Instructor: Prof. Frank van den Bosch  (Office: 52HH#320)
frank.vandenbosch@yale.edu

Course Website:  http:/campuspress.yale.edu/astro610/

Lecture Hours:  Mon-Wed 9.00-10.15am [KT 221]

Textbook:  Galaxy Formation & Evolution
Mo, van den Bosch & White (hereafter MBW)

Syllabus:  available on course website & canvas

Lecture Notes:  will be made available on course website

Grading:  40% Final Exam (oral)
30% Term Paper & Presentation (topic picked in class)
30% Problem Sets
Format: 24 lectures (see preliminary schedule)
2 classes with student presentations (week 14)

Requirements:
graduate student in physics or astronomy
familiarity with astronomy nomenclature (magn, Mpc, $H_0$)
basic knowledge of extra-galactic astronomy
(read chapter 2 of MBW)

My goal for you:
to teach you the physics related to galaxy formation
to teach you basic concepts & relevant nomenclature
to prepare you for research in extra-galactic astrophysics

What I expect from you:
participate actively in class (ask questions)
hand in problem sets on time
term paper (±8-10 pages on topic of current interest)
presentation in class (=online) on term paper
oral exam (1 hour, during exam period)
Good additional source of information. Somewhat less advanced than MBW. Does not cover the gasophysical processes of galaxy formation (cooling, star formation feedback) in any detail.

One of the best graduate textbooks on cosmology. Excellent coverage of Newtonian perturbation theory. Does not cover galaxy formation in any detail, though...
Detailed coverage of structure formation in the linear regime with superb treatment of relativistic perturbation theory. Nice chapter on likelihood analysis. Does not cover non-linear collapse, or galaxy formation.

A classic! Excellent textbook on dynamics. Has detailed information on equilibria, collisions and interactions of collisionless systems.
Additional Recommended Textbooks

Fairly new...an undergraduate companion to MBW. Excellent additional source of information, and very much up to date.

Good companion for MBW, with detailed treatment of reionization, first stars and 21cm cosmology.
Additional Recommended Textbooks

Excellent, brand new book on cosmology with detailed treatment of structure formation and large scale structure (including data analysis techniques).

Another fairly new and excellent book on cosmology and structure formation.
<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Topic</th>
<th>MBW</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Wed 01/17</td>
<td>Introduction; A Broad Brush Overview of Galaxy Formation</td>
<td>chapter 1</td>
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<td>1</td>
<td>Fri 01/19</td>
<td>Cosmology (Riemannian geometry, FRW metric, cosmological distances)</td>
<td>§3.1</td>
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<td>2</td>
<td>Mon 01/22</td>
<td>Relativistic Cosmology (GR, Friedmann eqs)</td>
<td>§3.2</td>
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<td>2</td>
<td>Wed 01/24</td>
<td>Newtonian Perturbation Theory: linearized fluid equations</td>
<td>§4.1</td>
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<td>3</td>
<td>Mon 01/29</td>
<td>Newtonian Perturbation Theory: baryonic perturbations</td>
<td>§4.1</td>
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<td>3</td>
<td>Wed 01/31</td>
<td>Newtonian Perturbation Theory: dark matter</td>
<td>§4.1</td>
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<td>4</td>
<td>Mon 02/05</td>
<td>Transfer Function and the Cosmic Microwave Background</td>
<td>§4.3 - §6.7</td>
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<td>4</td>
<td>Wed 02/07</td>
<td>Non-linear collapse and Relaxation</td>
<td>chapter 5</td>
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<td>5</td>
<td>Mon 02/12</td>
<td>Press-Schechter Theory, Excursion Set Formalism and Halo Mass Function</td>
<td>§7.2</td>
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<td>5</td>
<td>Wed 02/14</td>
<td>Merger Trees and Halo Bias</td>
<td>§6.1 - §6.2 - §6.5</td>
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<td>6</td>
<td>Mon 02/19</td>
<td>Structure of Dark Matter Halos</td>
<td>§7.3 - §7.4</td>
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<td>6</td>
<td>Wed 02/21</td>
<td>Large Scale Structure</td>
<td>§6.1 - §6.2 - §6.5</td>
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<td>7</td>
<td>Mon 02/26</td>
<td>Halo Model and Halo Occupation Statistics</td>
<td>§7.6 - §15.6</td>
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<td>7</td>
<td>Wed 02/28</td>
<td>Galaxy Interactions &amp; Transformations</td>
<td>chapter 12</td>
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<td>8</td>
<td>Mon 03/04</td>
<td>Cooling Processes &amp; Photo-Ionization Heating</td>
<td>§8.1 - §8.3 - §8.4</td>
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<td>8</td>
<td>Wed 03/06</td>
<td>Review of material covered so far [in class discussion]</td>
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<tr>
<td>9</td>
<td>Mon</td>
<td>03/11                NO CLASS: Spring Break</td>
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<td>Wed</td>
<td>03/13                NO CLASS: Spring Break</td>
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<td>10</td>
<td>Mon</td>
<td>03/18                NO CLASS: Spring Break</td>
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<td>Wed</td>
<td>03/20                NO CLASS: Spring Break</td>
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<td>11</td>
<td>Mon</td>
<td>03/25                Star Formation</td>
<td>§9.1 - §9.3 - §9.5</td>
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<td>11</td>
<td>Wed</td>
<td>03/27                Supernova Feedback</td>
<td>§8.6 - §10.5</td>
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<td>12</td>
<td>Mon</td>
<td>04/01                Structure and Formation of Disk Galaxies</td>
<td>chapter 11</td>
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<td>12</td>
<td>Wed</td>
<td>04/03                Structure and Formation of Elliptical Galaxies</td>
<td>chapter 13</td>
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<td>13</td>
<td>Mon</td>
<td>04/08                AGN and supermassive black holes</td>
<td>chapter 14</td>
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<tr>
<td>13</td>
<td>Wed</td>
<td>04/10                Numerical Simulations</td>
<td>App C</td>
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<td>14</td>
<td>Mon</td>
<td>04/15                Outstanding Issues in Galaxy Formation I</td>
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<tr>
<td>14</td>
<td>Wed</td>
<td>04/17                Outstanding Issues in Galaxy Formation II</td>
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<td>15</td>
<td>Mon</td>
<td>04/22                Student Presentations</td>
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<td>15</td>
<td>Wed</td>
<td>04/24                Student Presentations</td>
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Galaxy Formation in a Nutshell

- Big Bang
- Cosmic inflation
- Origin of fluctuations
- Particles form
- Recombination
- Dark ages
- First stars & galaxies
- Galaxy evolution
- Today

Timeline:
- 0 seconds
- 10^-32 seconds
- 1 second
- 100 seconds
- 1 year
- 100 years
- 380,000 years
- 200 million years
- 1 billion years
- 10 billion years
- 13.82 billion years

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Galaxy Formation in a Nutshell

- Super-horizon scales
- Jeans-stable
- Jeans-unstable
- Radiation-dominated
- Matter-dominated
- Linear growth
- Non-linear growth
- Stagnation
- Silk damping
- Galactic halo bias function
- Log[scale]
- Log[\delta_{MW}]
- Log[scale-factor]
- t_{eq}
- t_{dec}
- M~10^{15} M_{\odot}
- M~10^{12} M_{\odot}
- M~10^{6} M_{\odot}
- Silk damping
- Linear growth
- Non-linear growth
- Stagnation
- Silk damping
The halo bias function $\lambda$ in the Jeans-stable region.

Super-horizon scales $\lambda_{\text{H}}$, matter-dominated $\lambda_{\Lambda}$.

Log scale $\log[\text{scale}]$.

Jeans-stable, Jeans-unstable.

Radiation-dominated, matter-dominated.

Silk damping $\lambda_{\text{jbar}}$.

Log scale-factor $\log[\text{scale-factor}]$.

$t_{\text{eq}}$, $t_{\text{dec}}$.

Linear growth, non-linear collapse, virialization, Silk damping.

Dark matter, baryons.

Baryonic oscillations, stagnation, cooling, shock.

$M \sim 10^{15} M_\odot$, $M \sim 10^{12} M_\odot$, $M \sim 10^{6} M_\odot$. 

$\Lambda -3.5$, $\Lambda -3$, $\Lambda -0.3$.