APh 250 – Stochasticity and Resonance in Nanoscale Systems
California Institute of Technology
Spring Term 2020-21
9 units (3-0-6)

Instructor

- Prof. Sandra M. Troian
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Enrollment

- This course will be conducted in a "survey and seminar" style, which necessitates limited enrollment and active engagement by all attendees. Students are required to contact Prof. S. M. Troian by email *prior to registering for this course* in order to receive approval.

Meeting times

- Tuesdays and Thursdays 3:00 - 4:30 by Zoom.
  Alternative days/times may ultimately be selected depending on participants' schedules.

  Note: During the week of March 29, the instructor will Zoom individually with students to assist them in the selectioin of suitable technical papers for analysis and presentation. Student presentations are will commence the following week.

I. Course theme

Precise control over the motion of mass, momentum, heat or light in nanoscale systems requires fundamental understanding of the influence of stochastic fluctuations. By virtue of their size, ultra small systems maintain a very high surface to volume ratio - as such, interface mediated fluctuations can be especially important. To offer a few examples, membrane fluctuations in red blood cells are known to influence metabolic activity and interface shape. Vacuum electromagnetic fluctuations between solid substrates can give rise to Casimir forces which result in spontaneous net attraction leading to stiction, detrimental to operation of resonating fins. Thermal fluctuations in nanoscale films can induce spontaneous dewetting and island growth resembling spinodal decomposition. Many such nonlinear systems triggered by noise can spontaneously transition from uniform to inhomogeneous states, often resulting in pattern formation characterized by a preferred band of wave numbers. Stochasticity can also give rise to spontaneous resonant behavior. Typically the latter occurs in nonlinear systems where a weak signal can be boosted sufficiently to allow detection by application of white noise. Nonlinear systems, especially hydrodynamic ones, have been shown to exhibit a multiplicity of states in the presence of noise. These include among others, deterministic local dynamics that drive a field variable toward a uniform steady state, addition of a noisy component, that can drive the dynamics away from that state and diffusive spatial couplings which induce long range spatial coherence. In this course, we will explore the current literature and focus on how ambient or applied noise in nanoscale systems can induce coherent response.

II. Outcomes

Students working with the instructor will be assigned readings covering phenomena involving stochasticity and resonance in nanoscale systems. All participants are expected to debate the findings presented in order to place the work in context and distill from each reading the significant contribution. Actively debating the material will help students not only improve their oral presentation skills but also introduce them to the art of critiquing the technical literature, a skill worth honing for eventual refereeing of papers for professional journals.

III. Course protocol

This course will be conducted in "survey and seminar" style. Students will focus on a close reading of recent papers in the literature exploring the influence of stochasticity in small scale systems. In consultation with the instructor, students will select three or so published papers related to their research interests on which to focus during the entire term and through active participation and discussion learn how to evaluate and critique the approaches and findings reported. Supplemental readings will be assigned to provide background information to fill in knowledge gaps. Students can select to examine theoretical, experimental or numerical/simulation based publications depending on area of interest.

After a short preliminary discussion, each class will be devoted to a 20 min presentation by one or two students followed by an extensive discussion, question and answer period. Students can work in pairs if the number of registrants allows. Students are expected to provide concise summaries and informed critical opinions of the material reviewed. The frequency of these presentations will depend on the class size. Every student in the class will be required to deliver one or more presentations and to participate fully in discussions pertaining to their reviews and those of other students. Lively class discussions and critical commentary are essential to the success of this class. All students must therefore attend class "live" with cameras turned on and agree to active participation in order to facilitate contemporaneous discussion.

This class should provide students with an excellent opportunity to further their knowledge of the important influence of fluctuations and induced correlated motion in nanoscale systems. The course is also intended to teach students how to communicate in a substantive, compelling and concise fashion with a technically literate audience that may be unfamiliar with the particular topic but skilled in general analysis of physical principles. Since much of the material will be culled from recently published work, the student will also learn how to critique the technical literature and how to ascertain whether the findings and interpretations reported by the authors are supported by the evidence provided. A short final paper will also be assigned. Further details are provided below.

IV. Grading

This course is offered Pass/Fail - grades will be based on attendance and quality of class presentations, class participation and the final paper. Auditors are not allowed unless they agree to fully participate in the course although they will not be expected to write a final paper.

V. Instructor

This seminar course will be led by Prof. Sandra M. Troian. Be sure to contact her in advance of any class should you need assistance in identifying background material or in distributing material to course attendees.

VI. Final Paper

Throughout the term, students will be focusing on a comprehensive examination of a select set of recent technical papers in leading journals describing the influence of stochasticity on nanoscale systems. The presentations delivered to the class will consist of critical analysis of the procedures and conclusions reached by the authors reviewed. Students will be expected to dig deeply into the material to uncover potential dubious interpretations of results, errors in analysis, or flawed experimental designs that may have biased the data obtained.

For the final assignment, the student is expected to produce a short report offering summary and critique of the key papers reviewed during the term, along with original recommendations for future study. The length of the report cannot exceed 5 pages including figures but excluding references. The introduction of this report should explain clearly and concisely, with figures if helpful, the essential features of the phenomenon investigated and what are the advances claimed by the authors. The next section should address issues of scientific and/or mathematical validity and critical discussion of results and findings including identification of any “holes” in the arguments presented. The report should conclude with a set of detailed recommendations for future work designed to help resolve the problems identified.

In this final section, students are expected to describe specific and detailed theoretical, experimental or numerical avenues for future work in such a way as to persuade a critical reviewer of the merit of the research approach and soundness of the methods to be applied to the study. For this exercise, students should neglect the actual cost associated with the proposed program, although later in life financial constraints often limit the extent of a particular research plan.