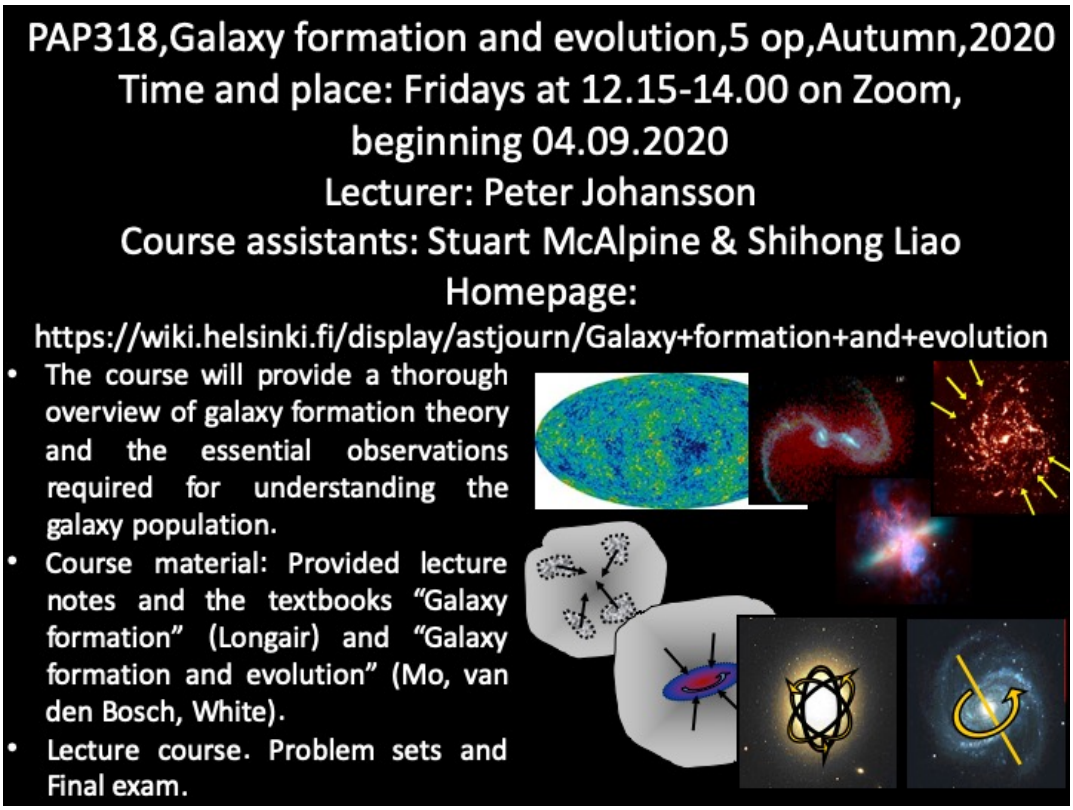
Galaxy formation and evolution



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 6x5=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.
- The problems consist of both regular exercises and problems based on journal articles.

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

Lecture 7: 16.10.2020: "Non-linear evolution of dark matter haloes" – Problem session 3

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

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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 2: galform_lecture2.pdf**
- **Lecture 3: galform_lecture3.pdf galform_lecture3_additional_notes.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

Problem sets:

- **Problem set 1: galform_prob_1.pdf**
- **Link to article used in problem set 1:** Straatman, C.M.S. et al., 2014, ApJL, 783, 14: **"A Substantial Population of Massive Quiescent Galaxies at z ~ 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 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**