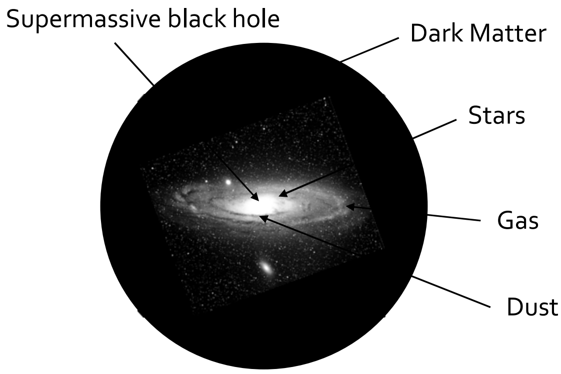
- Lecture 7:
  - Galaxy groups
  - Galaxy clusters
  - Gravitational lensing



Course Outline

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

The Anatomy of Galaxies



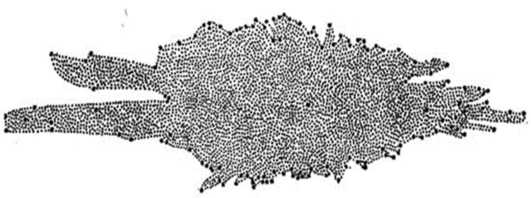
Intermission: What are you looking at?

Intermission: What are you looking at?

Intermission: What are you looking at?

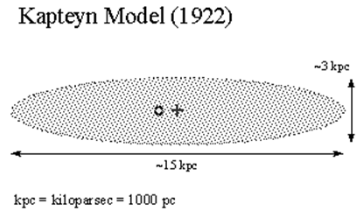
Historical Background: The Milky Way

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

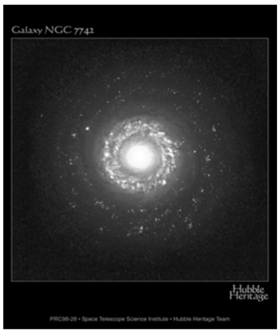


- Sun offset from centre
- Dust obscuration still not accounted for → wrong scale

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)

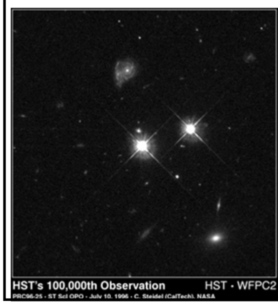
Historical Background: Active Galaxies

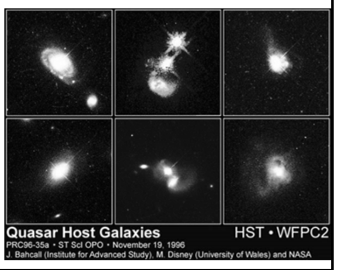


- 1943 - Seyfert Galaxies

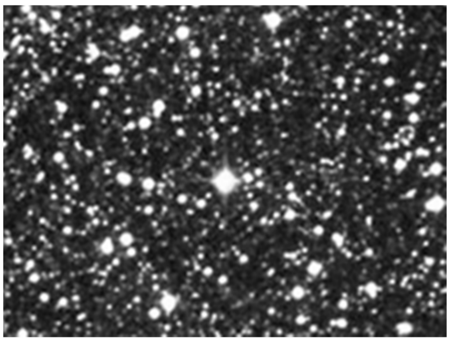
Historical Background: Quasars/QSO

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

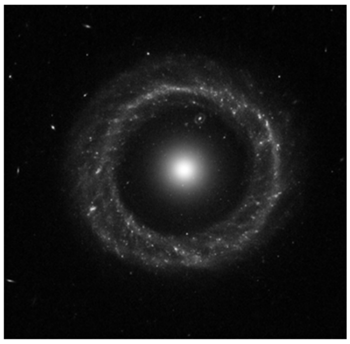




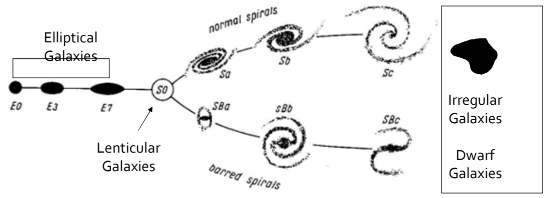
Intermission: What are you looking at?



Intermission: What are you looking at?



Galaxy Classification
The Hubble Tuning Fork

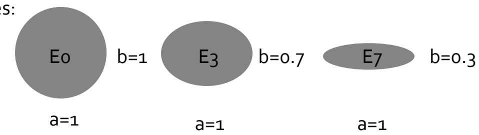


Other famous classification schemes:
- de Vaucoleur
- van den Bergh
- Vorontsov-Velyaminov

Galaxy Classification

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

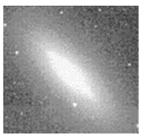
Examples:



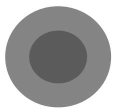
Galaxy Classification

Lenticular galaxies
- Disk and central bulge, but no spiral arms
- SB0 if barred, S0 otherwise

Examples:

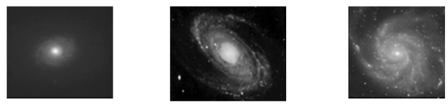

S0


Edge-on

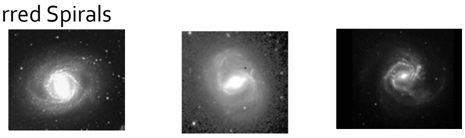

Face-on

Galaxy Classification

Normal Spirals


Sa Sb Sc

Barred Spirals


SBa SBb SBc

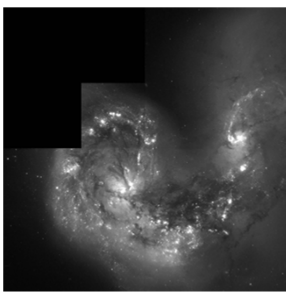
- Large bulges
- Tightly wound spiral arms
- Few star-forming regions in arms

→

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

Galaxy Classification

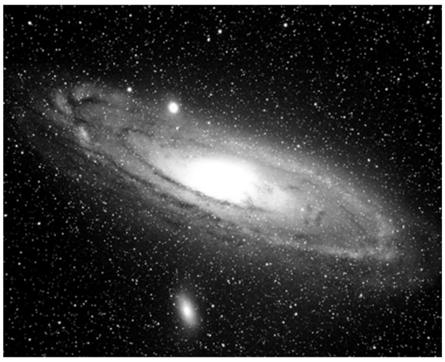
Irregular galaxies (I)



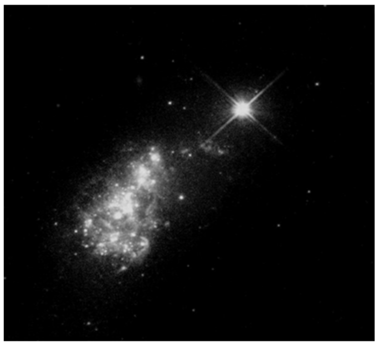
Galaxy Classification

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

Morphological Type?



Morphological Type?

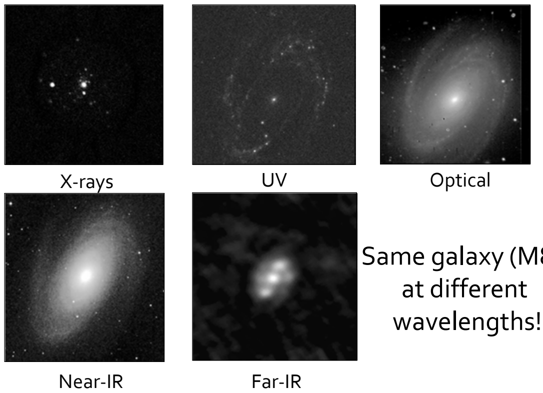


What is the Point of Morphological Classification?

Hubble class correlates with:

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

Morphological Complications



Same galaxy (M81) at different wavelengths!

Morphological Complications

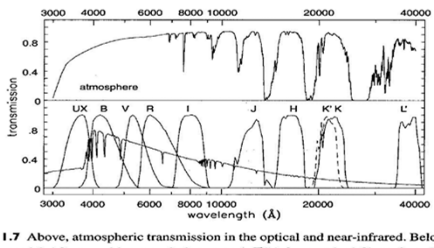
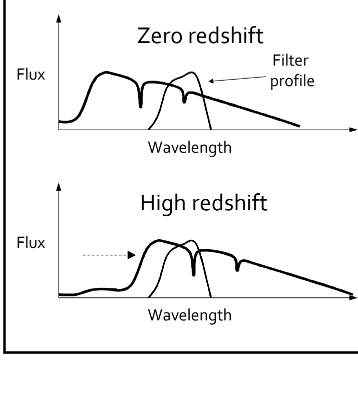


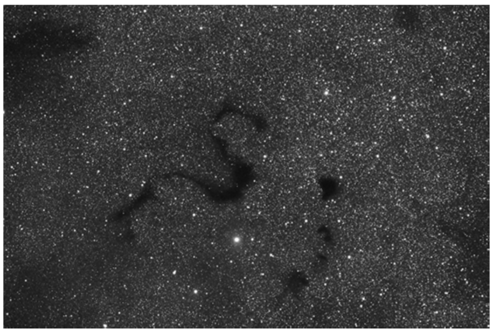
Figure 1.7 Above, atmospheric transmission in the optical and near-infrared. Below, flux F_λ of a model A0 star, with transmission curves $T(\lambda)$ for standard filters from Bessell, PASP 102, 1181; 1990. UX is a version of the U filter that takes account of atmospheric absorption. For $JHK'KL'$,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

Morphological Complications

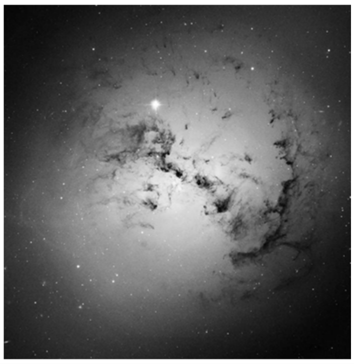


- Same filter probe different parts of spectrum at high and low redshifts
- Two galaxies with identical morphologies at a given rest wavelength may appear to have different morphologies

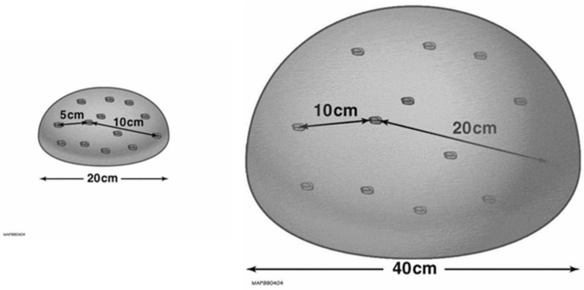
Intermission: What are you looking at?



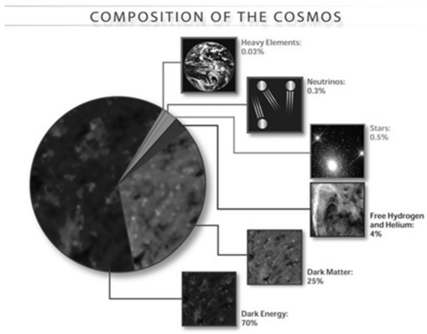
Intermission: What are you looking at?



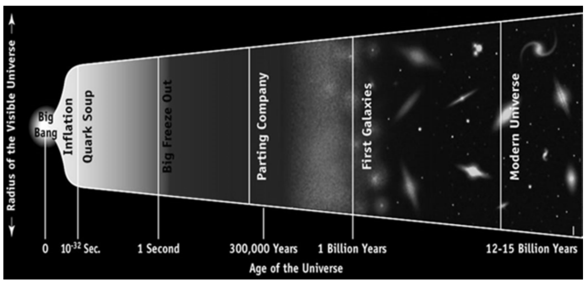
The Cosmological Framework I



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
- $\Omega_{Tot} \approx 1.0$
- $\Omega_{Baryons} \approx 0.04$
- $\Omega_M \approx 0.3$
- $\Omega_\Lambda \approx 0.7$