Astronomy 101: Principles of Astronomy
San Diego State University
Fall, 2009

Lecture times and locations:

Section 6 (Schedule Number 20311): T/Th 11:00 AM - 12:15 PM, Rm. PA-216 (Physics-Astronomy Building).

Section 8 (Schedule Number 20313): T/Th 2:00 - 3:15 PM, Rm. NE-060 (North Education Building).

Instructor: Douglas Leonard
Office: Room 238, Physics building
Email: leonard@sciences.sdsu.edu [Note: "Plain-text" emails strongly preferred!]
Telephone: 619-594-2215
Office Hours: Friday 12:00 – 2:00 PM, and by appointment.
Website: http://sciences.sdsu.edu/~leonard/astro101 (Note: This course is not on Blackboard.)
Required Course Material: Text: *Voyages To the Stars and Galaxies*, third edition, by Andrew Fraknoi, David Morrison, & Sidney C. Wolff.
[Note: It is recommended that you purchase a *new* copy at the campus bookstore of the text, so that you will get a valid "access code" that allows you to view the on-line *tutorials*.]
Course Reader: Available at the campus bookstore. Contains Powerpoint slides, exam information, and additional required reading material.

Course Description

Finding our place in the universe has been a perennial human pastime. Here we present the results of this ongoing endeavor, covering such topics as the solar system, stars, black holes, galaxies, and cosmology. A particular emphasis will be placed on the historical development of ideas and their philosophical implications. The class assumes no prior background in astronomy, although a general knowledge of science at the high-school level will be helpful. Mathematics will be limited to algebra and geometry. Prerequisite: Interest.

Student Learning Objectives

Upon completing this course, you should be able to:

•Describe the physical location of the Earth with respect to the other constituents of the observable universe, and articulate the process by which humans attained this understanding;

•Convince a fellow student who has never taken an astronomy class that it is possible to determine the chemical constituents of a star without ever visiting it, through the careful analysis of its light;

•Explain the process by which stars, like our sun, produce energy;

•Present the currently favored scientific theory for what the ultimate fate of our universe will be, and outline the astronomical observations upon which the theory is based;

•Read and comprehend articles concerning astronomy that appear in the popular press, and participate in discussions about them;

•Describe at least three major areas in which our astronomical knowledge is known to be incomplete.

Course Syllabus[1]

Week 1 (August 31 → September 4): *A Beginning*

Topics covered – The supernova of 1054 A.D.; the finite speed of light and the cosmic time machine; a brief tour of the universe; introduction to the night sky and the celestial sphere; conceptual schemes; the nature of science.

Readings from text – Prologue (all sections); Appendix 4; Appendix 5; Chapter 1: §1.1.1 and 1.1.2.

Week 2 (September 7 → September 11): *Finding our Place in the Universe, Part I*

Topics covered – Constellations; basic astronomical observations every theory must explain: motion of stars, Sun and planets; the zodiac; retrograde motion; astronomy in ancient times; the construction of cosmologies; Ptolemy's *Almagest*: the geocentric cosmology that (nearly) everyone believed; Aristarchus' heliocentric proposal; Aristotle and Plato; a mathematical toolkit; Eratosthenes measures the Earth.

Readings from text – Chapter 1: §1.1.3, 1.1.4, 1.1.5, 1.2.1, 1.2.2, 1.2.3, 1.2.5.

Readings from Reader – A Mathematical Toolkit; Reading Graphs; A Few Mathematical Skills.

Week 3 (September 14 → September 18): *A Monk Moves the Earth*

Topics covered – Ptolemy's *Tetrabiblos* and the perceived power of astrological prediction; Copernicus' *De Revolutionibus*; Galileo's telescope, and the "proof" of heliocentrism; Hipparchus and precession; Tycho's observations and painful death; Kepler's Laws; Newton's First Two Laws of Motion.

Readings from text – Chapter 1: §1.2.4, 1.3, 1.4; Chapter 2: §2.1, 2.2.1, 2.2.2.

Week 4 (September 21 → September 25): *Gravity Explains it All*

Topics covered – Isaac Newton's genius: His 3rd Law of Nature, the *Principia*, and the occult force of gravity; orbital motions; testing a prediction: the discovery of Neptune; solar and lunar eclipses.

Readings from text – Chapter 2: §2.2.3, 2.2.4, 2.3 → 2.6; Chapter 3: §3.7.

Readings from Reader – Kepler and Newton; Angular size; Other Worlds: An Introduction to the Solar System (§6.1.1 only).

Week 5 (September 28 → October 2): *Other Worlds*

Topics covered – A tour of the solar system: planets, moons, asteroids, and comets; origin and age of the solar system; structure of atoms; periodic table of elements; apparent brightness, luminosity, inverse square law of light propagation and the utility of standard candles; basic properties of light: speed, dispersion, ROYGBIV; introduction to spectroscopy.

Readings from text – Chapter 4: §4.1.4, 4.3.1, 4.4.1, 4.4.2; Chapter 8: §8.1.1.

Readings from Reader – Other Worlds: An Introduction to the Solar System (remainder of chapter).

[1] Specific reading assignments subject to change. Please consult each week's *Weekly Handout* for the exact reading being assigned.

Week 6 (October 5 → October 9): *Wrap-Up and Review*

Topics covered – Finish up and review material contained on Midterm Exam 1.

→ Midterm Exam #1 taken in class on Thursday, October 8.

Week 7 (October 12 → October 16): *Light: It's All We Have*

Topics covered – The science of spectroscopy; the fingerprints of the elements; Kirchoff's Laws; light as a wave: the electromagnetic spectrum.

Readings from text – Chapter 4: §4.1.1, 4.1.2, 4.2.1, 4.3.2, 4.3.3.

Readings from Reader – Light waves (first part).

Week 8 (October 19 → October 24): *And Still More About Light*

Topics covered – Light as a wave: the electromagnetic spectrum, radial velocity, Doppler effect, blue(red) shift; proper motion; the discovery of extrasolar planets; light as a particle: photons, and a brief introduction to quantum mechanics; introduction to blackbody radiation: hotter means bluer and brighter; Cecelia Payne-Gaposchkin's thesis, and the discovery of the sun's composition.

Readings from text – Chapter 4: §4.1.3, 4.2.2, 4.2.3 (qualitatively only), 4.4.3, 4.5, 4.6; Chapter 6: §6.1.1, 6.1.2 (partial); Chapter 8: §8.4.3, 8.4.4; Chapter 12: §12.4.1, 12.4.2.

Readings from Reader – Light waves (second part).

Week 9 (October 26 → October 30): *Powering the Stars: Einstein Shows the Way*

Topics covered – Energy source of the Sun and stars: Nuclear fusion; $E = mc^2$: $1 + 1 < 2$; neutrinos and antimatter; hydrostatic equilibrium; summary of stellar properties; how stars are born and how they live; low-mass vs. high-mass stars.

Readings from text – Chapter 7: §7.1, 7.2, 7.3.1, 7.3.2, 7.3.3, 7.4.2.

Readings from Reader – Nuclear Interactions; The Birth and Life of Stars.

Week 10 (November 2 → November 7): *How Stars Live and Die*

Topics covered – Approaching stellar death; binary stars; stellar corpses I: The death of low-mass stars, white dwarfs, Chandrasekhar limit; stellar corpses II: The death of high-mass stars, neutron stars, black holes, core-collapse supernovae; synthesis of heavy elements; SN 1987A.

Readings from text – Chapter 9: §9.2.1, 9.2.2, 9.4.4; Chapter 13: §13.4.3, 13.4.4, 13.5.1, 13.5.3; Chapter 14: §14.1.1, 14.1.2, 14.1.3, 14.1.4, 14.2, 14.3.1.

Week 11 (November 9 → November 13): *Stellar Corpses*

Topics covered – Pulsars; binary star evolution: Novae and Type Ia supernovae; black holes: the end of space and time; singularity; event horizon; finding black holes; proper care and feeding of black holes.

Readings from text – Chapter 14: §14.4, 14.5; Chapter 15: 15.1.1, 15.5.1, 15.5.2, 15.5.3, 15.6.

Week 12 (November 16 → November 20): *Hearts of Darkness I: An Introduction to Black Holes*

Topics covered – Einstein's General Theory of Relativity I: The principle of equivalence, and the deflection of starlight; curved space.

Readings from text – Chapter 15: 15.1.2, 15.2, 15.3.

→ **Midterm Exam #2 taken in class on Tuesday, November 17.**

Week 13 (November 23 → November 27): *Hearts of Darkness II: Into the Belly of the Beast*

Topics covered – Einstein's General Theory of Relativity II: Distorted time and gravitational redshift; adventures near a black hole; the search for gravitational waves.

Readings from text – Chapter 15: §15.4, 15.5.4, 15.7.

→ Note: No class on Thursday, November 26 (Thanksgiving!).

Week 14 (November 30 → December 3): *The Expanding Universe*

Topics covered – The mystery of dark matter; supermassive black holes; Edwin Hubble discovers a law: The expanding universe; Big Bang cosmology.

Readings from text – Chapter 10: §10.1, 10.2, 10.3.1; Chapter 16: §16.3, 16.4; Chapter 17: §17.1, 17.2; 17.3.1, 17.4.1, 17.4.2, 17.5; Chapter 18: §18.3.1; Chapter 19: §19.3.1.

Readings from Reader – An Expanding Universe; Measuring the Expected Deceleration; The Future of the Universe.

Week 15 (December 7 → December 11): *An Ending and a Beginning*

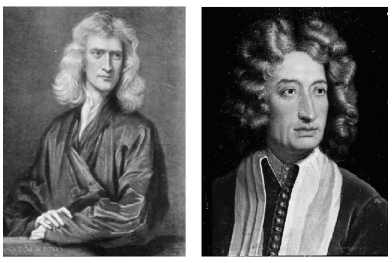
Topics covered – Age of the universe; cosmological redshift; effects of gravity and the expected deceleration; determining the expansion history of the universe with supernovae; the surprise of the decade (century?): the accelerating universe; the fate of our universe, and the limits of human knowledge.

→ Note: The last class is Thursday, December 10.

→ **Final Exam:**

Section 6 (11 AM class): Tuesday, December 15, 10:30 AM → 12:30 PM, Room PA-216 (normal lecture room).

Section 8 (2 PM class): Tuesday, December 15, 1:00 PM → 3:00 PM, Room NE-060 (normal lecture room).



(Isaac Newton and Archangelo Corelli, c. 1690)

Assignments and Course Grades

Course grades are based on the following scale:

Grade	Percentage
A	92.50 – 100%
A-	89.50 – 92.49%
B+	87.00 – 89.49%
B	82.50 – 86.99%
B-	79.50 – 82.49%
C+	77.00 – 79.49%
C	72.50 – 76.99%
C-	69.50 – 72.49%
D+	67.00 – 69.49%
D	62.50 – 66.99%
D-	59.50 – 62.49%
F	< 59.49%

Students taking the course using the credit/no credit option ("Cr/NC") will receive a grade of "Credit" for achieving an equivalent letter grade of C or better. "No credit" will be given for equivalent letter grades of C- and below.

The final course grade will be determined based on your work in the following areas:

- *Homework assignments*: 10% of the course grade. In addition to the weekly reading assignment, nearly every week there will be a set of multiple-choice "quiz" questions assigned for you to complete on-line, at the course text-book's web-site (http://www.ilrn.com). These assignments will be automatically graded on-line immediately after you take the quiz, with scores recorded in percentile form. *Your lowest <u>two</u> homework assignment grades will be dropped when computing your final homework grade for the course.* Details on these assignments, and how to access and complete them on-line, will be given during the second week of class.

- *Midterm Examination #1*: 20% of the course grade. The first midterm exam will be given in class on **Thursday, October 8**, and is worth 20% of the course grade. The nature of the midterm exams is described in the *Course Reader*, and will be discussed in detail a few weeks into the course.

- *Midterm Examination #2*: 30% of the course grade. The second midterm exam will be given in class on **Tuesday, November 17**, and is worth 30% of the course grade. It will be similar in form to the first midterm exam.

- *Final Examination*: 40% of the course grade. The final examination is a comprehensive exam covering the entire semester's material. It will be given at the following times and places (note: the final exam <u>must</u> be taken at the scheduled time):

  Section 6 (11 AM class): Tuesday, December 15, 10:30 AM → 12:30 PM, Room PA-216 (normal lecture room).

  Section 8 (2 PM class): Tuesday, December 15, 1:00 PM → 3:00 PM, Room NE-060 (normal lecture room).

→ Please note that no late homework assignments will be accepted for any reason; should you miss a homework assignment, then that will simply be one of the two homework grades that is dropped when computing your average for the "homework" component of the course. "Makeup exams" for the two midterms will be considered only for the most dire and verifiable circumstances beyond the control of the student.[2] Finally, there is no "extra credit" available

[2] To request an exam at a nonstandard time, please read and carefully follow all instructions on the form "Requesting an Exam at a Nonstandard Time", available at the course web-site (click on "Course Handouts", and then click on "Requesting an Exam at a Nonstandard Time"). Note that makeup exams will differ from the exams given in class, and may include (or consist entirely of) a one-on-one oral interview with the professor.

in this course, and no form of cheating will be tolerated; if cheating is determined to have occurred, it will result in automatic failure in the course and additional disciplinary action by the University.

Grade Calculator Worksheet

To compute your final grade in the course:

Step 1: Write down all of your homework grades (percentage equivalents):

Step 2: Now, cross out the *lowest* two homework grades. Add the remaining grades together and divide by the total number of graded homework assignments (i.e., total number of homework assignments given minus 2). Write down that number here:

Step 3: Take the number obtained in step 2, and multiply it by 0.1. Write that number down here, and put a box around it:

Step 4: Take your first midterm exam percentage and multiply it by 0.2. Write down that number here, and put a box around it:

Step 5: Take your second midterm exam percentage and multiply it by 0.3. Write down that number here, and put a box around it:

Step 6: Multiply your final exam percentage by 0.4, and write that number here, and put a box around it:

Step 7: Add the boxed numbers from Steps 3, 4, 5, and 6 together and write it here. This is your final percentage grade for the course.

Step 8: Use the grade scale given on the previous page to calculate your final letter grade, and write it down here:

In all likelihood, this is your final grade for the course. In exceptional cases, I may *raise* your grade by up to one mark (e.g., C- to C; B+ to A-, etc.) based on such subjective criteria as my sense of your overall *enthusiasm* for the class and course material. This can be demonstrated in many ways, including "class participation" (note that giving the sense that you are an engaged listener is considered to be just as important as actively contributing to the discussion), attendance, coming to office hours, evidence of effort and dedication, and so forth. Note that I will never *lower* a grade that you have earned; your enthusiasm can only help you.

Strategy

And now, some time-tested tips for success in this class:

- **Do the reading**. Each Tuesday you will be given a "Reading Guide" as part of the weekly handout, which includes the reading assignment for the week. The reading is generally due the following Tuesday. Do the assigned reading. The textbook contains the bulk of the material for which you are responsible in this course. That said, most students have found it very beneficial to...

- **Come to lecture**. Lectures are *based* on the text, but a conscious effort is made to present the material in a somewhat different manner from that given by the book. Everyone has a different preferred learning style; some find lectures the best way to learn the material, some find a textbook presentation most helpful, but everyone benefits from seeing the material presented more than one time and in multiple ways. By coming to lecture you will also see just what information is being emphasized – this is likely to be the same information that is stressed on your exams.

- **Use the weekly on-line reading quizzes to test your understanding of the material**. The on-line reading quiz questions are designed to be similar in form and content to those that will appear on your in-class exams. Since the quizzes are open book/note, there may be a temptation to simply read the questions and then "look up" the individual answers. Don't do this. Rather, *study* the material thoroughly before looking at the quiz; then, print out the quiz and take it off-line as though it is a test. After you've done this, *then* look up any answers that you are unsure about before submitting your quiz online. Use of this self-correcting technique will enable you to gauge how well you are mastering the material *before* facing it on an exam, and force you to engage in the material at a high level each week.

  Also, be sure to work through the assigned on-line tutorial exercises. While formally these exercises are optional, many students find them to be very helpful in gaining an understanding of conceptually difficult material.

- **Get help**. Come to my office hours. Go to TA Help Room hours.[3] There are lots of opportunities to get individual assistance on the course material – use them!

- **Study**. Material is covered at a fairly rapid pace in class, and must be reviewed at home for complete comprehension. **It is expected that you spend at least 6 hours per week studying the material outside of class!** Don't wait until the last minute to prepare for an examination. This course presents a large amount of information, and it can really "catch up to you" if you do not stay current with the readings.

- **Visit the course website, http://sciences.sdsu.edu/~leonard/astro101**, when needed. There you will find all of the class handouts and assignments, in case you missed anything. All Powerpoint slides from the lectures are also posted there, usually within a day after the lecture is given.

Other Things

- **Contacting the professor.** Ordered from the *best* way to get in touch with me to absolute *worst* way to get in touch with me:

  1. **Best way:** *Come to office hours.* This is absolutely the best way to get help from me in a one-on-one (or small group) setting. My office hours are a low-pressure environment, and you don't even need to come with specific questions in mind – if you just want to talk about the material in general or have me review some concepts with you that is fine. Office hours are Fridays, from 12:00 – 2:00 PM, in the physics building, Rm. 238, and I strongly encourage you to use them. If these hours don't fit your schedule and you must meet with me, let me know and we may be able to work out another time to meet.

[3] The TA Help Room is located in the Physics-Astronomy Building, Rm. PA-215. Hours to be announced.

2. **Good way:** *Send me email.* This is an effective way to contact me directly. I am very responsive to emails, often responding within minutes and almost always within 24 hours. When sending me email please, if at all possible, send it to me in "plain text" format. It is difficult for my ancient emailer to read "rich-text" or "HTML-formatted" emails. Usually, you can change the format of your outgoing email by changing the "settings".
3. **OK way:** *Catch me right after class.* If you have a very quick question (or need to let me know something) that can be dealt with in under a minute or so, catching me right after class can be effective. If your question turns out to be more complicated, I may ask you to come back to my office to discuss.
4. **Poor way:** *Call my office.* This is not such a great way to get hold of me, as I am frequently out of the office, or, if I am meeting with other students at the time, I may not even answer the phone. Send email, and you'll likely get a better response.
5. **TERRIBLE way:** *Come up right before class.* Please do not try to talk with me immediately before class, either at my office or in the lecture room. This is absolutely the worst time to attempt to communicate with me. Before lecture I am likely busy getting the lecture material ready/Powerpoint working/etc. If it's a quick question, or you need to let me know something, speak with me right after class or, even better, during office hours or through email.

- **Class videos.** If you get to class a little early, on most days you will find a video playing, usually having something to do with the material to be presented in that day's lecture. *Getting to class early to watch these videos is completely optional*; they will never contain required material that is not also presented during the formal lecture and/or by the textbook. The official class will never begin before class time (i.e., 11:00 AM or 2:00 PM, depending on your section). That said, many students in the past have found the videos to be a relaxing way to get introduced to the topics being discussed in the course, before class actually begins.

- **Asking questions.** Although our class is large, questions during lecture are encouraged – don't be afraid to put your hand up if something has confused you. In particular, the first ten minutes or so of every Tuesday's class will be specifically set aside to answer any questions that you may have about the course or material.

- **Your professor's "pet peeves".** Here are three things that *really* annoy me, so please do your best to not do them! The first two involve keeping our class time a focused, structured environment for learning, while the third is a more general issue.

  1. **Talking in class while I am lecturing.** This is my biggest single pet-peeve. Nothing bothers me more than this, so please refrain from *all* conversations with other students while the lecture is taking place.
  2. **Using a cell phone during class.** Please turn all cell phones off before entering the lecture room and store them out of sight. I do not want to *see* or *hear* any cell phones during class.
     → If you need to speak with another student or use your cell phone (for *either* text messaging or talking) during class, please quietly leave the lecture room and then quietly return when you are done.
  3. **Requesting an assignment extension.** Solutions to the weekly reading quizzes are posted on-line immediately after each quiz is due. It is therefore not possible to grant any assignment extensions for the reading quizzes. Furthermore, this course has built-in safeguards to prevent personal, unforeseen or "emergency" circumstances from adversely affecting your overall performance on these quizzes for the semester. Specifically, the lowest two homework scores (which may include an assignment on which you scored 0% – e.g., you were unable to take it) are not counted when computing your final course grade. Thus, you can completely miss up to two homework assignments (for any reason) and it won't hurt your grade. So please, do not ask for any extension to a reading quiz assignment.

4. **Leaving class before it is over.** I will lecture right up until the official end of our class period (12:15 or 3:15, depending on your section). I will never end class late, and will almost never end it early. The very end of each lecture is in fact the most important part, since all lectures end with a summary slide of the class. It is a *huge* distraction when students begin leaving with a few minutes to go; the shuffling and noise make it difficult for others to hear and see the final parts of the lecture. Thus, I request that you not get up to leave the lecture until it is over. If you are unable to stay for the entire lecture, then please exit the room more than ten minutes before the end (i.e., by 12:05 or 3:05, depending on your section).

- **Classroom safety**. For all information concerning safety in the classroom, please read the information contained at San Diego State University's "Emergency Preparedness" website: http://bfa.sdsu.edu/emergency/ .

Summary of Course Policies

To ensure that there is no confusion (or surprises at course's end) I explicitly state three of the more important course rules here.

- **There is no "extra credit" given in this course.** Focus all of your efforts on the "for credit" parts of the class (i.e., reading quizzes and exams)!
- **There are no assignment extensions, and "make-up" exams will be considered under only the most extraordinary (or otherwise unavoidable) and verifiable circumstances.**
- **No course grades of "Incomplete" (I) will be given under any circumstances.** If your performance in Astronomy 101 is less than satisfactory to you as the semester draws to a close, then your only options are:

  1. *Course Forgiveness.* At SDSU, you are permitted to retake up to 16 units of lower division courses when a grade of C- or lower is achieved, and have only the most recent grade counted towards your GPA. You can thus choose Course Forgiveness for Astronomy 101 if you do poorly the first time through, and retake it (once) in a future semester (either with me, or with a different professor) and hopefully improve your final grade. Please see p. 445 of the SDSU General Catalog (2009 – 2010 edition) for all of the details on repeating a course.
  2. *Course Withdraw.* If you feel that you have a compelling case, you can petition to get a "late" (i.e., it's after the 15-class day drop period) withdraw from Astronomy 101. Please see p. 443 of the SDSU General Catalog (2009 – 2010 edition) for details on the process. Note that all of the paperwork (this includes obtaining my signature, getting the approval of the dean of the college of your major, and filing the forms with the Registrar) must be completed by the last day of classes (Friday, December 11, 2009). In general, I am sympathetic to allowing you to withdraw from the class if you have a solid, documented reason (i.e., I will give you my signature; convincing your dean and the Registrar is up to you!). Note, though, that the last time that I am available to sign a course withdraw form is Thursday, December 10, at 3:30 PM.
  3. *Complete withdraw from the entire semester.* If your performance in all (or most) of your classes has been severely impacted by a cause beyond your control, you can consider a complete "retroactive withdraw" from the University for the Fall 2009 semester. Details on this process are on p. 443 of the SDSU General Catalog (2009 – 2010 edition). Note that this is your only option if it is after Thursday, December 10!

  →Note that the best way to avoid having to chose among any of the above actions is to do well in the class! In this regard, I point out that the final exam is worth 40% of the course grade, so that a strong performance on that can drastically improve your final mark.

(Mileva Maric and Albert Einstein, c. 1902.)

Key Concepts, Terms, People and Ideas

Here is a list of some of the more important concepts, terms, people, and ideas in the approximate order that you will encounter them in the course. You may wish to bring this list to class every day, as I will tell you (or have written on the board) the list of which terms you can expect to be covered during that day's lecture. This list can be used as both an organizational aid during lectures (i.e., as each term is discussed, you can write notes next to it) and to help you prepare for exams. Note, however, that this list is NOT exhaustive, and does NOT include "everything" for which you are responsible in this class. It is provided merely to assist you during lectures, and to provide a framework for what is being covered in class. That said, a mastery of these terms will certainly go a significant way towards giving you a more complete understanding of the material covered by this course.

Star

Light year

Nebula

Earth

North Pole

South Pole

Equator

Latitude

Longitude

Sun

Horizon

Celestial sphere

Conceptual scheme

Elevation

Zenith

Celestial Poles

Celestial Equator

Polaris (North star)

Circumpolar

Planets

Ecliptic

Constellation

Asterism

Zodiac

Retrograde motion

Parallax

Cosmology

Geocentric

Heliocentric

Aristotle

Eclipse

Lunar eclipse

Eratosthenes

Plato

Epicycle

Claudius Ptolemy

Aristarchus

Solar System

Copernicus

De Revolutionibus

Telescope

Galileo

Astrology

Hipparchus

Precession

Law of Inertia

Galileo's Principle of Equivalence

Johannes Kepler

Isaac Newton

Kepler's Three Laws of planetary motion

Orbit

Ellipse

Perihelion

Aphelion

Astronomical unit

Period

Mass

Speed

Velocity

Momentum

Acceleration

Force

Newton's Three Laws of motion

Conservation of momentum

Gravity

Fundamental forces of nature

Escape velocity

Weight

"Weightless"

Asteroid belt

Asteroid

Volume

Density

Angular momentum

Newton's law of gravity

Inverse square relation

Properties of an ellipse: focus, semimajor(minor) axis, eccentricity

Newton's version of Kepler's Third Law

Moon

Angular Diameter

Solar eclipse

Corona

Comet

Terrestrial planets

Jovian (or giant) planets

Differentiation

Meteor/meteorite

"Shooting Star"

Greenhouse effect

Solar nebula

Planetesimals

Electron

Proton

Neutron

Element

Atom

Periodic table of elements

Atomic notation

Ion

Apparent brightness

Luminosity (or power)

Inverse square law of light propagation

Standard candle (bulb)

Isotope

Speed of light

Reflection

Refraction

Dispersion

Spectrum

Spectroscopy

Continuous spectrum

ROYGBIV

Bright-line (emission-line) spectrum

Rarified

Dark-line (absorption-line) spectrum

Kirchoff's 3 laws of spectral analysis

Wave

Medium

Frequency

Wavelength

Electromagnetic waves

Electromagnetic spectrum: gamma, X, ultraviolet (UV), visible, infrared (IR), radio

Hα line

Doppler effect

Blueshift

Redshift

Radial velocity

Extrasolar planet

Proper motion

Photon

Quantum mechanics

Ionization energy

Sunspot

Photosphere

Blackbody radiation

Conservation of Energy

$E = mc^2$

Strong force

Nuclear fusion

Thermonuclear reaction

Neutrino

Antimatter

Neutrino oscillations

Gas pressure

Radiation pressure

Hydrostatic equilibrium

Nucleosynthesis

Nuclear fission

Interstellar gas/dust

Main-sequence star

Stellar evolution

Red giant star

Low mass vs. high mass star

Mass loss

Planetary nebula

Binary star

Center of mass

White dwarf

Electron-degeneracy pressure

Chandrasekhar limit

Neutron star

Supernova

SN 1987A

Core-collapse (Type II) supernova

Neutron-degeneracy pressure

Black hole

Neutron bombardment

Pulsar

Mass transfer

Accretion disk

Thermonuclear (Type Ia) supernova

Nova

Singularity

Event horizon

Schwarzschild radius

General theory of relativity

Principle of equivalence

Space curvature

Gravitational time dilation

Gravitational redshift

Spacetime diagram

Gravitational waves

Photon sphere

Tidal force

Arcsecond

Parsec

Henrietta Swan Leavitt

Cepheid star

Edwin Hubble

Galaxy

Milky Way

Spiral galaxy

Elliptical galaxy

Irregular galaxy

Galaxy rotation curve

Dark matter

Supermassive black hole

Vesto Slipher

The Big Bang

Hubble diagram

Hubble law

Hubble constant

Cosmological principle

Cosmological redshift

Critical density

Accelerating universe

Cosmological constant

Dark energy