SYLLABUS

OPTI 600K Cavity Optomechanics I (1 unit)

Spring 2019
2/14/19 – 3/27/19
M/W/F 11:00 – 11:50 AM
Location: Meinel 422

Description of Course

This course (1st in a two-module series) will introduce the field of cavity optomechanics. Early lessons will review mechanical resonators, optical cavities, and their coupling via radiation pressure. Detailed treatment will then be given to the canonical optomechanical system, a Fabry-Pérot cavity with a compliant end-mirror, leading to the concepts of radiation pressure dynamical back-action (optical stiffening and damping), stochastic back-action (radiation pressure shot noise), and the standard quantum limit for a continuous position measurement.

Course Prerequisites or Co-requisites

Students must have completed a course in graduate level quantum mechanics (e.g. OPTI-570 or equivalent). Students are furthermore encouraged to take OPTI-600G (1 unit, Laser Beams and Resonators), during the first 5 weeks of the term.

Instructor and Contact Information

Prof. Dalziel J. Wilson

Meinel 650

621-2584

dalziel@optics.arizona.edu

Office Hours:

Web information:

Course Format and Teaching Methods

Lecture only.

Course Objectives and Expected Learning Outcomes

Course objectives:

1. Provide students with a basic background in the physics of optical cavities, mechanical resonators, and their coupling via radiation pressure.
2. Develop a theoretical framework for studying coherent and stochastic radiation pressure effects in optical cavities.
3. Explore fundamental applications of optomechanical coupling, including trapping, cooling, and precision measurement of mechanical objects.
4. Formulate the standard quantum limit for an interferometric position measurement.

Expected learning outcomes:

Upon completion of this course, students will be able to:

1. Compute basic properties of mechanical and optical resonators, such as
    a. Effective mass & mode volume
    b. Resonance frequency & free spectral range
    c. Quality factor & finesse
    d. Thermal and vacuum noise spectra
2. Derive the coupled equations of motion for a driven cavity optomechanical system and use them to compute:
    a. The force sensitivity of a mechanical oscillator.
    b. The displacement sensitivity of an optical interferometer.
    c. Coherent (stiffening and damping) radiation pressure forces in an optical cavity.
3. Derive the standard quantum limit for a continuous position measurement.

Absence and Class Participation Policy

The UA's policy concerning Class Attendance, Participation, and Administrative Drops is available at: http://catalog.arizona.edu/policy/class-attendance-participation-and-administrative-drop

The UA policy regarding absences for any sincerely held religious belief, observance or practice will be accommodated where reasonable, http://policy.arizona.edu/human-resources/religious-accommodation-policy.

Absences pre-approved by the UA Dean of Students (or Dean Designee) will be honored. See: https://deanofstudents.arizona.edu/absences

Participating in the course and attending lectures and other course events are vital to the learning process. As such, attendance is required at all lectures and discussion section meetings. Students who miss class due to illness or emergency are required to bring documentation from their health-care provider or other relevant, professional third parties. Failure to submit third-party documentation will result in unexcused absences.

Required Texts or Readings

There are no required texts for the class, and class notes will be made available. Alternative reading sources will be referred to throughout the class and made available in the reading room and Science Library. As a starting point, the student is strongly recommended to download the recent review on cavity optomechanics by Aspelmeyer *et. al.* (Rev. Mod. Phys. **86**, 1391 (2014)).

Required or Special Materials

Students may find a symbolic programming language like *Mathematica* useful.

Assignments and Examinations: Schedule/Due Dates

The class will include weekly homework and a final exam.

Final Examination or Project

The date and time of the final exam or project, along with links to the Final Exam Regulations, https://www.registrar.arizona.edu/courses/final-examination-regulations-and-information, and Final Exam Schedule, http://www.registrar.arizona.edu/schedules/finals.htm

Grading Scale and Policies

The final grade will be based on weekly homework and a final exam.

Homework	50%
Final exam	50%
Total	100%

The grade will be determined according to the cumulative percentage earned such that 80-100% = A, 60-80% = B, 40-60% = C, 30-40% = D, below 30% = E.

Requests for incomplete (I) or withdrawal (W) must be made in accordance with University policies, which are available at http://catalog.arizona.edu/policy/grades-and-grading-system#incomplete and http://catalog.arizona.edu/policy/grades-and-grading-system#Withdrawal respectively.

Scheduled Topics/Activities

The intended topics to be included are as follows:

1. Introduction to cavity optomechanics, historical ties to gravitational wave astronomy and cold-atom phiscs
2. Basic properties of mechanical and optical resonators
3. Brownian motion: Fluctuation-dissipation theorem and the Langevin equation.
4. Optomechanical coupling: forms of radiation pressure in various optical cavities.
5. Input-output relations for an optical resonator: the transmission line model.
6. Coupled equations of motion for a cavity optomechanical system.
7. Coherent radiation pressure back-action: optical damping, stiffening, cooling, and amplification.
8. Stochastic radiation pressure back-action: radiation pressure shot noise (RPSN).
9. The Standard Quantum Limit of a continuous position measurement

The final exam date will be on the date set by the UA.

Classroom Behavior Policy

To foster a positive learning environment, students and instructors have a shared responsibility. We want a safe, welcoming, and inclusive environment where all of us feel comfortable with each other and where we can challenge ourselves to succeed. To that end, our focus is on the tasks at hand and not on extraneous activities (e.g., texting, chatting, reading a newspaper, making phone calls, web surfing, etc.).

Threatening Behavior Policy

The UA Threatening Behavior by Students Policy prohibits threats of physical harm to any member of the University community, including to oneself. See http://policy.arizona.edu/education-and-student-affairs/threatening-behavior-students.

Accessibility and Accommodations

At the University of Arizona we strive to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability or pregnancy, you are welcome to let me know so that we can discuss options. You are also encouraged to contact Disability Resources (520-621-3268) to explore reasonable accommodation.

If our class meets at a campus location: Please be aware that the accessible table and chairs in this room should remain available for students who find that standard classroom seating is not

usable.

Code of Academic Integrity

Students are encouraged to share intellectual views and discuss freely the principles and applications of course materials. However, graded work/exercises must be the product of independent effort unless otherwise instructed. Students are expected to adhere to the UA Code of Academic Integrity as described in the UA General Catalog. See: http://deanofstudents.arizona.edu/academic-integrity/students/academic-integrity.

The University Libraries have some excellent tips for avoiding plagiarism, available at http://new.library.arizona.edu/research/citing/plagiarism.

Selling class notes and/or other course materials to other students or to a third party for resale is not permitted without the instructor's express written consent. Violations to this and other course rules are subject to the Code of Academic Integrity and may result in course sanctions. Additionally, students who use D2L or UA e-mail to sell or buy these copyrighted materials are subject to Code of Conduct Violations for misuse of student e-mail addresses. This conduct may also constitute copyright infringement.

UA Nondiscrimination and Anti-harassment Policy

The University is committed to creating and maintaining an environment free of discrimination; see http://policy.arizona.edu/human-resources/nondiscrimination-and-anti-harassment-policy

Our classroom is a place where everyone is encouraged to express well-formed opinions and their reasons for those opinions. We also want to create a tolerant and open environment where such opinions can be expressed without resorting to bullying or discrimination of others.

Additional Resources for Students

UA Academic policies and procedures are available at http://catalog.arizona.edu/policies

Student Assistance and Advocacy information is available at http://deanofstudents.arizona.edu/student-assistance/students/student-assistance

Confidentiality of Student Records

http://www.registrar.arizona.edu/personal-information/family-educational-rights-and-privacy-act-1974-ferpa?topic=ferpa

Subject to Change Statement

Information contained in the course syllabus, other than the grade and absence policy, may be subject to change with advance notice, as deemed appropriate by the instructor.