Astronomy 2 - Celestial Navigation: A Hands-on Tutorial

Fall 2023, Draft Syllabus and Course Information

(subject to change)

The registrar information above may not be correct. Class times are:

Tuesday and Thursday 12:00-1:15, plus evening lab (stars are not visible in the daytime). Tuesdays 7-10PM. Most session are taught "in lab," through team-based activities with little in the way of lecture or of "cookbook" style science experiments. Evening "labs" involve: telescope observation, planetarium experiences, use of sextants and other rnioght-time navigational devices.

Teaching Staff:

Instructor: Philip M. Sadler, Ed.D., psadler@cfa.harvard.edu

F.W. Wright Senior Lecturer in Astronomy

Obs. D-315, 617-496-4709;

Office hours, Wednesday 4:00-5:00

Head Teaching Assistant: Max Mulhern maximillian.mulhern@cfa.harvard.edu

617-571-4854

Office Hours, Friday 1030-1400

Schedule of Class Meetings:

Each student is expected to attend two Noon Labs and the one Evening Lab. If you are not feeling well or have a conflict, these labs should be made up by arrangement with one of the teaching fellows. All classes meet in the Science Center 106 or in the 8th for Astronomy room and outdoor deck with occasional displacement due to field trips.

Noon Lab: 12:00-1:15, Tuesday and Thursday

Evening Lab: 7:00 pm - 10:00 pm, Tuesdays

Key Dates in the Course (tentative):

First Class	9/3/24
Map Collection	10/22, 224/2024
Mid-term Exam	10/22/24
Poster Proposal Due	11/5/24
Cruise	depends on weather and ocean conditions: 10/12, 113/2024
Cruise Raindates	depends on weather and ocean conditions: 10/19, 20/20242
Instrument Collection	11/12/24, 11/14/24
Poster Paper Sessions	11/28/23 and 12/3/23

Final Exam Assigned by registrar 12/09-18/2024

See attached weekly schedule for topics and reading assignments.

What Makes Celestial Navigation Special?

â€œThis course teaches you how to learn science. It also teaches you to appreciate, understand, and use facts about the way the earth is and relates to surrounding objects. The teachers are knowledgeable, caring, and helpful, and the students are diverse and committed. This class will probably in the long-run be the one that means the most to my life and that I remember most clearly.â€ Astro 2 Student

Every culture throughout history has had to develop methods to find their way and map their world, whether applied to trade, warfare, or cultural survival. Technological advances have aided in increasing accuracy and the capacity to teach essential concepts and skills to the next generation. Many of the most sophisticated navigational methods of the modern age have roots deep in the past and retracing their development to the current day makes for a great historical narrative. Claims about the future direction of many modern methods, as well as the history of exploration, can better be understood by developing the traditional skills and knowledge of the navigator. The techniques learned can be employed in every corner of the globe and respect for the solutions of navigational and mapping problems by every culture provide a context for appreciating the ingenuity of traditional societies. Consideration of ethical dimensions of development and employment of more accurate and autonomous navigational techniques are considered as a cost of technological progress: in military weapons systems, for exacting exploration of untouched or sacred environments, and in their impacts on other species (e.g., bees, whales, birds). As a student of navigation, you will come to realize that that you are never truly lost (but perhaps, as Daniel Boone said,*â€â€¦ but I will admit to being confused for several weeks.â€),* that cues from the day or night sky, from simple instruments like compass or quadrant, and simple rules of thumb will establish your position and heading.

This is a course that produces a firm grounding in the physical world: the ability to map accurately, find your location, and proceed (almost) unerringly to a distant goal. Key concepts include the ability to measure important quantities, describing the world with increasingly accurate instruments, finding patterns among noise, and conducting long-term investigation of nature that reveal the secrets of its workings. From GPS and robotics to satellites and submarines, navigational issues permeate modern technologies. All are more thoroughly understood and perfected by understanding the underlying science, as well as being able to use them well and impact their future development.

In this course, the answer to the question many asked in high school classes will be revealed on a daily basis, *â€Of what practical use is algebra, geometry, trigonometry, or physics?â€* You will finally put to use the concepts and skills honed in high school math (no calculus necessary) and science and apply them to a plethora of fascinating problems, for example

- How do we keep animal migration from being impacted by humans?
- Can we live on a world without terrestrial magnetism?
- What are the limitations of models that serve to predict future events?
- How did the lodestone turn into the electric motor that powers the Tesla (and why does it carry that particular name)?

Using mathematics, we will develop the ways in which maps inform (and misinform) us, how motions in the sky form predictable patterns (and build quantitative models for their motion), and explore the development of instruments and methods that resonant in current technologies and systems. Alumni are adamant that they will never again take GPS or smartphone â€œmap appsâ€ for granted. These many issues and technologies share the same behind-the-scenes abstractions and quantitative tools as ships sailing the Atlantic, aircraft flying above it or submarines below it, and those who will eventually travel to Mars and beyond.

Many students have described Celestial Navigation as *â€œthe most hands-on course at Harvard.â€* Teaching is almost entirely experienced in a laboratory setting with constant day and night climbs to the roof for sextant and telescopic observation, time in the Astronomy Departmentâ€™s Starlab planetarium, field trips to Harvardâ€™s Historical Instrument Collection and Map Collection, and a day on the water navigating eastward until Boston sinks below the horizon (a good 40 miles) and returning to port. Past alumni have provided an endowment that furnishes students with their own navigational and mapping instruments and field trips. Teams of students present oral reports using artifacts from one of the universityâ€™s collections and a poster project applying knowledge learned to a topic of their own interest.

.

Several aspects of the courseâ€™s pedagogy are intended to allow students of vastly different skills, preparation, and interests to engage with the course in a variety of ways. All class sessions are interactive and hands on â€“ with short presentations offered by the instructor and a discussion when new topics are introduced. Each student is explicitly encouraged to follow their unique interests, inspired by those that they expect to pursue in life after college: whether they are recreational, hobbyist, professional, intellectual, historical, military, or involve the teaching of science or mathematics in formal or informal settings.

This is a course without physics or math prerequisites. High school math and science is all you need, but be prepared to use them often and use them well on a range of problems. We focus upon non-telescopic observation of patterns of motion in the sky and careful recordkeeping from week to week. You will build many of your own instruments from scratch and use them to solve navigational problems. This course starts from the most basic observations of the sky and builds up to accurate, reliable methods for navigation using the sun, moon, stars, and planets. This is not a fact-based course, but one in which concepts are learned from a multitude of approaches and skills are built to a high level of mastery through a mix of observation, calculation, and theory, with a heavy focus on the practical application of knowledge. Facts can be easily looked up, although memorizing a few key ones rarely hurts. Concepts must be learned and integrated into our own knowledge structures, while unproductive conceptions must be unlearned and abandoned. Skills must be acquired through "apprenticeship" with those who are expert and they must be practiced until they are near automatic. As one student summed up:

â€œThe subject matter is fascinating: the topics added to my understanding of the world I encounter every day. The teaching staff was phenomenal: each instructor brought a different perspective and balanced giving tips with letting students struggle. The students were great: everyone was interested and engaged in the laboratory activities. The field trips were enjoyable and useful: going out to see and into the museums added experiential and historical components to the course. The assignments were thoughtfully constructed: the cruises [i.e., problem sets] felt like adventures.â€

Work Load:

The workload in this course is substantive, although the â€œpayoffâ€ is great. In choosing to take this course, you should be sure that you can commit an appropriate amount of time to preparation for labs and completion of assignments. A strategy of "cramming for exams" is ineffective. Just as in a race on the ocean, you can't count on a huge effort at the last minute to get you to the finish line first. Slowand steady does it! A typical week requires:

Noon Lab	2.5 hrs
Evening Lab	2-3 hrs
Reading preparation for labs	1 hrs
Problem set	3 hrs
Journal	1 hr
Total weekly load	10 hrs

In addition, over the duration of the term you must complete a team project, study for exams, and prepare and present in one of the historical collections.

Student Selection:

This is a laboratory course and enrollment is limited to 25 students. We have not had to intentionally reduce the number of students in recent years, but if need be, students are selected to produce a class diverse in background and experience. One delightful aspect of the class is that it is quite heterogeneous. Freshmen, sophomores, juniors and seniors are usually represented. Graduate students from FAS, Education, Law, and Public Health, ROTC undergrads, post-docs, and Harvard staff are welcome and can also be found with some frequency.

Grading:

Students receive feedback for most course activities. The purpose for this is not to increase your stress level, but to give you continual support on what you are mastering and what it is you are missing. If you do poorly on a lab or problem set that you thought you had understood, please talk to the instructor or a teaching fellow. You may need a bit of extra help in learning a skill or concept. Take note that assignments not completed will hurt your grade. This is not a course in which you can skip classes or assignments with impunity. Every class builds on earlier ones and making up a lab that you miss is definitely worth the time. Your final grade in the course is determined by the following weights:

Course Component	Weight # of each

10% Class session attendance and participation

5% Oral report (either instrument or map)

20% Weekly problem sets (assignments)

10% Journal with summary (and some exam questions)

10% Term Project

15% Midterm Exam

30% Final Exam

Per university policy, graduate students must complete additional work to obtain graduate credit. This is usually in the form of a short paper that relates navigation to their chosen field or generation of a new or improved problem set or lab. These projects must be approved by the instructor. For example, students from the Graduate School of Education have prepared an in-depth critique of the pedagogy of the course with suggestions for improvement.

Collaboration Permitted in Written Work, Problem Sets, and Presentations

For assignments in this course, you may work with teammates in lab and on presentations, but all members should contribute equally. Presentations and labs are expected to be carried out in teams of 2, 3, or 4. You must also adhere to standard citation practices in this discipline and properly cite any books, articles, websites, lectures, etc. that have helped you with your work. If you received any help with your writing (feedback on drafts, etc.), you must also acknowledge this assistance.

Discussion and the exchange of ideas are essential to this course. For assignments, you are encouraged to consult with your classmates as you work on problem sets. However, make sure that you can work through the problem yourself and ensure that any answers you submit for evaluation are the result of your own efforts. You should not share the text of answers or have others plot on your charts. Each student should write their own answers in their own words. You may utilize other students' journal data in your journal entries and analysis, but you must credit them specifically. Journal data should be the results of your own measurements using compass and quadrant (or sextant). Data drawn from software, the web, or other sources cannot be passed off as your own observations. All observations are assumed to be yours unless otherwise noted by you in writing. When taking data as a team, each member should have a unique dataset (e.g. sextant, quadrant, compass, accelerometer, etc.) even though you are working together. This will require more than one set of observations or data runs. In addition, you must cite any books, articles, websites, lectures, etc. that have helped you with your work using appropriate citation practices. Similarly, you must list the names of students with whom you have collaborated on problem sets.

No Collaboration on Exams

All exams are completed individually. There is no collaboration or sharing allowed during exams. No computer programs or web tools are allowed for sight reduction; they must be completed by hand. Calculators can be used during exams for arithmetic and trig functions (if needed). Navigational instruments that are used for exams (e.g. sextants) should be return to their "zeroed" positions before being used by another student. Take-home exams (if permitted), must be completed without any outside help from classmates or others. Exams are "open book," but no sharing of books is allowed. You must have your own copy of the text for reference and your own nautical almanac. AI applications like ChatGPT cannot be used on exams. Instructors use software to check for noncompliance.

Required Books:

- 2023 Nautical Almanac, Yachtsmanâ€™s Edition
- Learn To Navigate, by F. Wright and C. Whitney (written especially for this course)
- Longitude, Dava Sobel

Materials distributed for free in class:

Charts: **1210 TR, North Atlantic Chart**

Required Equipment (provided by the course, but you may wish to invest in your own after trying all the options):

Lensatic Compass or other sighting compass ($5-$10)

Spiral (or similar) notebook for journal (5â€ x 8â€ or smaller).

2H, 3H or mechanical pencils, eraser.

parallel rule, two triangles, or rolling ruler (about $7)

drawing compass ($3 to $15)

dividers ($3-$10) (Staples, Charrette or Bob Slate)

Philosophy of this Course

Students who take Astronomy 2 offer a variety of reasons for enrolling. Many have some sailing experience and think it would be useful, safer, or even romantic to know more about navigation. Others have always wanted to know something about the movements and constellations of the sky and how they relate to the Earth. The history of science is of great interest to some and this course draws on Harvardâ€™s special status in development of American science. All will end up proficient in coastal and celestial navigation.

To teach navigation so that you can use it, explain it to others, and really understand it, the course must deal with your prior beliefs about the nature of the night sky and its motions, maps, coordinate systems, and direction-finding. It turns out that all of us have ideas about how the world works based on years of observation and interaction. Many of these ideas, however, fail to help us make accurate predictions. We spend time and effort in this course discussing what our conceptions are, whether they lead to correct predictions or not, and how to modify them if they are problematic. Keeping journals of the sky and making predictions of celestial events is a way to test our internal models against nature. The result of this way of learning is that you are more likely to reconstruct navigational techniques after a long period of dormancy. If the basic concepts are solidly implanted, the skills return quickly. This all is very interesting to students following Education Secondary or in graduate programs at Harvard's School of Education

Most of class time is spent in practical exercises. Students work with the tools of navigation: compass, sextant, watch, charts, and drawing instruments, to solve a multitude of navigational problems. Many exercises involve finding where the observer is from making terrestrial and celestial observations. As a result, students often can themselves judge their own mastery by comparing their calculated results with their actual position. Most of the time students work in small groups, cooperating with each other to solve problems that are difficult to solve alone. Those with more knowledge of the sky, sailing, or astronomy can contribute to their teammatesâ€™ learning. Many students who take Astronomy 2 will at some time in their lives have the responsibility to teach someone something, whether as a teacher, teaching fellow, parent, colleague, or supervisor. Experience in this course will not only highlight that â€œtellingâ€ is a particularly ineffective method of teaching, but there are a multitude of methods to more effectively and painlessly to get learning to occur.

Some students are attracted by the unconventional pedagogy of the course. There is very little lecturing; students learn navigation through a variety of active methods. I teach this course because I can mix the subject of navigation with a method of teaching that helps students retain skills for later use and make more sense of the world. For students who prefer to put in minimal time and then cram in the requisite knowledge just before exams, this course will be a disappointment. Skills such as using a sextant, plotting on a navigational chart, or measuring the positions and motions of stars take applying effort over a long period of time. Much like any skill that can become second nature (e.g., bicycle riding, playing a musical instrument, or still life drawing), navigation requires practice to gain proficiency. The guidance of the courseâ€™s instructors during class will be valuable in helping students develop the tacit knowledge necessary to master these skills. Students who miss classwork and fall behind on assignments cannot easily make up these losses by reading the textbook or asking classmates for pointers. Also, students who like to work alone will be frustrated in working with every other student over the term. An important part of the course is learning from other students, in lab, working together in study groups, preparing oral presentations, and making observations. Some say that this is a course designed for extroverts or, at least, â€œextrovert-wannabes.â€

Navigational techniques have helped build empires, win wars, and free those with the urge, to wander the seas safely in small boats. Graduates of this course have sailed around the world and soloed across the Atlantic. They have written articles about bees and ways of teaching science. With simple equipment, you too can safely plan and complete voyages. Navigation is a practical skill. Knowledge of celestial and coastal navigation will make you a desirable guest on a sailboat or can be parlayed into access to the bridge on the largest of ships. Many navigation courses teach navigation in a cookbook fashion in which students follow a series of rather cryptic steps. This is not such a course. By the end of the semester you should not only have mastered a variety of navigational skills, but be able to explain how they work and teach your friends and roommates (or whoever expresses interest). Graduates of this course have gone on to be teaching fellows and teachers of science.

The class provides field trips to take advantage of Harvardâ€™s unique assets. A visit to Harvardâ€™s Map Collection in Pusey Library allows students to view examples of the progression of representation of the Earthâ€™s surface resulting in todayâ€™s highly accurate charts of the seas. The Historical Instrument Collection possesses hundreds of navigational instruments that help illustrate the development of navigational technology during the past 200 years. Students are encouraged to utilize the University Archive for research on Harvardâ€™s navigational history and the Houghton Library to examine captainâ€™s logs of merchant, naval, and whaling vessels running back to 1780. Course alumni visit to reveal to students how best to keep a journal of the sky, how to plan and complete individual projects, and to share their experiences on the seas.

Preparation for Class

Students should prepare for each class by completing the required reading. You should be sufficiently familiar with any description of a technique to begin a lab on that topic. As an aid to preparing for class, I have included a sample discussion question for each class. Most classes will start with a discussion of the reading, so be prepared to contribute to the group on a summary of the reading.

Labs

The laboratories are the key element in this course. You are expected to attend them all and, if you miss any, make them up. The labs are well-planned and should end punctually, although a few may occasionally run over in the evening sessions.

Labs are usually worked on in teams of two or three students. Problems can be broken into manageable pieces and shared among group members, but each student should fill out his or her own lab sheet. The purpose of this group learning is that each student will learn more, not less, so it is important that everyone masters the material. It is expected that during the first half of the semester, you will work with new partners in every lab, until you have worked once with every student in the class. In this way, you will have enough knowledge about your classmates to choose (or avoid) partners for your oral presentation and your final project.

Lab sessions usually end with a discussion of the groupâ€™s findings. We attempt to answer outstanding questions and dispel misconceptions. You should plan on always staying for the full duration of the lab time. If you finish early, you can start on the problem set, help another team finish up, or do some other work until the group is ready to meet.

Two of the labs are field trips. You are require to present an oral report, with a partner, in one of the two collections. You will be able to select your artifact a few weeks earlier. Make sure you reserve your topic by signing up on the official list. You should start your research well before each of these trips. You will have 10 minutes to give your talk, with an additional 5 minutes to answer questions. You may wish to prepare an outline of your talk in the two collections with bibliographic references. You will be graded on this lab. We pay special attention to :

1. Clarity - Have you rehearsed your talk?
2. Conceptual Content - What is the depth of your understanding?
3. Familiarity with the artifact - Do you know it well?
4. Use of references - Have you sought out the relevant literature?
5. Organization of the talk - How well do you work as a team?
6. Brevity - Do you keep to the scheduled time limit?

Each oral report counts as a 2.5x lab grade due to the substantial preparation required. You and your partner(s) will receive the same grade.

Problem Sets

At the end of each evening lab, problem sets will be distributed and posted online. You have one week to complete it; it must be handed in at the next evening lab for full credit. Over the following week they will be corrected by the teaching fellows. Only papers that are perfect will receive the highest grade, so you should check them over before submitting them. Grades are assigned on the following basis:

Check plus	Highest quality: organized, correct, insightful
Check	Good work with minor errors or mistakes
Check minus	Many error, gaps, incomplete
No credit	not submitted or submitted with less than 70% correct

Journals

Students are expected to keep a journal of observations and thoughts about navigation for the first half of the course. This should be in a separate small bound notebook, pereferably one that has pages that can be used as graph paper. Make sure you buy a journal and start entries in the first week. The journal must be handed in for the first time at our second Tuesday class. Write only on the right-hand pages to allow room for comments by the instructors and leave an extra page between weeks. Date all entries.

Your journal should be brought to each noon class where you will hand it in for comment between the noon and evening sessions by the instructor. It is expected that students make at least two detailed observations each week and a prediction of what they expect to see in the future. Every week should include some reflection on a concept touched on in the lab or in the reading. During a month, you are expected to carry out *at least:*

1. Four measurements of sunrises (or sunsets).
2. Four measurements of consecutive daily observations of the Moon.
3. Four measurements of a planet against the background stars.
4. Two noon curves using a quadrant and compass.
5. One moon curve using a quadrant and compass.

During the term, students should engage in at least two additional investigations. A few examples from last year:

1. Exploration of compass deviation.
2. Alignment of campus buildings.
3. Fixes using a map and compass.
4. Preparation of a starchart using compass and protractor.

Journals are counted as a separate grade and are required. In the past, those students who invested time and energy in keeping good journals found the course (and the exams) much easier than those who did not keep extensive journals. In addition, there will be at least one question on the mid-term and final examination that can only be answered with information from your journal.

In the past, some students who are quite familiar with the night sky, such as those majoring in physics or astronomy thought that keeping a journal would be a trivial exercise. Be assured that it is not. Even if you understand some of the theories of celestial motion, predicting changes in the heavens is trying. You should attempt to confirm the theories in which you believe from your own observations.

Term Projects

Each student is expected to plan and complete a team â€œposterâ€ project related to coastal or celestial navigation with one or two partners. Your team should write a short outline of your proposed project and hand it in on the deadline noted above. You are free to suggest your own topic for approval, but it must fit in with some navigation topic (use the labs as a key) and use knowledge that you have gained from the course. Some possibilities for report topics are listed below. The instructor has some books and files that might be useful, otherwise you can find the needed materials in the Harvard libraries.

Projects are to be presented in â€œposterâ€ format in class. This means that you are expected to present your project orally using exhibits, models, diagrams, and graphs that are posted for display. In addition, you should include a short written description of your project and bibliography. Photographs and models should be on display at this time. Grading will take place at this session. Your grade is based on the same factors as the field trip oral reports, except for familiarity with the artifact. There is nothing to hand in to the instructor. Instead, the quality of your poster and presentation will be judged on:

1. Clarity of Presentation,
2. Conceptual Content,
3. Poster Quality,
4. Use of References, and
5. Organization of Project.

Be aware that projects that are thrown together a few days before the presentation usually fare quite poorly. Those that have been thought about for a month, required the location and assembly of various resources, and have been completed with enough time for reflection (and shown to your friends for feedback) do quite well. If you start early, you can use your journal to correspond with the instructor for feedback or you can meet with him during class, during office hours, or lunch with him after class. Occasionally students make the mistake of constructing an instrument and think that the project is over. If you choose to build something, the majority of the time you spend should be put into using the device to assess its performance.

Midterm Exam

There will be a single mid-term exam administered at an evening session. You are expected come on time. Only under exceptional conditions will a make-up exam be offered. This is an open book exam and you can bring any written materials you wish: text, homework assignments, labs, etc. In the past, some students have been hard pressed to complete the mid-term. Although this is an open book exam, you should be very practiced with the techniques you learned in lab and not overly reliant on the text. You should also be fluent in the use of the Nautical Almanac. This is an open book exam, but no use of navigation software, AI Chatbots, or access to the web is allowed.

Final Exam

There will be one final exam. It will cover the entire content of the course: problem sets, field trips, journals, class discussions, projects, the readings, and labs (especially celestial navigation). It will meet in an evening session. Only under exceptional conditions will a make-up exam be offered. If you have a problem with the date, talk to the instructor well ahead of time. This is also an open book exam, but no use of navigation software, AI Chatbots, or access to the web is allowed.

Academic Integrity

Any material submitted to meet course requirementsâ€”homework assignments, papers, projects, examinationsâ€—is expected to be a studentâ€™s own work. Collaboration on studying and on homework assignments is encouraged, but you must ensure that anything submitted is the result of your own work and reflects your own approach to the topic. Students must make note of any collaborators when submitting work.

Accommodations for students with disabilities

Students needing academic adjustments or accommodations because of a documented disability must present their Faculty Letter from the Accessible Education Office (AEO) and speak with the professor by the end of the second week of the term. Failure to do so may result in the Course Head's inability to respond in a timely manner. All discussions will remain confidential, although faculty will contact AEO to discuss appropriate implementation.

Syllabus Table F2023 2.1.docx