ASTR-3760: Solar and Space Physics CU Boulder Course Syllabus (Spring 2016)

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Course Times:	Mon., Wed., Fri., 9:00–9:50 am
Location:	Duane Physics, Room G-131
Course web page:	http://lcd-www.colorado.edu/∼axbr9098/teach/ASTR_3760
Office hours:	JILA A604: Mon. 10:00-11:00, Fri. 4:00–6:00, or by appointment

SUMMARY

The physics of the Sun and interplanetary space combines several key disciplines in astrophysics: stellar structure, radiation transport, magnetohydrodynamics, turbulence, etc. The Sun drives space weather, which affects not only spacecrafts in various ways, but it is also closely being monitored in aviation, by electric power companies, and even the military. Understanding the Sun is thus not only an exciting topic of research, but it has increasing practical relevance in our daily lives.

This course is an elective for the APS undergraduate major and minor. Pre-requisite (or co-requisite) courses include Modern Physics (PHYS-2130 or PHYS-2170), and Calculus 3 (MATH-2400 or APPM-2350). A recommended, but not required, pre-requisite is Electricity & Magnetism (PHYS-3310).

COURSE GOALS

At the end of the course, you should be able to:

- Define what a plasma is, and describe (mathematically) the basic properties of some important plasmas in our solar system.
- Employ order-of-magnitude physical reasoning to describe how energy flows from the core of the Sun to the surface of the Earth.
- Discuss how measurements in solar physics and space plasma physics are carried out.
- Describe to interested laypeople and family members what we can learn from solar & space physics, and how it affects our everyday life.

COURSE MATERIAL

Primary textbooks:

- *The Sun: An introduction,* by Michael Stix (Springer, 2002).
- *Understanding space weather and the physics behind it,* by Delores Knipp (McGraw-Hill, 2011).

In preparation of this course, I have benefitted from the material used in earlier years: Robert Ergun in 2007, Mark Rast in 2011, and in particular Steven Cranmer in 2015. I recommend looking at Steve's website for detailed information: `http://lasp.colorado.edu/~cranmer/astr_3760_sp2015.html`

GRADING

The final grade will be assembled from the following components:

5 Homework Sets	5/10
Midterm Exam	3/10
Final Project/Paper & Presentation	2/10
In-Class Engagement	1/10
Total	11/10

Each of these components is described in more detail below. Note the total grade comes to 11 out of 10 points. To produce the final grade, I will drop the lowest 1/10 of your score from either the homework sets, midterm exam, or final project. (The score for in-class engagement is not droppable.)

SCHEDULE OF TOPICS

The dates listed here for each set of topics are approximate. There will be an actively maintained web page that stays up-to-date on the topics to be covered in each class session. Below, each sub-topic is listed along with relevant chapters from Stix and Knipp. It is highly recommended that students become familiar with these topics before their discussion in class.

Week 1: Introduction

```
Mon 11 Jan  (homework 1 out)
            Knipp 1.1.1 Solar-terrestrial effects, Knipp 1.3 Kp values
            Stix 1 observational properties, (spectral) irradiance
Wed 13 Jan  Stix 1 cont'd, Knipp Box 2.5 (p.78)
            Stix 2 stellar structure eqns, radiation transport (i)
Fri 15 Jan  Stix 2.3.4 equation of state, ionization physics, nuclear reactions
```

Week 2: Internal structure

```
Wed 20 Jan  Stix 3.6 solar neutrinos, Knipp Box 2.2 (p.59)
Fri 22 Jan  Stix 2.3.7 opacity, Knipp 3.1.2 solar model
```

Week 3: Tools for solar observations

```
Mon 25 Jan  (homework 1 due, homework 2 out)
            Stix 3 observational techniques, Stix 3.6 pyrheliometer
Wed 27 Jan  visit to LASP (LSTR building, Lab. Space Tech. Res., TBC)
Fri 29 Jan  Stix 3.5 polarimetry
```

Week 4: Solar atmosphere

```
Mon  1 Feb  Stix 4 solar atmosphere, Stix 4.3.1 limb darkening
            Knipp 3.4.2 absorption interactions
Wed  3 Feb  Stix 5 linear waves, waves in inhomogeneous medium
Fri  5 Feb  Stix 5.3 global helioseismology
            Knipp Box 3.1 (p.96)
```

Mathematical learning benefits so far: ordinary differential equations, technique of linearization, partial differential equations with constant coefficients, stability and instability.

Week 5: Solar atmosphere and oscillations

```
Mon  8 Feb  (homework 2 due, homework 3 out)
            Stix 5.3.9 local helioseismology
Wed 10 Feb  Stix 5.2.4 gravity waves, Stix 6 convective instability
Fri 12 Feb  Stix 6 solar convection, mixing length theory, simulations
            Knipp 3.1.3 convection, Stix 7.4.3 meridional circulation
```

Week 6: Magnetic fields

```
Mon 15 Feb Stix 4.4 chemical abundance, simulations
Wed 17 Feb Knipp 1.4 Lorentz force, Knipp 6.2.2 charged particle trajectories
Fri 19 Feb Knipp 2.1 kinetic energy, Knipp 3.3.2 solar cycle
           Knipp 1.2.2 solar activity
```

Week 7: Magnetic fields (continued)

```
Mon 22 Feb  (homework 3 due, homework 4 out)
            Knipp 4.1 electric and magnetic fields
Wed 24 Feb  Knipp 4.1.3 Maxwell's equations, Stix 8.1.1
Fri 26 Feb  Knipp 4.2.2 Ohm's law, Knipp 4.3.1 frozen-in magnetic fields
            Stix 8.1.3 Frozen magnetic fields
```

Week 8: Solar cycle

```
Mon 29 Feb Stix 8.2 flux tubes, Stix 8.3 sunspots
Wed  2 Mar Knipp 6.4 magnetohydrodynamic equations, Knipp 3.5 waves
Fri  4 Mar Stix 8.4 solar cycle
```

Week 9: Solar dynamo

```
Mon  7 Mar  (homework 4 due, prep material for midterm exam)
            Stix 8.4.2 mean-field dynamo
Wed  9 Mar  Stix 8.4.4 magnetic helicity
Fri 11 Mar  dynamos, history, example
```

Week 10: Solar dynamo (continued)

```
Mon 14 Mar  questions on midterm exam
Wed 16 Mar  Midterm exam
Fri 18 Mar  Stix 8.4.4 dynamo waves, solar cycle
```

Week 11: Solar wind

```
Mon 28 Mar  (homework 5 out)
            Knipp 3.1.1 solar differential rotation
            Stix 7.4 solar rotation, differential rotation
Wed 30 Mar  Knipp 5.1.2 solar wind, critical points, iterative solutions
Fri  1 Apr  Knipp 5.1.4 Parker spiral, Knipp Box 10.6 (p.484)
            turbulence in solar wind, dimensional arguments
```

Week 12: Solar corona

```
Mon  4 Apr  Stix 9.1.1 solar chromosphere, Stix 9.1.3 corona
            Stix 9.2.1 heat conduction, coronal heating
Wed  6 Apr  Stix 9.3.4 prominences, reconnection, particle acceleration
Fri  8 Apr  Knipp 9.2.1 flares, Knipp 9.2.3 coronal mass ejections
```

Week 13: Coronal heating

```
Mon 11 Apr  (homework 5 due, prep material for final exam)
            Stix 9.3.5 magnetic braking
            Stix 9.4.2 heating by acoustic and magnetic waves
Wed 13 Apr  Stix 9.5.2 solar flares
Fri 15 Apr  Knipp 7.2.2 inner magnetosphere, Knipp 7.4.2 night side reconnection
            Knipp 11.2.2 magnetic substorms, Knipp 11.2.3 trapping regions
```

Week 14: Planetary magnetospheres

```
Mon 18 Apr  Knipp 5.2 solar wind interactions in the heliosphere,
            shocks, jump conditions
Wed 20 Apr  planetary magnetospheres
Fri 22 Apr  planetary magnetospheres (cont'd)
```

Week 15: Space weather impact

```
Mon 25 Apr  Knipp 9.1 Review of solar dynamo
Wed 27 Apr  Knipp 9.1.2 Review of sunspots and active regions
            Knipp 13.1 biological impact, Knipp Box 13.13 GICs
Fri 29 Apr  Last Day of Classes: discussion of sample exams
```

HOMEWORK SETS

There will be approximately five homework assignments distributed throughout the semester. A detailed schedule of distribution and due dates will be given out in class and posted on the course web page. All but one of them will be mostly mathematical "problem sets." The remaining one will be a mini-project to find a popular news article on a topic relevant to this course, and critique it. Requirements for this written critique will be handed out later.

Hardcopy submissions are preferred, but email is fine, too. Students choosing the latter option are encouraged to write out solutions long-hand (neatly!) and scan them. This way you won't be tempted to leave out intermediate steps when typing in equations.

Homeworks are due at the beginning of class on the dates to be given. However, since it is our top priority that students have sufficient time to learn from the homework sets, we will grant one lateness exception per student: One homework set can be turned in up to three business days late with no penalty. (Though please let me know, in person or email, if/when you'll be taking this option.) Any other homework that is late will incur a penalty of a 5% lower grade per business day that it is late.

MIDTERM EXAM

This will be more like a "two thirds of the way through the semester" exam, to be given in the week before Spring Break. There will be at least one full class period (maybe two) devoted to reviewing the relevant material prior to the exam. Details about its format will be forthcoming.

FINAL PROJECT OR PAPER

In lieu of a sit-down final exam, there will be a project or term paper that will enable you to explore a chosen topic in a bit more detail, and gain some extra experience with either scientific writing or computing. The project can involve either of the two following components (or, if you're ambitious, both):

- A written review of a topic relevant to the course, that goes beyond the material discussed in class. The paper must convey some background (i.e., how did we come to understand the topic), motivation (i.e., why is it relevant), and some quantitative exploration of the physics (i.e., some relevant equations). The length to aim for is about 10 double-spaced pages—i.e., about 2500 words—not counting the (required) bibliography.
- Some kind of mathematical or computational calculation that explores some topic relevant to the course. The types of things you could do include:

  a. exploring a wider "parameter space" of a textbook model,

  b. numerically solving an equation (that was presented in class) that has no analytic solution,

  b. constructing your own model or simulation,

  c. downloading and analyzing some publicly available data, or

  d. testing (or debunking?) the claims made in a recent paper.

  Feel free to use whatever tools you want (i.e., computing languages, software packages, output formats), but the whole thing—including source code and data—must be submitted.

Additional information, including lists of possible topic ideas and deadlines, will be distributed during the semester.

IN-CLASS ENGAGEMENT

Attendance is important, because frequently the class will separate either individually or into small groups. In these break-out sessions, you will work out some interesting implication, or draw some useful conclusion, from the lecture material. No written answers need to be submitted; just verbal discussion of the outcomes.

The grade for this component is essentially "try" or "not-try;" i.e., all you need to get your 1/10 (of the total grade) is to attend class regularly and show consistent engagement with the material. This can be demonstrated through asking questions in class, answering questions that someone else has raised, and/or participating actively in the break-out sessions.

ACADEMIC INTEGRITY

All students at CU Boulder are responsible for knowing and adhering to the academic integrity policy of this institution. Violations of this policy may include: cheating, plagiarism, aid of academic dishonesty, fabrication, lying, bribery, and threatening behavior. All incidents of academic misconduct will be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found to be in violation

of the academic integrity policy will be subject to both academic sanctions from the faculty member and non-academic sanctions (including but not limited to university probation, suspension, or expulsion).

For this course, I encourage you to discuss the assignments and topics with your fellow students. However, everything that is written up and submitted must be your own independent work. If you do collaborate with other students, a good time to split off from the group is when you start to write up your answers. If someone were to ask you questions about your work, you should be able to explain everything about how & why you did it the way you did.

STUDENTS WITH DISABILITIES

If you qualify for accommodations because of a disability, please submit to me a letter from Disability Services in a timely manner (for exam accommodations provide your letter at least one week prior to the exam) so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities, and they can be contacted at 303-492-8671, by e-mail (dsinfo@colorado.edu), or on the web (disabilityservices.colorado.edu).

RELIGIOUS OBSERVANCES

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. If you have religious obligations that result in schedule conflicts, please contact me in the first two weeks of class to make alternate arrangements.

DISCRIMINATION AND HARASSMENT

CU Boulder is committed to maintaining a positive learning, working, and living environment. The University of Colorado does not discriminate on the basis of race, color, national origin, sex, age, disability, creed, religion, sexual orientation, or veteran status in admission and access to, and treatment and employment in, its educational programs and activities. CU Boulder will not tolerate acts of discrimination or harassment based upon protected classes or related retaliation against or by any employee or student. For purposes of this CU Boulder policy, "protected classes" refers to race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, or veteran status. Individuals who believe they have been discriminated against should contact the Office of Discrimination and Harassment (ODH) at 303-492-2127 or the Office of Student Conduct (OSC) at 303-492-5550.

CLASSROOM BEHAVIOR

Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, color, culture, religion, creed, politics, veteran status, sexual orientation, gender, gender identity and gender expression, age, disability, and nationalities. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records.