Physics 650 – Spring Semester 2015
Research Methods in Physics & Astronomy

Instructors

This course is being taught this semester by three faculty members of the Department of Physics & Astronomy –

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Where and When

The class will meet Tuesday and Thursday from 5:30 to 6:45 PM in Natural Science 312, a conference room on the third floor of the Natural Science Building.

Objectives

This course is a survey of research methodologies that in this term are drawn primarily from optical physics, but are broadly applicable for graduate students who are engaged in doctoral level research. With the objective of providing useful tools and a perspective on how advanced scientific research is conducted, we will cover three topics:

1. Programming for data analysis, modeling, image processing, and instrument control (Kielkopf)

2. Lasers (Mendes)

3. Ultrafast optical phenomena (Smadici)

This is a required course for students in the doctoral program in Physics & Astronomy.

Requirements

Students should be enrolled in the graduate program in Physics & Astronomy or have comparable experience.

You are expected to

1. Attend and participate in all classes
2. Study the in-class, text, and on-line material for the topics
3. Respond in a timely way to homework assignments

Blackboard and other websites

The gateway for this course is the University's Blackboard system,

`http://blackboard.louisville.edu/`

which offers access to announcements and to grades. Your University *User ID* and *Password* are required to log into Blackboard.

An instructional site for the section on Python with other useful links is

`http://prancer.physics.louisville.edu/classes/650/`

For the section on lasers, you will find classnotes, homework assignments and solutions, exams and solutions, with additional literature here

`http://www.physics.louisville.edu/sbmendes/`

There may be other websites used in this class to support the topics covered, and they will be linked on Blackboard and described in class meetings.

Textbooks, software, and computer access

Topic 1 on computing has a required textbook:

Python in a Nutshell, 2nd Edition, O'Reilly, 2007, by Alex Martelli(ISBN 9780596100469). It is available inexpensively new and used from Amazon in paperback, and in a Kindle version, and from the publisher in various open E-book formats.

Topic 2 on lasers has a recommended textbook:

Fundamentals of Photonics, 2nd Edition, Wiley, 2012, by Bahaa E. A. Saleh (ISBN 9780471358329). It may be available in a recent paperback edition at lower cost than the original hardbound version. Some chapters and sections of the textbook will be omitted due to time constraints.

Other references for lasers are

- *Lasers*, Milonni and Eberly, 2nd edition, Wiley Interscience, 2010.

- *Laser Physics*, Simon Hooker and Colin Webb, Oxford Master Series in Atomic, Optical, and Laser Physics, 2010.
- *Laser Fundamentals*, Silfvast, 2nd edition, Prentice-Hall, 2004.
- *Principles of Lasers*, Svelto, 5th edition, Plenum Press, 2009.

You will need access to a computer connected to the Internet on which you can load and run software. Most laptop computers running OSX, Windows, or Linux will fill this need. Current tablet computers may not, because of operating system limitations. For those who prefer desktop access, the department's computing resources are available, including consoles in the astronomy lab, the computational physics cluster, and graduate student labs and offices. We do not require proprietary software, but we may ask that you install Open Source or free software.

Topic 1 – Programming – Kielkopf

In this topic we will introduce you to writing your own programs using Python with examples drawn from astronomy and astrophysics. We will discuss the merits (and pitfalls) of programming in contrast to using commercial or community-based programs, and compare commonly used languages and tools. Python was chosen for the course because it is free, flexible, and now widely used in physics, astronomy, space science, and engineering. We will use the time available to help you develop core skills that you can turn to in your own research. Prior experience with programming is not required, but the skills developed here may be useful if you want to explore other languages or programming systems.

Topic 2 – Lasers – Mendes

The laser is a ubiquitous tool present in many research labs and utilized in a wide range of technological applications. A good understanding on the peculiar features of laser light and how it is generated can be crucial for its proper applications. This section will introduce the basic theory and design of lasers. Topics to be discussed will include interaction of light and matter, stimulated and spontaneous emission processes, optical amplifiers, laser cavities, and Gaussian optical beams.

Topic 3 – Ultrafast optics – Smadici

The last topic of the course will be an introduction to ultrafast optics. We will demonstrate how the classical electrodynamics of wave propagation and the quantum mechanics of radiative transitions are applied in research. We will present how ultrafast pulses are generated and measured, and how they are applied in examinations of transient phenomena. The topic will conclude with an illustration of a practical application. Familiarity with optics at the level of an advanced undergraduate course will facilitate understanding but is not required.

Grades

This is a Pass/Fail course and it will be graded as an average of the 3 grades for each topic, assigned by the faculty teaching that topic.

Caveats

We reserve the right to make changes in the syllabus when necessary to meet learning objectives, or when there is a technical or software issue that requires a change in content or methodology. Any changes will be announced in class, by email, and posted in the current on-line syllabus and schedule.

Syllabus version of December 23, 2014

Schedule and Content

Programming

8 January Why program? Choosing a language. Simple Python.

13 January and 15 January Data types: numbers and strings, lists, tuples, and statements

20 January and 22 January Assignments, flow control and functions

27 January and 29 January Scientific computing with Numpy and Scipy, Fourier Transforms, and graphics

3 February and 5 February Handling image files and image processing

10 February Developing graphical user interfaces

Lasers

12 February Beam optics

17 February and 19 February Optical resonators

24 February and 26 February Photons and atoms

3 March and 5 March Optical amplifiers

10 March and 12 March Lasers operation and specific lasers

16 March to 22 March *Spring break*

Ultrafast Optics

24 March Femtosecond pulses and optics

26 March Ultrafast laser modelocking

31 March Non-linear optics and optical mixing

2 April Autocorrelation and pulse shaping

7 April FROG and Grenouille

9 April Grenouille laboratory

14 April Optical Bloch equations

16 April Pump-probe experiments

21 April Optical frequency combs