ASTR 554 – Astrophysics of the Sun
Spring 2016

Instructor: Prof. Stephen Bradshaw (302 Herman Brown Hall, ext. 4045)
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Class Website: Owl Space
Lectures: Tuesday & Thursday, 9:25am – 10:40am, Location: TBA
Office Hours: After each class and by email appointment

Course Description

This graduate-level course focuses on the physics of the solar corona. The corona is a plasma laboratory within which an enormous variety of fascinating physical processes take place. Solar observatories can gather coronal data at very high spectral, spatial and temporal resolution, which gives us a large amount of information about its properties and morphology. By comparing observational data with predictions made by theoretical models we can gain an understanding of the physics of the solar corona. Furthermore, by studying the corona we not only gain insight into the corona itself, but also into a great range of related astrophysical phenomena.

The course will begin with a survey of the solar corona and its features of interest, based on state-of-the-art observations. We will then take a detailed look at the Extreme Ultra-Violet (EUV) and X-ray radiation which are characteristic of the solar corona, due its extremely high (> 1 MK) temperature. This will include an examination of the atomic processes that lead to the formation of emission lines and how spectroscopic diagnostics can be used to determine such fundamental quantities as the temperature, density, emission measure, filling factor, bulk flows and element abundances.

When we have developed an understanding of how the corona is observed and how its physical properties are derived from observations, we will look at theoretical treatments of coronal structures and processes. We will begin with hydrostatic approaches to understanding the physics of closed magnetic structures (coronal loops; the fundamental building block of the corona) and follow this by exploring hydrodynamic approaches to study in-depth the coronal heating and cooling cycle. We will then move on to open magnetic structures and discover the inevitability of solar and stellar winds as the expansion of hot coronae into the interstellar medium.

The reason for million degree coronal temperatures is one of the outstanding problems of modern astrophysics. In the final part of the course we will examine some of the most popular, contemporary theories of coronal heating and associated attempts to uncover observational clues to the physical mechanism responsible for such high temperatures.

This course will constitute a thorough treatment of the plasma physics of the solar corona. The emphasis will be on the practical application of the tools and techniques that we use to observe and learn about astrophysical plasmas.

Learning Outcomes

Upon successful completion of this course, participating students will be prepared to undertake research at the forefront of solar coronal physics. In particular, the students will be able to:

- Describe the various structures and phenomena observed in the solar atmosphere;
- Understand the atomic processes that form the solar EUV and X-ray spectrum;
- Use the emission spectrum to explain how different types of observations (e.g. imaging, spectral) are created by solar instrumentation;
- Use observational data and standard diagnostic techniques to calculate the properties of the plasma (e.g. temperature, density, emission measure, bulk velocity, non-thermal speeds);
- Explain how to interpret observational data to inform our understanding of the different kinds of structures and phenomena observed in the solar atmosphere;
- Demonstrate an understanding of the principles of hydrostatics and hydrodynamics as applied to the physics of plasmas;
- Find analytical and numerical solutions to the hydrostatic and hydrodynamic equations in various situations and using particular approximations;
- Apply the principles of hydrostatics and hydrodynamics to the structures and phenomena observed in the solar atmosphere to gain insight into the dominant forces and energy transport mechanisms;
- Appreciate the limitations of the fluid treatment of the solar atmosphere plasma;
- Derive the commonly used scaling laws that connect the heat input, maximum temperature, pressure, and length of coronal structures;
- Solve the steady-state hydrodynamic equations to find Parker's solution for the solar wind in 1, 2 and 3 dimensions;
- Find the classical "nanoflare" solution to heating the solar corona by magnetic reconnection from the magnetohydrodynamic equations.

Prerequisites

While much of the course material is reasonably self-contained, a background of courses at the undergraduate or graduate level in electromagnetism, atomic physics, plasma physics and fluid dynamics will be beneficial. A relatively high level of proficiency in calculus, and differential and partial differential equations will be necessary.

Course Textbook

There is no single, comprehensive textbook that covers all of the topics for this course to a suitable depth at the graduate level. I will be working to greater or lesser degrees from

Physics of the Solar Corona, by Aschwanden, published by Springer - Praxis, ISBN-10 3-540-30765-6

Principles of Magnetohydrodynamics with Applications to Laboratory and Astrophysical Plasmas, by Goedblood and Poedts, published by Cambridge University Press, ISBN-13 978-0-521-62607-1

Magnetic Reconnection, by Priest and Forbes, published by Cambridge University Press, ISBN-13 978-0-521-03394-7

Heliophysics: Plasma Physics of the Local Cosmos, Edited by Schrijver and Siscoe, published by Cambridge University Press, ISBN-13 978-0-521-11061-7

These books will be augmented by in-class lecture notes, hand-outs and published research papers that can be obtained from the SAO/NASA ADS website (http://adswww.harvard.edu).

Class Website

All course materials including problem sets and solutions, links to relevant websites, supplementary material, and class updates and announcements will be posted on the Owl Space page. It is the responsibility of the student to check Owl Space regularly for the most recent information concerning the class.

Special Needs

If you have a documented disability that requires special consideration for this class then please contact the professor as soon as possible to discuss your needs. Students with disabilities should also contact the Disability Support Services Office in the Ley Student Center (http://dss.rice.edu).

Assessment

Problem sets: Nine problem sets will be assigned during the semester (1 for every 3 classes). These will consist of problems based on the material covered in class. They may also be used to introduce additional (but related) topical material.

Review paper and presentation: To strengthen understanding of modern solar physics, and to allow the student to delve a little more deeply into a particular subject area than would otherwise be possible, students will write two review papers on a topic of current interest in solar physics. Each review paper will also form the basis of an in-class presentation of approximately 20 minutes (depending upon eventual number enrolled) duration. Presenting scientific material in an accessible and understandable manner to your peers is an extremely important skill to develop during graduate training. Therefore, students will grade each other's presentations.

Modeling project: Science at the graduate level is not a spectator sport and a short modeling project designed to solve a particular problem, to be determined by the professor, will be set. It will involve the numerical solution of a set of partial differential equations and it is therefore recommended that the student spend some time brushing up on their numerical analysis and programming skills before the project is set. The student may choose any suitable programming language to implement the model, but the code must be comprehensively commented / documented.

It is expected that each student will attempt each of the assessment tasks on their own. However, active discussion of any difficulties with classmates and the professor is perfectly acceptable to attain a clearer understanding of the issues, once the task has been attempted to the best of each student's ability.

The Honor Code applies to all assessment tasks. You can review Rice's Honor Council documentation online at: http://honor.rice.edu/index.cfm

Plagiarism will not be tolerated and the professor has no discretion about whether to report it. The procedure for dealing with cases of suspected plagiarism is manifestly unpleasant and stressful (for student and professor), and emphatically not worth the risk to your academic career and to your future. Your work should be clearly distinguishable from its sources and be a direct result of your own understanding of the material. For a guide to what constitutes plagiarism and how to avoid it please consult the Honor Council's document concerning academic fraud: http://honor.rice.edu/bluebook.cfm?doc_id=10355

Grading

Task	Total Points	Weighting
9 problem sets × 40 points each	360	34%
2 review papers and presentations × 100 points each	200	33%
1 modeling project	100	33%

The overall score (S) will be calculated from the total score for each task, with the appropriate weighting. The letter grade will be determined from the overall score (S) by:

$$S \geq 90\% \text{ (A)};\ 80\% \leq S < 90\% \text{ (B)};\ 70\% \leq S < 80\% \text{ (C)};\ 60\% \leq S < 70\% \text{ (D)};\ < 60\% \text{ (F)}$$

Class Schedule (may be subject to change)

<u>January</u>

(1) Tuesday 12th - General properties of the solar corona
(2) Thursday 14th - Coronal EUV and X-ray radiation
(3) Tuesday 19th - Coronal EUV and X-ray radiation
(4) Thursday 21st - Coronal EUV and X-ray radiation
(5) Tuesday 26th - Coronal EUV and X-ray radiation
(6) Thursday 28th - Coronal EUV and X-ray radiation

<u>February</u>

(7) Tuesday 2nd - Coronal EUV and X-ray radiation
(8) Thursday 4th - Coronal hydrostatics
(9) Tuesday 9th - Coronal hydrostatics
(10) Thursday 11th - Coronal hydrostatics
(11) Tuesday 16th - Coronal hydrostatics
(12) Thursday 18th - Coronal hydrostatics
(13) Tuesday 23rd - Coronal hydrostatics
(14) Thursday 25th - *Student presentations*

<u>March</u>

Tuesday 1st - SPRING BREAK
Thursday 3rd - SPRING BREAK
(15) Tuesday 8th - Coronal hydrodynamics
(16) Thursday 10th - Coronal hydrodynamics
(17) Tuesday 15th - Coronal hydrodynamics
(18) Thursday 17th - Coronal hydrodynamics
(19) Tuesday 22nd - Coronal hydrodynamics
(20) Thursday 24th - Coronal hydrodynamics

(21) Tuesday 29th	-	Coronal hydrodynamics
Thursday 31st	**-**	**MIDTERM RECESS**

April

(22) Tuesday 5th	-	Solar wind
(23) Thursday 7th	-	Solar wind
(24) Tuesday 12th	-	Solar wind
(25) Thursday 14th	-	Coronal heating
(26) Tuesday 19th	-	Coronal heating
(27) Thursday 21st	-	*Student presentations*

Summary of Deadlines

January

(4) Thursday 21st	-	Problem set 1 (C1-3) distributed

February

(7) Tuesday 2nd	-	Problem set 1 due. Problem set 2 (C4-6) distributed
(10) Thursday 11th	-	Problem set 2 due. Problem set 3 (C7-9) distributed
(13) Tuesday 23rd	-	Problem set 3 due. Problem set 4 (C10-12) distributed First review paper due

March

(16) Thursday 10th	-	Problem set 4 due. Problem set 5 (C13-15) distributed
(19) Tuesday 22nd	-	Problem set 5 due. Problem set 6 (C16-18) distributed
(20) Thursday 24th	-	Modeling project due

April

(22) Tuesday 5th	-	Problem set 6 due. Problem set 7 (C19-21) distributed
(25) Thursday 14th	-	Problem set 7 due. Problem set 8 (C22-24) distributed
(26) Tuesday 19th	-	Second review paper due
(27) Thursday 21st	-	Problem set 8 due. Problem set 9 (C25-27) distributed

May

Wednesday 4th	-	Problem set 9 due no later than 5pm

(CX-Y indicates that the questions will be based on the material covered in classes X to Y)