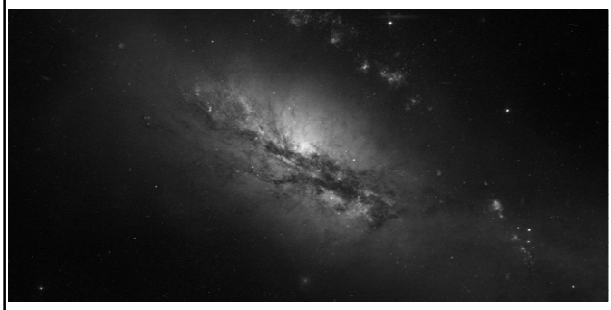
Galaxies AS7007, 2012
Lecture 1: Introduction



Outline for today I

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

Outline for today II

- What is a Galaxy?
- Historical Background
- The Cosmological Framework
- Evolution of the Universe
- The Extragalactic Distance Ladder
- Galaxy Classification

Formal Information

- Teacher:
  - – Erik Zackrisson
  - – Room C6:1007
  - – Telephone: 08-5537 8556
  - – E-mail: ez@astro.su.se
- Course homepage:
  - – ttt.astro.su.se/~ez/kurs/Galaxies12.html

Course literature

- Galaxies in the Universe
  Linda S. Sparke & John S. Gallagher
  ISBN 9780521671866 (paperback)
  Around 350 SEK

Examination

- 3 sets of hand-in exercises
- Literature assignment:
  - –Written essay (≈ 3 pages)
  - –Oral presentation (≈ 10 minutes)
- 2 Seminars

But no written test!

Hand-in exercises I

- 27 exercises downloadable from the course homepage
- Around 18 exercises will be solved (by me) on the blackboard during the tutorials
- Remember: Much easier to grasp the solutions if you have already attempted to solve these, before going to class!

Hand-in exercises II

- 9 of the exercises are hand-in problems
- Somewhat similar to those solved on the blackboard
- 3 sets with deadlines: April 24, May 14, June 7
- Note: These are not compulsory – but successful solutions will boost your grade!

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 18
- Oral presentation, May 31 (≈ 10 minutes)
- What if you cannot attend?
  → Presentation at later time, possibly in front of the extragalactic research group…

Literature exercise

- Suggested topics:
  - The first stars
  - Origin of supermassive black holes
  - The role of galaxies in cosmic reionization
  - Tidal dwarf galaxies
  - Ultrafaint dwarfs
  - Ultracompact dwarfs
  - Pseudobulges
  - Extragalactic research with ALMA/JWST/E-ELT
  - Extragalactic background radiation (IR, X-rays…)
- But please feel free to suggest other topics!

Seminars

- Small “simulations” of what research is really like
- 2 Seminars:
  - 1. April 20, 13-15
  - 2. May 29, 10-12
- Instructions soon available from course homepage
- 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!)

Schedule

Complete schedule available on course homepage!

- 8 Lectures:
  - March 26, 10—12
  - March 27, 10—12
  - March 29, 10—12
  - March 30, 13—15
  - ← Note the gap
  - April 19, 10—12
  - April 26, 10—12
  - April 26, 13—15
  - ← Note the gap
  - May 14, 10—12
- 3 Tutorials:
  - April 16, 10—12
  - April 24, 10—12
  - May 16, 10—12

Grades I

- The total score P_{tot} determines the grade:

A: $P \geq 90$ % of max(P_{tot})
B: P=80-89.9 % of max(P_{tot})
C: P=70-79.9 % of max(P_{tot})
D: P=60-69.9 % of max(P_{tot})
E: P=50-59.9 % of max(P_{tot})
Fx: P=40-49.9 % of max(P_{tot})
F: P<40 % of max(P_{tot})

Grades II

- P_{tot} is made up of 5 components (with equal weights):
  1) Hand-in exercises
  2) Seminar 1
  3) Seminar 2
  4) Literature exercise, written report
  5) Literature exercise, oral report

Note: Failure to meet the deadline for any single component → The contribution from that component is automatically lowered by 20% of the maximum

Grades III

Example:

1) Hand-in exercises (max 15 p per set of hand-ins): 5 p, 10p, 12p
   But: Set 2 handed in late → Subtract 0.2*15 = 3
   Hence: 5p + (10-3)p + 12p = 24 p
   Contribution to total: 24/45 * 0.2 ≈ 0.11
2) Seminar 1: 3p (out of max 5p)
   Contribution to total: 3/5*0.2 = 0.12
3) Seminar 2: 4p (out of max 5p)
   Contribution to total: 4/5*0.2 = 0.16
4) Literature exercise, written report: 2p (out of max 5p)
   Contribution to total: 2/5*0.2 = 0.08
5) Literature exercise, oral report: 5p (out of max 5p)
   Contribution to total: 5/5*0.2 = 0.2

Total: 0.11 + 0.12 + 0.16 + 0.08 + 0.2 = 0.67 (i.e. 67%)
→ Grade D (interval 60-69.9%)

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

My estimates:

- Reading the textbook ≈ 1.25 weeks
- Attending lectures, tutorials, seminars etc. ≈ 0.75 weeks
- Problem sets ≈ 1 week
- Seminars ≈ 1 week
- Essay (written report + oral presentation) ≈ 1 week

Sum: 5 weeks, i.e. 7.5 hp

Where to cut corners

My estimates:

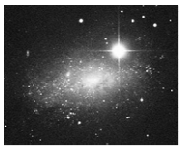
- Reading the textbook ≈ 1.25 weeks
- Attending lectures, tutorials, seminars etc. ≈ 0.75 weeks
- Problem sets ≈ 1 week ← 20% of grade
- Seminars ≈ 1 week 40% of grade
- Essay (written report + oral presentation) ≈ 1 week 40% of grade

Smartest strategy: Drop problem sets if stressed for time!

Course Outline

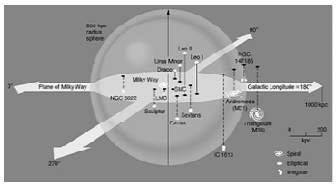
- Lecture 1:
  - Introduction
  - The Extragalactic Distance Ladder
  - Galaxy Classification





Course Outline

- Lecture 2:
  - The Local Universe
  - The Stellar Initial Mass Function
  - Star Formation Rate
  - Surface Brightness
  - The Spectral Energy Distribution of Galaxies
  - The Galaxy Luminosity Function

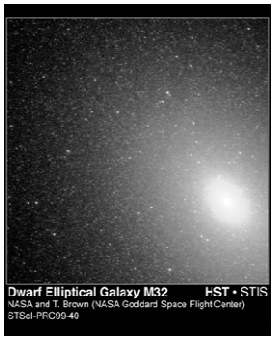


Course Outline

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

Course Outline

- Lecture 4:
  - Disk galaxies
  - Elliptical galaxies
  - Mass determinations

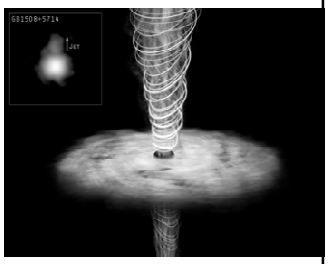


Course Outline

- Lecture 5:
  - Dwarf galaxies
  - Star Formation
  - Starburst Galaxies
  - Interacting & Merging Galaxies
  - Chemical Evolution

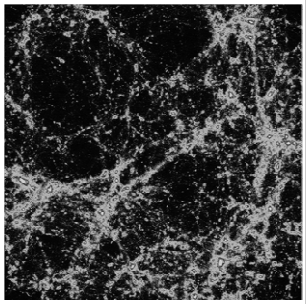
Course Outline

- Lecture 6:
  - Active galaxies:
    - Quasars
    - Blazars
    - Seyfert Galaxies
    - Radio Galaxies
  - Supermassive black holes



Course Outline

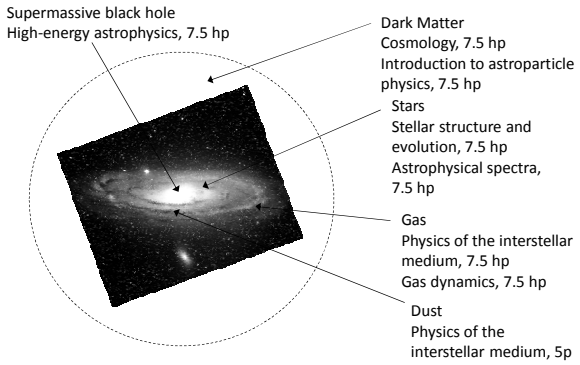
- Lecture 7:
  - Groups & Clusters of Galaxies
  - Large Scale Structure
  - The Intergalactic Medium
  - Gravitational Lensing



Course Outline

- Lecture 8:
  - The first stars and galaxies
  - Finding high-redshift objects
  - Reionization of the Universe

What is a Galaxy?

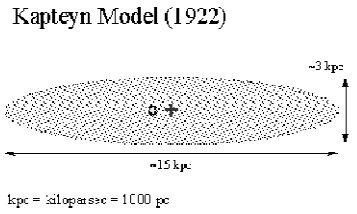


Historical Background: The Milky Way

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

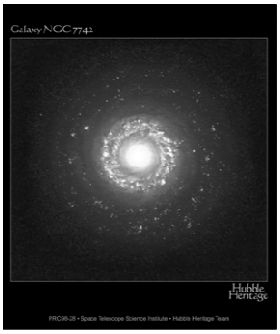


- Sun offset from centre
- Dust obscuration still not accounted for → wrong scale

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)

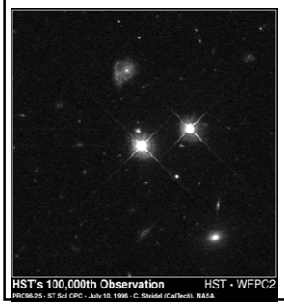
Historical Background: Active Galaxies

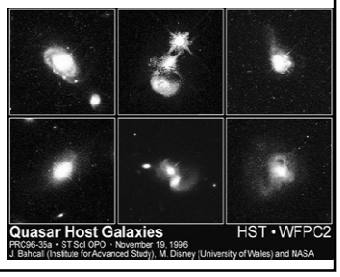


- 1943 - Seyfert Galaxies

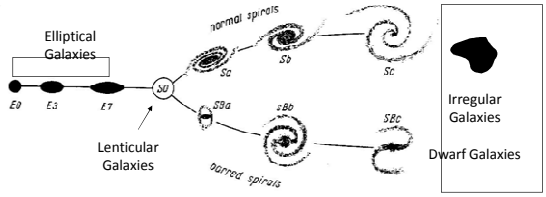
Historical Background: Quasars/QSO

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





Galaxy Classification The Hubble Tuning Fork



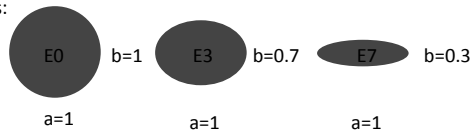
Other famous classification schemes:
- de Vaucoleur
- van den Bergh
- Vorontsov-Velyaminov

Galaxy Classification

Elliptical galaxies

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

Examples:

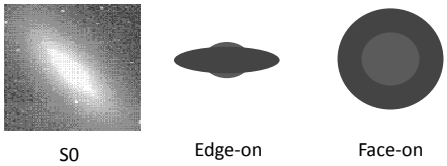


Galaxy Classification

Lenticular galaxies

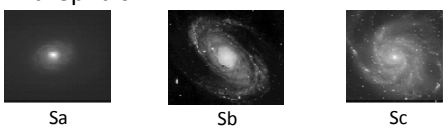
– Disk and central bulge, but no spiral arms
– SB0 if barred, S0 otherwise

Examples:



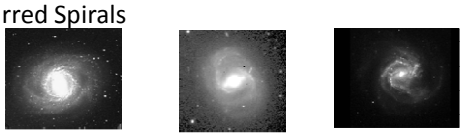
Galaxy Classification

Normal Spirals



Sa Sb Sc

Barred Spirals



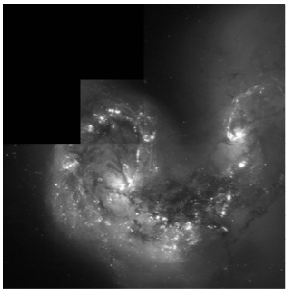
SBa SBb SBc

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

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

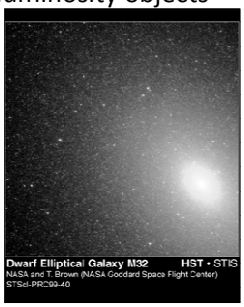
Galaxy Classification

Irregular galaxies (I)

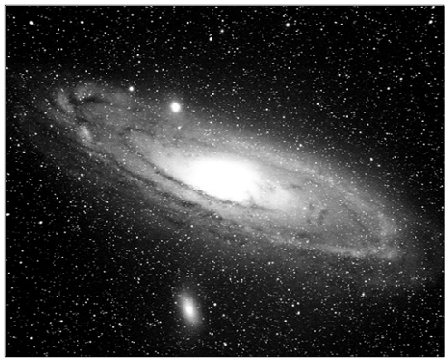


Galaxy Classification

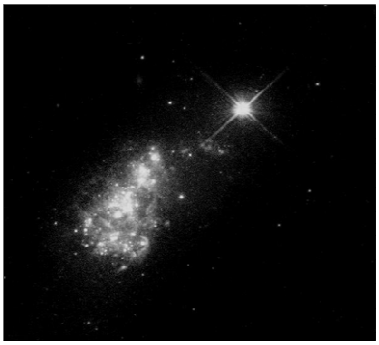
Dwarf galaxies (dE, dSph, dI…)
= Low-luminosity objects



Morphological Type?



Morphological Type?

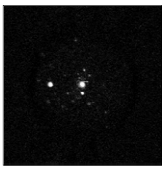


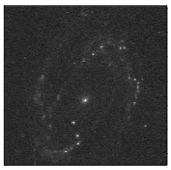
What is the Point of Morphological Classification?

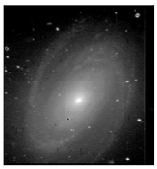
Hubble class correlates with:

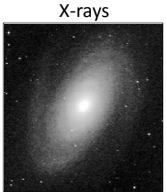
- –Gas content
- –Dust content
- –Star-forming properties
- –Spectrum
- –Metallicity

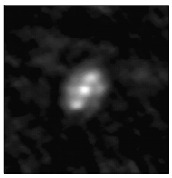
Morphological Complications


X-rays


UV


Optical


Near-IR


Far-IR

Same galaxy (M81) at different wavelengths!

Morphological Complications

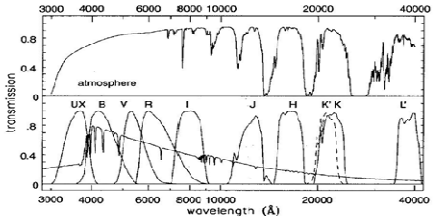
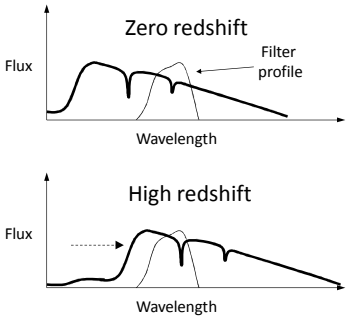


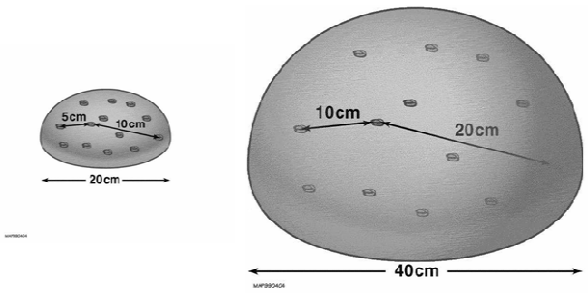
Figure 1.7 Above, atmospheric transmission in the optical and near-infrared. Below, flux F_λ of a model A0 star, with transmission curves $T(\lambda)$ for standard filters from Bessell, PASP 102, 1181; 1990. UX is a version of the U filter that takes account of atmospheric absorption. For $JHK'KL'$,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

Morphological Complications

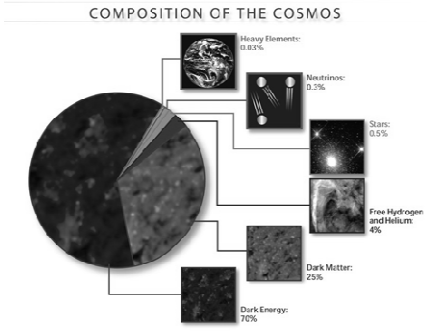


- Same filter probe different parts of spectrum at high and low redshifts
- Two galaxies with identical morphologies at a given rest wavelength may appear to have different morphologies

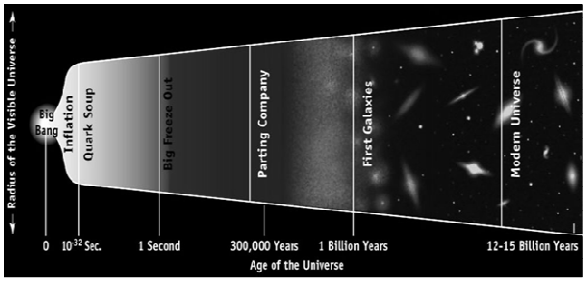
The Cosmological Framework I



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

The Cosmological Framework

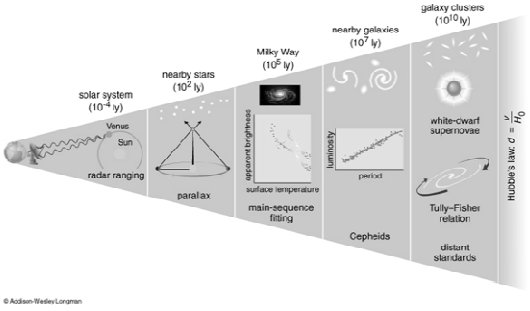
- Baryonic & Non-baryonic dark matter:
  - $\Omega_{Non\text{-}baryonic\ DM} = \Omega_M - \Omega_{Baryons} \approx 0.3 - 0.04 = 0.26$
  - $\Omega_{Baryonic\ DM} \approx 0.35\ \Omega_{Baryons} \approx 0.35 * 0.04 \approx 0.014$ (missing baryons)

or

  - $\Omega_{Baryonic\ DM} \approx \Omega_{Baryons} - \Omega_{Stars} \approx 0.04 - 0.0025 \approx 0.038$

    (Depending on what one considers to be "dark")

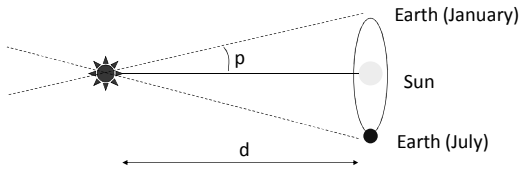
The Extragalactic Distance Ladder



Note: Outdated range estimates…

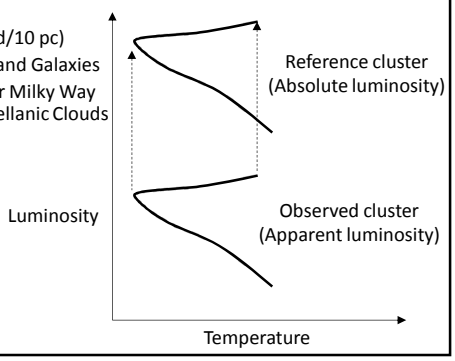
The Extragalactic Distance Ladder: Trigonometric Parallax

- d (pc) = 1 / p (arcsec)
- Currently applicable out to ~ 500 pc (closest stars)
- Satellites (e.g. Gaia) → Applicable out to 10000 pc



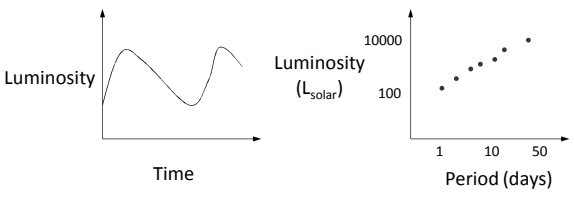
The Extragalactic Distance Ladder: Main-Sequence Fitting

- M=m - 5log (d/10 pc)
- Star clusters and Galaxies
- Applicable for Milky Way and the Magellanic Clouds



The Extragalactic Distance Ladder: Cepheid Variables

- Period → Luminosity (Absolute Magnitude) → Distance
- Applicable out to ~ 30 Mpc (slightly beyond the Virgo galaxy cluster)

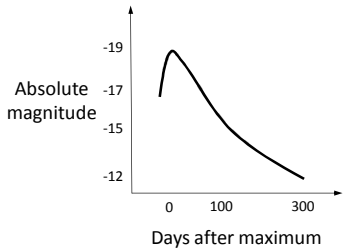


The Extragalactic Distance Ladder: Tully-Fisher / Faber-Jackson

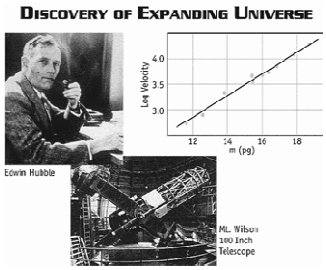
- Tully-Fisher: $L \propto v_{max}^4$ (for disk galaxies)
- Faber-Jackson: $L \propto \sigma_v^4$ (for elliptical galaxies)
- Applicable out to ~ 100 Mpc (the Coma galaxy cluster)

The Extragalactic Distance Ladder: SN Type Ia

- Applicable at least out to z≈2 (≈ 3000 Mpc)
- Formed in binary system in which matter from a red giant falls onto a white dwarf



The Extragalactic Distance Ladder: Hubble's Law



- $v = H_0 d$
- Note! Not a real velocity!
- Peculiar motions irrelevant at high distances
- $z \ll 1 \rightarrow v/c \approx z$
- Higher-order terms required at high redshifts