The Cosmos: A Survey of Modern Astronomy
Syllabus

Deep Springs College
Prof. Brian Hill
Academic Year 2020-2021, Terms 5 & 6

June 27th, 2021 (additional materials at brianhill.github.io/astronomy)

Overview

The goal of the discipline of astronomy is to understand the great variety of astronomical observations in terms of the rather few principles of physics. Understanding astronomical observations from physics turns out to be a two-way street. Some of the principles of physics — for example, Newton's Law of Universal Gravitation — were deduced from astronomical observations in combination with laboratory physics experiments.

To do justice to the subject and to the scientific method, the class will use mathematics, but the mathematics will be limited to algebra and trigonometry. Every physics theory that we are confident of, we are confident of precisely because it has been tested quantitatively as well as qualitatively. Theories that are motivated principally by esthetic considerations, or that only give qualitative answers, have generally turned out to be embarrassingly wrong.

The course will first focus on fundamentals such as the light and the black-body spectrum, the astronomical coordinate system, the motion of objects within our solar system, and the composition of Earth and the other planets. It will then proceed to our understanding of the nearby stars and the rest of our galaxy. At each step along the way we will emphasize not just what is known, but how it has been determined through the interplay of theory and observation.

With these fundamentals, you will be prepared to move farther out into the cosmos, starting with what is known about nearby galaxies, then moving to the evidence for the Big Bang. Near the end of the course, we will get to the complications of the properties of galaxies and the expansion since the Big Bang that can only be explained by dark matter and dark energy.

Hands-On Special Projects

The course will also have a hands-on component. Pairs of students will do a special project from among the many that are possible with a 130mm refractor, a high-performance CMOS sensor, and research-grade software to control the equipment and analyze data. Possible projects include astrophotography of galaxies and nebulae, imaging of planets, and variable star observation.

Materials

We will rely on the latest edition of a textbook with a fully modern perspective. In a semester-long course most, but not all, of the textbook can be covered.

- *The Cosmos: Astronomy in the New Millennium*, 5th Edition, Jay M. Pasachoff and Alex Filippenko, Cambridge University Press, 2019.
- Will be adding a history book, such as *Miss Leavitt's Stars*, by George Johnson, or perhaps original reading, such as *The Starry Messenger* by Galileo Galilei.
- Will be adding literature or science fiction, such as a critique of *Interstellar*.

Unit Outline

I. Light, Matter, Energy

Units, Scientific Notation
Light, Frequency, Waves, Color, Matter, Temperature, and Energy

II. Solar System Motions

The Motions of the Earth, the Moon, and the Planets
The Scale of the Solar System
Kepler's Laws

III. Supplementary Materials (parallel with Units I, II, and IV)

Venus in Transit by Eli Maor
The Friendly Stars by Martha Evans

==== First Midterm ====

Newton's Laws of Motion
Newton's Law of Universal Gravitation

IV. The Composition and Properties of Our Solar System and Others

The Rocky Planets
The Gas Giants
Asteroid Belt
Kuiper Belt
Exoplanets

==== Term 5/6 Break ====

V. Stars and the Galaxy

Hertzsprung-Russell Diagram
Novas, Planetary Nebula, White Dwarfs

==== Second Midterm ====

Supernovas, Neutron Stars, Pulsars, Gravitational Waves
Black Holes

VI. Galaxies and the Cosmos

The Milky Way Galaxy and the Magellanic Clouds
Other Galaxies
Active Galactic Nuclei

==== Presentation of Special Project ====

The Big Bang

==== Last Midterm (no further exams!) ====

Dark Matter, Dark Energy, and Particle Physics

Daily Schedules

- Daily Schedule Term 5 (link to online page)
- Daily Schedule Term 6 (link to online page)

Exams and Grades

All three exams will be "midterms" since none of them are coming at the very end of a term. The dates are: Friday, April 9; Friday, May 21; Friday, June 18. The midterms will be designed to be done in 45 minute so that we can continue developing new material after each of them. The Special Project presentations will be in early June (tentatively, Tuesday, June 8th). The course will be graded 35% on problem sets (of which there will be an average of one every week), 20% on the special project, and 15% on each of the three midterms.

Requirements and Suggestions for Doing Problem Sets and Scientific Reading

Problem sets must be on 8 1/2 x 11 paper, stapled, with name, problem set #, and due date (a lot of this is for the professor's benefit). People that work in pen usually make mistakes and messes. I recommend working in pencil, rubbing out mistakes completely, and recopying work that gets convoluted due to wrong turns. I will supply complete solutions to all problem sets.

When you sit down to do problems, if the problem has a description with no diagram, it really helps to make your own diagram that captures what is being described as your first step in solving it. When doing problems with values that can be plugged in, keep the variables around. For example, if a problem says $l = 5$ light-years, keep l around as a variable. You can plug in 5 light-years (and maybe do some units conversions) at the end.

Scientific texts are generally much denser than non-scientific texts. When the authors make cross-references (to equations, to figures, to results in prior chapters, or to end-of-chapter problems), take time to follow the cross-reference. Pay close attention to diagrams and read the captions until you understand what is being depicted. If a diagram is a graph, pay close attention to what is on the axes.

In order to be able to do problems, it is important to follow the definitions and derivations. In *The Cosmos: Astronomy in the New Millennium,* most of these have been isolated in "Figure it Out" boxes. If this sounds daunting, fear not, you can most definitely do it.

Astronomy Daily Schedule Term 5

Course **home page**

Note: Unless otherwise noted, page numbers, equation numbers, and problem numbers refer to the **5th edition of The Cosmos by Pasachoff and Filippenko**.

See also **Daily Schedule Term 6**

Week 1 — Chapters 1 and 2 — Units, Scientific Notation, Light, Temperature, Atoms, Atomic Spectra

- Tuesday, March 16 — Reading: Sections 1.1 to 1.4 (we'll be skipping 1.5 to 1.7) — Study Figure it Out Box 1.1 and Figure it Out Box 1.2 on units and scientific notation — In-Class Problems: Chapter 1, Problems 2, 8, and 24
- Friday, March 19 — Reading: Sections 2.1 to 2.4 including all four Figure it Out Boxes in Chapter 2 — In-Class Problems: Chapter 2, Problems 21, 22, and 24.

Week 2 — Chapter 4 — The Daily, Monthly, and Annual Motions of the Heavens

- Tuesday, March 23 — The Cosmos: Section 4.1 (on the synodic and sidereal motion of Sun and Moon, moon phases) — The Friendly Stars: Chapters I and II — Venus in Transit: Chapter 3
- Friday, March 26 — The Cosmos: Sections 4.2 to 4.5, including Figure it Out Boxes 4.1 and Box 4.2 (eclipses, atmospheric effects of reddening and twinkling, daily motion of the stars, apparent magnitude) — The Friendly Stars: Chapters III and IV (on Capella and Arcturus) — Venus in Transit: Chapters 1 and 2 (Copernicus and Kepler) — **2017 Eclipse Animation** — **2024 Eclipse Animation** — **The Ecliptic** — Problem Set 1: Chapter 2, Problems 25, 26, 29, 30, Repeat problem 25 for 2.45 GHz microwave oven radiation — **Problem Set 1 Solution**

Week 3 — Chapter 4 — The Daily, Monthly, and Annual Motions of the Heavens

- Tuesday, March 30 — Finish Chapter 4 of The Cosmos. — Read Chapters XI, XII, XIII, and XIV from The Friendly Stars (the winter stars, which are now setting in the west) — Observe the stars in the west (compare with the **star chart for the west** that I handed out) and add your observing notes for those stars to **Friendly Stars - 15 Brightest** worksheet — Read Chapter 4 from Venus in Transit (but not the appendix on parallax)
- Friday, April 2 — Read *The Cosmos* Sections 5.1-5.4 — Read Chapter 5 of *Venus In Transit* — Problem Set 2: Aristarchus Measures the Size and Distance of the Moon — **Problem Set 2 Solution**

Week 4 — Start Chapter 5 — Gravitation and Motion

- Tuesday, April 6 — Read *The Cosmos* Section 5.5 and 5.6 (Kepler's Laws) — Read Chapters V, VI, and XV from *The Friendly Stars* (Spica, Vega, and Regulus) — Read Chapter 6 of *Venus In Transit* — Problem Set 3: **Mars Retrograde Construction** — **Problem Set 3 Solution** — Problem Set 4: Chapter 4, Problems 1, 11, 12, 30, 31, 46, and Chapter 5, Problems 35 and 39 — **Problem Set 4 Solution** — 9pm Star Party with readings from Ian Ridpath's *Star Tales* on Canis Major, Canis Minor, Gemini, and Orion (the spectacular display setting in the west right now)
- Friday, April 9 — **First Midterm** — In-Class: rounding out our understanding of Kepler's Laws — Finish Reading Chapter 5 of *The Cosmos* (Newton's Laws)

Week 5 — Chapters 6 and 7 — The Rocky Planets and the Gas Giants

- Tuesday, April 13 — Problem Set 5: Handout on Newton's Laws — Newton's **thought experiment from The Principia** — Reading: ***Starry Messenger* Excerpts** — Reading: Chapter 7 of *Venus In Transit*
- Friday, April 16 — Reading: *The Cosmos* Chapters 6 and 7 (The Four Rocky Planets and the Four Gas Giants) — Topics: Tides, Magnetic Fields, Volume, and Density — **Solar System Sizes** table — **Black Rock Desert** scale model — **Orbital Resonance** explanation

Week 6 — Chapters 8 and 9 — The Asteroid Belt, The Kuiper Belt, and Solar System Formation

- Tuesday, April 20 — The class is rescheduled to be an observing night and telescope operation night starting at 9pm on Sunday evening — Problem Set 6: **Solar System Densities Worksheet** (put in my box on Tuesday since we are not actually meeting on Tuesday)
- Friday, April 23 — Reading *The Cosmos* Chapter 8 and Section 9.1: Our Solar System and Solar System Formation

Week 7 — Astrology in Shakespeare (a pre-break interlude to support the campus pre-break Shakespeare festival)

- Tuesday, April 27 — Read Chapters 8 and 9 of *Venus In Transit* — **Shakespeare and Astrology, Chapter IV** by William Bruce Smith, Master's Thesis, 1989 — **Problem Set 7**

Astronomy Daily Schedule Term 6

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Week 8 — Chapters 10, and 11 — Our Sun and Other Stars

- Tuesday, May 11 — Our Sun – Guide to Reading and **Problem Set 8**
- Friday, May 14 — Other Stars — The HR diagram — **Absolute Magnitude Handout** — **HR Plot Handout**

Week 9 — Chapter 12 — Fusion and Nova

- Tuesday, May 18 — Chapter 12 — Fusion in the Interior of Stars — Reading and Discussion Guide and **Problem Set 9**
- Friday, May 21 — **Second Midterm** — Start Chapter 13 on the Death of Stars

Week 10 — Finish Chapter 13 and Start Chapter 14; Supernovas, Pulsars, Stellar Mass Black Holes, Schwarzschild Metric

- Tuesday, May 25 — Remainder of Chapter 13 — Supernovas, Neutron Stars, Pulsars
- Friday, May 28 — Reading: Start Chapter 14 on Black Holes, Sections 14.1 to 14.6 — Supplementary Reading: Taylor and Wheeler, Exploring Black Holes, pp. 2-16 to 2-30

Week 11 — Chapters 14 and 15 — Black Holes, The Milky Way

- Tuesday, June 1 — Finish Chapter 14 on Black Holes (Supermassive Black Holes, Gravitational Wave Detection) — Excellent explanation by Veritasium of what a **black hole accretion disk** looks like — **Problem Set 10**
- Friday, June 4 — Read all of Chapter 15 on Our Galaxy with more than 100 billion stars — **Density wave theory animation**

Week 12 — Chapters 16, and 17 — Hubble's Expanding Universe, Other Galaxies, Gravitational Lensing, Quasars, Active Galactic Nuclei

- Tuesday, June 8 — Chapter 16: More than 100 billion galaxies — **Hubble's 1925 paper** — **Hubble's 1929 paper** — **Problem Set 11** — Worksheet on **Understanding Hubble's Law**
- Friday, June 11 — A **Deeper Dive on Gravitational Lensing** — Video on **Deflection of starlight** — Chapter 17: Quasars, Active Galactic Nuclei — Event Horizon Telescope **image of supermassive black hole** in M87

Week 13 — Chapter 18 — Cosmology — Third Midterm

- Tuesday, June 15 — Chapter 18 — General Relativity and the Expanding Universe — The New Standard Candle: Type 1a Supernovae and Modern Measurements of Hubble's Law — The Evidence for Dark Matter and Dark Energy on Cosmological Scales — **Problem Set 12** — High-Z supernovae results, **Riess et al 1998**
- Friday, June 18 —**Third Midterm (Final)** — Penzias and Wilson Discover Black-Body Radiation of 3000K with z=1000 — **Penzias and Wilson, 1965**

Week 14 — Chapter 19 — The Cosmic Microwave Background Radiation — Special Projects

- Tuesday, June 22 — Finish Chapter 19 — Echoes of the Big Bang — **Dicke, Peebles, Roll, and Wilkinson, 1965** — The Universe when it was Only 380,000 Years Old — Density Fluctuations in the Early Universe — The Inflationary Universe — Discuss Project Writeups and Results — **Chen, Lunar Eclipse and Two-Day Old Moon — Lucia, Wild Duck Open Cluster — Alice and Declan, Veil Nebula**