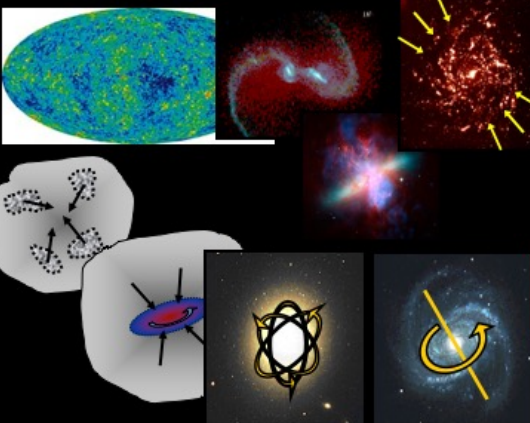


# GALAXY FORMATION AND EVOLUTION

Created by Peter Johansson, last modified on 2021-01-05

**PAP318, Galaxy formation and evolution, 5 op, Autumn, 2020**  
**Time and place: Fridays at 12.15-14.00 on Zoom,**  
**beginning 04.09.2020**  
**Lecturer: Peter Johansson**  
**Course assistants: Stuart McAlpine & Shihong Liao**  
**Homepage:**  
<https://wiki.helsinki.fi/display/astjournal/Galaxy+formation+and+evolution>

- The course will provide a thorough overview of galaxy formation theory and the essential observations required for understanding the galaxy population.
- Course material: Provided lecture notes and the textbooks "Galaxy formation" (Longair) and "Galaxy formation and evolution" (Mo, van den Bosch, White).
- Lecture course. Problem sets and Final exam.



Information about the course:

## PAP318 Galaxy formation and evolution (Galaksien synty ja kehitys)

Lecturer: Prof. Peter Johansson (Room D311)

Course assistant: Dr. Stuart McAlpine (Room D326) & Dr. Shihong Liao (Room D325)

**Lectures: Fridays 12.15-14.00. Due to the Corona virus situation this course will be organised as an online course, with all lectures given over Zoom. The problem sets will be appear on the course homepage and the problem set answers are returned by email to the course assistant.**

**Problem sessions: Fridays 14.15-16.00 in Zoom, every two weeks on the following dates: 18.9, 2.10, 16.10, 6.11, 20.11, 4.12**

**First lecture on 6.9.**

- In total 14 lectures (the last lecture is on 5.12.)
- Problem sets will appear on the course homepage every two weeks. Each problem set will contain 5 questions totalling  $6 \times 5 = 30$  questions.
- The minimum requirement for the problem sets is 1/3 of the points, surplus points will result in bonus points for the exam.
- Problem sets should be returned on Wednesdays every two weeks by email to the course assistant.

**Course material:**

- The primary course material will consist of the lecture notes provided by the lecturer.
- In addition parts of the two following books will be extensively used:
  1. M. Longair: *"Galaxy formation"*, 2nd ed. Springer, 2008
  2. H. Mo, F. van den Bosch & S. White: *"Galaxy formation and evolution"*, Cambridge Univ. Press, 2010

**Final exam:**

- **The final exam will be held on Friday 18.12.2020 at 10.00-14.30. The exam will be an open book home exam, with the answers returned by email.**

**Course dates and syllabus:****Lecture 1: 04.09.2020: "Introduction to galaxy formation and overview"**

- Basic elements of galaxy formation
- Galaxy formation timescales
- Historical review of galaxy formation theory

**Lecture 2: 11.09.2020: "Observations of galaxies"**

- The classification of galaxies
- Statistical properties of the galaxy population
- Galaxies at high redshifts

**Lecture 3: 18.09.2020: "Cosmology and the evolution of small perturbations" – Problem session 1**

- Robertson-Walker metric and the Friedmann equations
- The age of the Universe and cosmological distances
- The evolution of small perturbations

**Lecture 4: 25.09.2020: "Jeans' instabilities and horizons in an expanding Universe"**

- The Jeans' instability in a static and expanding Medium
- Instabilities in the relativistic case
- Cosmological horizons and perturbations on superhorizon scales

**Lecture 5: 02.10.2020: "Baryonic and dark matter models of galaxy formation" – Problem session 2**

- The sound speed and baryonic models of galaxy formation
- Adiabatic and isothermal perturbations
- Hot and cold dark matter in galaxy formation models

**Lecture 6: 09.10.2020: "Correlation functions and the spectrum of the initial fluctuations"**

- The two-point correlation function for galaxies
- The initial power spectrum
- Transfer functions

- 
- The non-linear collapse of density perturbations
  - Top-hat collapse and the Zeldovich approximation
  - The Press-Schechter mass function and dark matter density profiles
- 

### **Lecture 8: 30.10.2020: "Formation and evolution of gaseous haloes"**

- The cooling and heating of gas in dark matter haloes
- Radiative cooling and photoionization heating
- The cooling function and galaxy formation

### **Lecture 9: 06.11.2020: "Star formation and supernova feedback in galaxies" – Problem session 4**

- Molecular clouds and self-regulated star formation
- Empirical star formation laws
- Supernova feedback: The ejection and heating of gas

### **Lecture 10: 13.11.2020: "Formation of disk galaxies"**

- Observations: Mass components, angular momentum and rotation curves
- Formation of disk galaxies
- The origin of disk scaling relations

### **Lecture 11: 20.11.2010: "Galaxy interactions and transformations" – Problem session 5**

- Galaxy interactions and encounters
- Tidal stripping and dynamical friction
- Orbital decay and galaxy merging

### **Lecture 12: 27.11.2020: "Formation of elliptical galaxies"**

- Structure and dynamics of elliptical galaxies
- Formation of elliptical galaxies
- Observational constraints on formation scenarios

### **Lecture 13: 04.12.2020: "Formation of active galaxies" – Problem session 6**

- The physics of AGNs
- Formation and evolution of AGNs
- AGNs and galaxy formation

### **Lecture 14: Wed 9.12.2020 at 14.15, note the unusual time: "Summary lecture"**

- Summary of the main results.
  - Putting it all together.
  - How do galaxies form and evolve?
- 

### **Lectures:**

- **Lecture 1:** [galform\\_lecture1.pdf](#)

- **Lecture 4:** [galform\\_lecture4.pdf](#) [galform\\_lecture4\\_additional\\_notes.pdf](#)
- **Lecture 5:** [galform\\_lecture5.pdf](#) [galform\\_lecture5\\_additional\\_notes.pdf](#)
- **Lecture 6:** [galform\\_lecture6.pdf](#) [galform\\_lecture6\\_additional\\_notes.pdf](#)
- **Lecture 7:** [galform\\_lecture7.pdf](#) [galform\\_lecture7\\_additional\\_notes.pdf](#)
- **Lecture 8:** [galform\\_lecture8.pdf](#) [galform\\_lecture8\\_additional\\_notes.pdf](#)
- **Lecture 9:** [galform\\_lecture9.pdf](#) [galform\\_lecture9\\_additional\\_notes.pdf](#)
- **Lecture 10:** [galform\\_lecture10.pdf](#) [galform\\_lecture10\\_additional\\_notes.pdf](#)
- **Lecture 11:** [galform\\_lecture11.pdf](#) [galform\\_lecture11\\_additional\\_notes.pdf](#)
- **Lecture 12:** [galform\\_lecture12.pdf](#) [galform\\_lecture12\\_additional\\_notes.pdf](#)
- **Lecture 13:** [galform\\_lecture13.pdf](#) [galform\\_lecture13\\_additional\\_notes.pdf](#)
- **Lecture 14:** [galform\\_lecture14.pdf](#)

Videos showing the formation of disk galaxies also by the FIRE

collaboration: [http://www.tapir.caltech.edu/~phopkins/Site/animations/Movies\\_cosmo.html](http://www.tapir.caltech.edu/~phopkins/Site/animations/Movies_cosmo.html)

### Problem sets:

- **Problem set 1:** [galform\\_prob\\_1.pdf](#)
- **Link to article used in problem set 1:** [Stratman, C.M.S. et al., 2014, ApJL, 783, 14: "A Substantial Population of Massive Quiescent Galaxies at  \$z \sim 4\$  from ZFOURGE"](#)
- **Problem set 2:** [galform\\_prob\\_2.pdf](#)
- **Link to article used in problem set 2:** [Reichardt, C.L. et al., 2012, ApJL, 749, 9: "New Limits on Early Dark Energy from the South Pole Telescope"](#)
- **Problem set 3:** [galform\\_prob\\_3.pdf](#)
- **Link to article used in problem set 3:** [Guo, Q. et al., 2010, MNRAS, 404, 1111: "How do galaxies populate dark matter haloes?"](#)
- **Problem set 4:** [galform\\_prob\\_4.pdf](#)
- **Link to article used in problem set 4:** [Daddi, E. et al., 2010, ApJL, 714, 118: "Different Star Formation Laws for Disks Versus Starbursts at Low and High Redshifts"](#)
- **Problem set 5:** [galform\\_prob\\_5.pdf](#)
- **Link to article used in problem set 5:** [Guedes, J. et al., 2011, ApJ, 742, 76: "Forming Realistic Late-type Spirals in a  \$\Lambda\$ CDM Universe: The Eris Simulation"](#)
- **Problem set 6:** [galform\\_prob\\_6.pdf](#)
- **Link to article used in problem set 6:** [van Dokkum, P. & Conroy, C., 2010, Nature, 468, 940: "A substantial population of low-mass stars in luminous elliptical galaxies"](#)
- **Link to article used in problem set 6:** [Mortlock, D.J. et al., 2011, Nature, 474, 616: "A luminous quasar at a redshift of  \$z = 7.085\$ "](#)

### Final results and course grading:

- **Results from the problems sets:** [galform\\_problems\\_points\\_final\\_2020\\_public.pdf](#)
- **Final grades:** [Galform\\_results\\_2020\\_public.pdf](#)

### Set of equations that will be distributed in the exam:

- [equations\\_galform.pdf](#)