Star and Planets

– Syllabus (updated Jan 2025) –

Instructor: Chris W. Ormel
email: chrisormel@tsinghua.edu.cn

Course description and Goals

Stars are the objects that have enabled us to learn how our universe works. There may be over 10^{22} stars in the universe and modern estimates indicate that most of these stars are accompanied by planets. This course aims to understand the formation, structure, and observational properties of stars and planets from elementary physical principles. Questions that will be addressed include: why do stars have a mass of about 1 solar mass, which conditions must be met for nuclear fusion, why are stars stable, how do planets form and what determines the size and composition of planets, how can we detect exoplanets, how do planetary bodies influence each other? In addressing these questions, the student will learn and apply a great number of concepts that shape our modern understanding of these objects.

This course is organized along seven modules. In no particular order:

1. Light
2. Exoplanet detection techniques
3. Matter under astrophysical conditions
4. Planet and stellar Birth
5. Stellar Evolution and Death
6. Planet Dynamics
7. Numerical integration of two, three-, and N-body problems (if time permits)
8. Planet and Stellar atmospheres (if time permits)

Student participation and problem sets are essential components of the course. The classical instruction will be further supplemented by student presentations of a mini research project. For this project, students will conduct numerical integrations on a topic of their choice within the field of planet or stellar gravitational dynamics.

恒星是了解宇宙如何运作的基础。宇宙中有超过 10^22 颗恒星，而现今的估测显示大多数恒星周围都有行星作伴。本课程将从基本物理原理出发讲解恒星和行星的形成过程，结构以及观测性质。本课将回答以下问题：为什么恒星的质量大都在一个太阳质量附近？恒星核聚变的条件是什么？为什么恒星能稳定存在？行星是如何形成的，什么决定了它们的大小和组分？怎样探测系外行星，行星之前如何相互作用？在尝试解答这些问题的同时，学生将学习并应用大量天体物理概念，这些概念塑造了我们对这些天体的现代理解。本课程的内容将分成如下几部分：

1. 光

2. 系外行星探测方法
3. 天体物理环境下的物质基本性质
4. 行星和恒星的诞生
5. 恒星的演化和死亡
6. 恒星和行星大气
7. 行星动力学

本课程中，学生将深度参与课堂互动，并完成课后练习题。除课堂讲授外，学生将在期末选择一个有关恒星与行星的题目撰写学习报告并进行课堂展示

Lecture Plan (by week)

The intended weekly lecture plan, subject to slight changes is:

1. Course Overview

2. Module **I. Light –** Black body radiation, magnitudes, distance measurements, the Hertzsprung-Russell diagram, stellar classification

3. Module **II. Exoplanets –** exoplanet demographics, Doppler spectroscopy, astrometry, microlensing, transits, direct imaging

4. Module **III. Planet Dynamics I –** the two body problem and Kepler orbit solution, guiding center approximation, resonances. Numerical gravitational dynamics.

5. Module **IV. Matter under Astrophysical Conditions –** equation of state (ideal, degenerate, radiation), mean molecular weight, hydrostatic balance, polytropes, white dwarfs, Chandrasekhar mass, stellar energy sources, nuclear fusion, stellar nucleosynthesis

6. Continue with III. Matter under Astrophysical Conditions

7. Module **V. Planet and Stellar Birth –** virial theorem, Jeans mass, free-fall time, Eddington luminosity, initial mass function, dispersion analysis, Toomre-Q stability criterion, structure of planet-forming disks, core accretion model for planet formation

8. Continue with IV. Planet and Stellar Birth

9. Module **VI. Stellar Evolution and Death –** opacity, diffusion, radiative and convective energy transport, stellar structure equations, homology relations, elements of stellar evolution

10. Continue with V. Stellar Evolution and Death

11. Module **VII. Planet Dynamics II –** the three-body problem, Lagrange points, tides, Earth-Moon system

12. Continue with VII. Planet Dynamics II

13. Student Presentations

14. Student Presentations

15. Optional module **VIII. Atmospheres –** Boltzmann and Saha distributions; atomic, vibrational and molecular line emission, hydrogen spectrum, stellar classification, planet atmospheres and the greenhouse effect.

Requirements

It is recommended that students have followed basic mathematics and physical courses. Apart from following the lectures, students must be prepared to commit a significant amount of effort towards self study and problem solving. This course is aimed towards students in physical sciences, engineering, mathematics, and computational sciences. It is not recommended that students from social sciences and humanities follow this course.

Evaluation

Problem solving plays an instrumental part of the course. The classical instruction will be further supplemented by a presentation by students on a topic of their choosing related to the field of stars and planets. There is a final exam. The grade composition, subject to minor changes, is:

- problem sets: 20%
- student presentation: 20%
- in-class quizzes: 10%
- final exam: 30%
- report: 20%

Teaching methods and lecture material

Teaching is delivered through a combination of blackboard instruction and HTML presentations. The lecture notes from these presentations will be available online. Solutions to the problem sets will be discussed in class. Several days will be reserved for presentations by students on their mini-research topic.

The main reference book of this course is:

An Introduction to Modern Astrophysics
– 2nd edition; Carroll & Ostlie (2006)
ISBN-13: 978-0805304022
ISBN-10: 0805304029

Supporting text books are:

Stellar Structure and Evolution (Astronomy and Astrophysics Library)
Kippenhahn & Weigert, Springer (1996)

The Astrophysics of Planet Formation
Armitage, Cambridge University Press (2009)

Solar System Dynamics
Murray & Dermott, Cambridge University Press (1999)