Term Information

Effective Term	Spring 2016
Previous Value	*Autumn 2014*

Course Change Information

What change is being proposed? (If more than one, what changes are being proposed?)

We request that Astron 1101 be designated as a GE Physical Sciences course for BS students.

What is the rationale for the proposed change(s)?

The level of rigor in the lab exercises and homework and the course prerequisites are comparable to other GE Physical Sciences for BS students.

What are the programmatic implications of the proposed change(s)?

(e.g. program requirements to be added or removed, changes to be made in available resources, effect on other programs that use the course)?

No programmatic changes.

Is approval of the requrest contingent upon the approval of other course or curricular program request? No

Is this a request to withdraw the course? No

General Information

Course Bulletin Listing/Subject Area	Astronomy
Fiscal Unit/Academic Org	Astronomy - D0614
College/Academic Group	Arts and Sciences
Level/Career	Undergraduate
Course Number/Catalog	1101
Course Title	From Planets to the Cosmos
Transcript Abbreviation	Planets to Cosmos
Course Description	Overview of the Copernican revolution, the discovery of the nature of our solar system, light, gravity, and planets around other stars; the nature and evolution of stars and origin of the chemical elements; the history of galaxies and the expanding universe. Weekly laboratory. Not recommended for students who plan to major in astronomy or physics.
Semester Credit Hours/Units	Fixed: 4

Offering Information

Length Of Course	14 Week
Flexibly Scheduled Course	Sometimes
Does any section of this course have a distance education component?	No
Grading Basis	Letter Grade
Repeatable	No
Course Components	Laboratory, Lecture
Grade Roster Component	Lecture
Credit Available by Exam	No
Admission Condition Course	No
Off Campus	Never
Campus of Offering	Columbus

Prerequisites and Exclusions

Prerequisites/Corequisites	Prereq: Math 1050 (075) or 102, or an ACT math subscore of 22 or higher that is less than two years old, or Math Placement R or higher; or permission of instructor.
Exclusions	Not open to students with credit for 1140, 1144, 1161H (H161), 1162H (H162), 2161H, 2162H, 2291 (291), or 2292 (292).

Cross-Listings

Cross-Listings

Subject/CIP Code

Subject/CIP Code	40.0201
Subsidy Level	Baccalaureate Course
Intended Rank	Freshman, Sophomore, Junior, Senior

Requirement/Elective Designation

General Education course:
Physical Science

Course Details

Course goals or learning objectives/outcomes

- Quantitative Reasoning: Students will understand how quantitative measurements and predictions are used to test scientific ideas and to draw new conclusions.
- Scientific Process: Students will understand the scientific method, interplay between theory and empirical evidence, notions of incremental science and scientific revolutions, and the simultaneous existence of established knowledge and open questions
- Physical Laws: Students will understand that the universe is governed by a set of physical laws and principles that determine the appearance, behavior, and evolution of astrophysical systems.
- Evolution: Students will understand how we infer the evolution of astrophysical systems and the universe from observations at the present day.
- Relevance: Students will identify ways in which science in general and astrophysics in particular are relevant to global issues, US politics, advances in technology, and understanding humanity’s place in the universe.

Content Topic List

- The Long Copernican Revolution. "We are not the center of the Universe." Solar system, heliocentric model, orbits. Gravity and the Newtonian revolution. Extrasolar planets: detection (emphasis on transit method), atmospheres, habitability.
- Stars. "We are star stuff." Distances and masses of stars. Nuclear fusion and the origin of the elements, nucleosynthesis, stellar lifetimes. Supernovae, white dwarfs, neutron stars, black holes.
- Galaxies. "Space is big, time is long." Dark matter, evolution and growth of structure. Evidence for the Big Bang.

Attachments

- Syllabus_1101_Au14.pdf: Syllabus and Schedule

  (Syllabus. Owner: Peterson,Bradley Michael)
- GEassessment.pdf: Assessment Plan

  (GEC Course Assessment Plan. Owner: Peterson,Bradley Michael)
- GErationale.pdf: GE rationale w/sample labs and homework

  (Other Supporting Documentation. Owner: Peterson,Bradley Michael)

Comments

- We would like to implement this change as soon as possible. *(by Peterson,Bradley Michael on 03/22/2015 02:18 PM)*

Workflow Information

Status	User(s)	Date/Time	Step
Submitted	Peterson,Bradley Michael	03/22/2015 02:18 PM	Submitted for Approval
Approved	Peterson,Bradley Michael	03/22/2015 02:21 PM	Unit Approval
Approved	Haddad,Deborah Moore	03/22/2015 07:19 PM	College Approval
Pending Approval	Nolen,Dawn Vankeerbergen,Bernadette Chantal Hanlin,Deborah Kay Jenkins,Mary Ellen Bigler Hogle,Danielle Nicole	03/22/2015 07:19 PM	ASCCAO Approval

Astronomy 1101: Planets to Cosmos

Professor Todd A. Thompson

Lectures: MWF 12:40-1:35pm, University Hall 0014
Weekly Laboratory: All lab sections will start in 5033 Smith Lab (see below).
M: 1:50-3:40pm Smith 1042, 1064; T: 2:20-4:10pm Smith 1042, 1076

Professor: Todd Thompson
Office: 4019 McPherson Lab (292-7971)
Office Hours: Monday 9:30-10:30am, Thursday 1:30-2:30pm, or by appointment
E-Mail: thompson.1847@osu.edu

TA: Joel Zinn
Office: 4020 McPherson Lab
Office Hours: Tuesday, 12:30-1:50pm, or by appointment
E-Mail: zinn.44@osu.edu

Recommended Textbook (not required): *Astronomy Today*, 7th Edition, by Chaisson & McMillan

Course Web Page: www.astronomy.ohio-state.edu/∼thompson/1101

Course Goals & Learning Objectives:
Astronomy 1101 is an overview of astronomy from our solar system to the universe as a whole. It is a General Education (GE) Physical Science course in the Natural Science category. The goals of courses in this category are for students to understand the principles, theories, and methods of modern science, the relationship between science and technology, the implications of scientific discoveries and the potential of science and technology to address problems of the contemporary world.

The expected learning outcomes for GE courses in the Natural Science category are as follows:

1. Students understand the basic facts, principles, theories and methods of modern science.
2. Students understand key events in the development of science and recognize that science is an evolving body of knowledge.
3. Students describe the inter-dependence of scientific and technological developments.
4. Students recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.

Astronomy 1101 will meet these expected outcomes by covering three overarching and interconnected themes: (1) the long Copernican revolution, the discovery of the nature of our solar system and planetary systems around other stars, the physics of light and gravity; (2) the nature and evolution of stars and black holes and the origin of the elements we find in nature; (3) the history of galaxies and the universe, evidence for the Big Bang, and the structure of the universe on its largest scales. I will attempt to convey a number of the facts that astronomers and astrophysicists have learned about these topics, to describe the outstanding scientific problems that are the focus of current research, to illustrate ways in which physical principles are used to understand the universe, and to show how scientific theories are developed and tested against observations.

Among the questions that you should be able to answer by the end of the course are the following: What is the architecture of our solar system, and how do we find other planetary systems? What is a star? What is a galaxy? What is the evidence for dark matter? What is the Big Bang theory? What empirical evidence supports and/or challenges our explanations for the physical nature of stars, galaxies, and the cosmos?

Course Organization: This is a four-credit hour course; each week, there will be 3 hours of lecture and one two-hour laboratory session. For Arts and Sciences students in a Bachelor of Arts program, this course meets the Arts and Sciences GE requirement of a natural sciences course that includes a laboratory component.

Weekly Laboratory, Laboratory Write-Ups, & Homework:
Astronomy 1101 laboratory is weekly. Attendance is required. The primary goal is to reinforce the concepts covered in lecture and to introduce quantitative thinking. The lab will typically start with 0.5 hour in the Ohio State University Planetarium (5033 Smith Laboratory) or an introduction by the instructor to the topic and the analysis that will be carried out. Then the class will be divided into smaller groups who carry out the work of the lab and answer questions presented by the TA or professor. Each student will turn in a laboratory write-up at the end of the laboratory session. These lab components will be carried out in Smith 1042, 1064, and 1076. Attendance at the weekly laboratory and the lab write-ups account for 20% of the final grade.

Before leaving the lab, students will be given a homework assignment that is due at the start of the next week's laboratory. The homework will consist of short-answer and multiple-choice questions that follow from the laboratory exercises and the class lectures. Collectively, these homeworks will account for 20% of the final grade.

Collectively, laboratory attendance, writeups, and homework count for 40% of the final grade. No missed laboratory or late homework will be accepted, except for legitimate, documented emergencies. The grading policy is described further below.

In-Class Quizzes:
There will be three in-class quizzes, held at normal class time. There will be no lecture on quiz days, and the quiz will start promptly at class time. Each quiz will cover the material in the lectures and laboratory sessions since the previous quiz (accounting for the fact that not all students may have had the same number of lab sections at the time of each quiz). All quizzes are closed-book, closed-notes tests. The lowest score of the three quizzes will be dropped. Collectively, the remaining two quizzes will account for 30% of the final grade.

The quizzes are scheduled for the following class days at normal class time:

Friday, September 26
Friday, October 31
Friday, December 5

Makeup quizzes are only offered by advance arrangement with the professor. Exceptions are for legitimate, documentable emergencies. If you will be away on an official University-sponsored activity (e.g., ROTC, sports teams, band, etc.), please bring me a letter from your coach, director, etc. in advance of the quiz. Quizzes must be made up by the Wednesday after the quiz you missed, otherwise that quiz becomes the one that I will drop in computing your final grade.

Final Exam:
Attendance at the Final Exam is mandatory. The final will be comprehensive, covering all lectures and laboratories, and has the same multiple-choice/short answer format as the in-class quizzes and homeworks, only about two times longer. It is worth 30% of your grade.

Students who miss the final exam will be given an incomplete (I) with an alternative grade equal to getting a zero on the final, and have to make it up early the following Semester, as per University policy, to avoid the alternative grade. In keeping with official University policy, early finals will not be available for those persons who wish to depart early for break. Please plan ahead and make your travel plans accordingly.

Grading Policy:

- Weekly laboratory attendance and laboratory writeups account for 20% of your final grade. Laboratory attendance is required and graded pass/fail. The writeups will be graded as "check" (100% = complete), "check-plus" (105% = exceptional effort), "check-minus" (90% = items missing). The lowest score on the laboratory writeups will be dropped in calculating a final laboratory grade.

- Weekly homework accounts for 20% of your final grade. It will be graded on a 100 point scale. The lowest score on the homeworks will be dropped in computing your final homework grade.

- Quizzes account for 30% of your final grade. The lowest score of the 3 in-class quizzes will be dropped in computing your final quiz grade.

- The comprehensive final exam accounts for 30% of your final grade, and must be taken by all students.

- Curving: If the median of the distribution of scores on the combined homeworks, any individual quiz, or the final exam is substantially below C+/B-, scores for that element of the class will be curved to a C+/B- scale.

- Attendance at lectures is strongly encouraged. Attendance counts towards your final grade, and will be used to bump it up (e.g., from a B+ to an A-) in the event that your calculated final grade is within approximately 1 % of the higher score.

- Participation is strongly encouraged. I will often ask if there are any questions or comments on the topics covered, or on sample Quiz and Homework questions we discuss in class. Participation counts towards your final grade, and will be used to bump it up (e.g., from a B+ to an A-) in the event that your calculated final grade is within approximately 1 % of the higher score. If you are reticent to speak up in class, please email me your questions and comments and I will incorporate them into the next lecture.

- Extra credit: Up to 5% may be earned by carrying out 20 measurements of the Moon's phases and motions throughout the semester (see handout) and turn in an observing log at the end of the semester. Students who wish to complete the extra credit should start early in the semester.

Lectures, Notes, & Readings:
The lectures, laboratory meetings, and homeworks, are your primary resource for this course. The textbook may be used as a secondary reference from which related readings will be suggested, but it is not required for the course.

In between these two resources in importance are the lecture notes available on the web. These notes are meant to be useful aids for studying and following along during lectures; they are no substitute for attendance. Most students find that the best strategy is to print out the notes, bring them to class, and then add their own notes in the margins. Remember, these are only outlines of what I cover each day in class, not comprehensive transcripts of the lectures.

Textbook:
The textbook is not required. Because introductory astronomy textbooks designed for non-majors are rarely organized exactly the same as our courses, we will not strictly follow the order of topics in the book. You can expect to jump around as the course progresses. As such, instead of specific reading assignments, each section of the course has related reading suggestions from the text. Not all topics in this course are covered by the book, and similarly not all topics covered in the book will be discussed in class. You are only responsible for the contents of my lectures and the laboratory meetings.

Academic Misconduct:
It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term "academic misconduct" includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct http://studentlife.osu.edu/csc/.

Students with Disabilities:

Students with disabilities that have been certified by the Office for Disability Services (ODS) will be appropriately accommodated and should inform the instructor as soon as possible of their needs. The Office for Disability Services is located in 150 Pomerene Hall, 1760 Neil Avenue; telephone 292-3307, TDD 292-0901; http://www.ods.ohio-state.edu/. We will rely on ODS to verify the need for accommodation and to help develop the appropriate strategies. Students with disabilities who have not previously contacted ODS are encouraged to do so, by visiting the ODS website and requesting an appointment. Please take care of this well in advance of the quizzes, as processing the paperwork takes time.

Astronomy 1101 - Autumn 2014

Week	Date	Day	Topic	Lab
1	27-Aug	W	Introduction to class, scientific notation, metric system, time, weight, speed of light, astro concepts	
	29-Aug	F	Motions+Wanderers	
2	1-Sep	M	Labor Day - No Class	
	3-Sep	W	Measuring Earth: Eratosthenes, Aristarchus, Ptolemy	
	5-Sep	F	Greek Astronomy, Harmony of the Spheres, heliocentrism	
3	8-Sep	M	Copernicus	Lab 1
	10-Sep	W	Tycho+Kepler	
	12-Sep	F	Galileo	
4	15-Sep	M	Newtonian Revolution	Lab 2
	17-Sep	W	Gravity and Orbits	
	19-Sep	F	Family of the Sun, Dance of the Planets	
5	22-Sep	M	Discovery of Exoplanets	Lab 3
	24-Sep	W	Properties of Exoplanets and the Habitable Zone	
	26-Sep	F	**Exam 1**	
6	29-Sep	M	Measuring the stars I: temperature and brightness	Lab 4
	1-Oct	W	Measuring the stars II: the HR diagram	
	3-Oct	F	Internal structure of stars	
7	6-Oct	M	The age of the Sun	Lab 5
	8-Oct	W	Energy generation, thermal equlibrium, transport	
	10-Oct	F	The main sequence	
8	13-Oct	M	Star formation	Lab 6
	15-Oct	W	The Evolution of low mass stars	
	17-Oct	F	The Evolution of high mass stars	
9	20-Oct	M	Supernovae	Lab 7
	22-Oct	W	Neutron stars and white dwarfs	
	24-Oct	F	Black Holes	
10	27-Oct	M	Tests of stellar evolution	Lab 8
	29-Oct	W	We are star stuff, enrichmentof galaxies	
	31-Oct	F	**Exam 2**	
11	3-Nov	M	Island universes and the discovery of galaxies	Lab 9
	5-Nov	W	The cosmic distance scale	
	7-Nov	F	Galaxies, clusters, voids and super clusters	
12	10-Nov	M	Special relativity	Lab 10
	12-Nov	W	General relativity	
	14-Nov	F	Einstein's universe: isotropy and homogeneity	
13	17-Nov	M	The expanding universe: Hubble's law, cosmological redshifts	Lab 11
	19-Nov	W	Constituents of the universe, Dark Matter and Dark Energy	
	21-Nov	F	The Big Bang	
14	24-Nov	M	Tests of the Big Bang	Lab 12
	26-Nov	W	Thanksgiving	
	28-Nov	F	Thanksgiving	
15	1-Dec	M	Cosmic timeline, the early universe, first 3 minutes	Lab 13
	3-Dec	W	Fate of the Universe	
	5-Dec	F	**Exam 3**	
16	8-Dec	M	Finale: life in the universe, drake equation, Fermi paradox	Lab 14

NiB = Not in Book
supp = supplemental notes

GENERAL EDUCATION RATIONALE FOR
ASTRON 1101 "FROM PLANETS TO THE COSMOS"

Astronomy 1101 is an overview of astronomy from our solar system to the universe as a whole. It is a General Education (GE) Physical Science course in the Natural Science category, with an integral laboratory component. It was originally intended only for BA students. While the course is numbered at the 1000-level, it is our experience that astronomy GE courses are taken by students at all ranks.

We offered Astron 1101 for the first time in Autumn 2014 and Spring 2015. During the course of developing the laboratories and homework exercises, we realized that they were suitably rigorous for BS students. We have compared Astron 1101 with other GE Physical Sciences courses for BS students and find that the prerequisites, content, and level of Astron 1101 are about the same as other GE BS courses. The only change in this resubmission is a request to designate this course as a suitable GE option for BS students.

The expected learning outcomes for GE courses in the Natural Science category are as follows:

1. Students understand the basic facts, principles, theories and methods of modern science.
2. Students understand key events in the development of science and recognize that science is an evolving body of knowledge.
3. Students describe the inter-dependence of scientific and technological developments.
4. Students recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.

We designed Astron 1101 in collaboration with UCAT, starting by defining the course-specific objectives and designing assignments to achieve these objectives. The course-specific objectives and their mapping to the GE course goals are as follows:

(a) Quantitative reasoning. Students will understand how quantitative measurements and predictions are used to test scientific ideas and to draw new conclusions. Maps to GE Goal #1.
(b) Scientific process: Students will understand the scientific method, interplay between theory and empirical evidence, notions of incremental science and scientific revolutions, and the simultaneous existence of established knowledge and open questions. Maps to GE goals #1 and #2.
(c) Physical laws. Students will understand that the universe is governed by a set of physical laws and principles that determine the appearance, behavior, and evolution of astronomical systems. Maps to GE goal #1 and somewhat to goal #3.

(d) Evolution. Students will understand how we infer the evolution of astrophysical systems and the universe from observations at the present day. Maps to GE goals #1 and #4.
(e) Relevance. Students will identify ways in which science in general and astrophysics in particular are relevant to global issues, US politics, advances in technology, and understanding humanity's place in the universe. Maps to GE goals #3 and #4.

(a) How do the course objectives address the expected learning outcomes?

Astronomy 1101 meets these expected outcomes by through coverage of three overarching and interconnected themes: (1) the Copernican revolution, the discovery of the nature of our solar system and planetary systems around other stars, the physics of light and gravity; (2) the nature and evolution of stars and black holes and the origin of the elements we find in nature; (3) the history of galaxies and the universe, evidence for the Big Bang, and the structure of the universe on its largest scales. Students learn basic observational facts (motions of bodies in the Solar System and proof of the Earth's motion; nature and composition of stars; fossil evidence of the Big Bang, including elemental abundances and cosmic background radiation), the methodology used in astronomy (measurement of positions and brightness of celestial sources and principles of spectroscopy), and the theories derived from the observations (the Copernican Solar System, universal gravitation, stellar evolution, and the Big Bang). It is worth emphasizing that this course was designed in collaboration with UCAT personnel following the "Understanding by Design" framework, beginning with the high-level goals that are listed in the Course Request and proceeding to more specific objectives that then guide the ordering and design of individual laboratories and other assignments. The high-level goals, though constructed specifically for this course, map well to the four expected learning outcomes for GE courses in the Natural Science category. While the content and context of the course is defined by the astronomical themes above, the laboratories and associated assignments are intended specifically to achieve the learning objectives described in the Course Request and to assess the degree to which students are attaining the desired learning outcomes.

(b) How do the readings assigned address the expected learning outcomes?

Readings are selected to reinforce lessons learned in lecture and laboratory.

(c) How do the topics address the expected learning outcomes?

The three themes that are covered form the underpinnings of modern astronomy and astrophysics. The first topic, "The Long Copernican Revolution" is the on-going development of humanity's place in the universe. Copernicus first elucidated our modern view of the Earth in the Solar System. In the last 100 years, we have come to understand that we are on the outskirts of an undistinguished galaxy that is in turn on the outskirts of a large, but typical, supercluster comprised of thousands of galaxies. The second topic, the evolution of stars, leads to an understanding of the origin of elements heavier than helium, i.e., the elements that are common on Earth, yet cosmically relatively rare. The third topic, history of the universe, affords an explanation for the origin of the universe that is consistent with a wide variety of basic data and amenable to rigorous tests. In each instance, understanding how we came to this realization requires understanding of the methodology, observations, and underlying physics.

(d) How do the written assignments address the learning outcomes?

Written assignments that accompany the laboratory sessions are designed to reinforce how the basic data are assembled coherently, lead to hypotheses that are then amenable to tests.

(e) How do the prerequisites provide an appropriate level of preparation for the proposed course?

The laboratories have been designed so that basic geometry, algebra, and trigonometry are required to execute and understand the assignments. We often emphasize geometrical arguments as these are among the most elegant in astronomy.

(f) What type(s) of experience will students have in the laboratory component of the course?

The individual laboratory exercises vary, both week-to-week, depending on content, and through the course as students develop skills and knowledge that they can build on. Nearly all laboratories begin with a planetarium component in which the principles to be explored are demonstrated. We then break into smaller (30 person) sections to work through exercises that demonstrate or reinforce the principles or methodology learned. The laboratory also includes a take-home component that is intended to deepen students' understanding. We attach three sample laboratories (Labs 3, 4, and 6) and associated take-home assignments that we think demonstrate that the level of rigor and sophistication is suitable for BS students.

Student Name: *Lab TA Name:*
Lab Partner Name:

A1101, Lab 3: Exploiting Galileo's Observations
Laboratory Worksheet

Part 1: The Phases of Venus

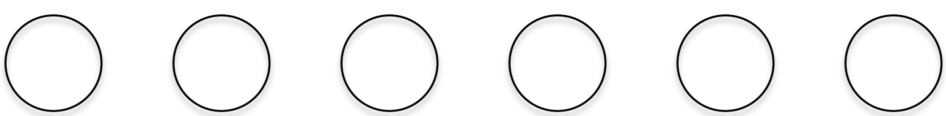
The first two pages on the graphs handout show the positions of the Earth, Sun, and Venus according to the Ptolemaic (geocentric) theory of the solar system and the Copernican (heliocentric) theory, at six times over the course of 1.6 years.

In the geocentric diagram, the dashed circle marks the orbit of the Sun around the Earth, and the dotted circle marks the epicycle of Venus. According to Ptolemy, Venus moves on this epicycle, and the center of the epicycle itself revolves around the Earth and is always aligned with the position of the Sun.

The large filled circle marks the position of the Earth, the star marks the position of the Sun, and the unfilled circle marks the position of Venus.

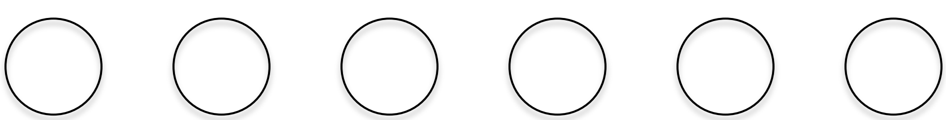
In the heliocentric diagram, the dashed circle marks the orbit of the Earth around the Sun, and the solid circle marks the orbit of Venus around the Sun. The points are the same as before.

For the geocentric case, sketch the expected phase of Venus at each of the six epochs shown in the diagram. Don't worry about showing which "side" of the planet is bright -- it will always be the one closer to the Sun – but figure out whether Venus as seen from Earth will be a crescent (like a crescent Moon), half illuminated (like a first-quarter or third-quarter moon), or more than half illuminated (like a gibbous moon). In the circles below, shade in the portion of Venus that will be *dark*, leaving the illuminated portion unshaded. *Also indicate whether Venus will appear bigger than average or smaller than average at that epoch, by writing "big" or "small" above the circle.*



(a) (b) (c) (d) (e) (f)

Now do the same thing for the heliocentric case.



(a) (b) (c) (d) (e) (f)

What is the key difference in the predictions that these two theories of the solar system make for the phases of Venus?

Which of the predictions is consistent with the observations of Venus shown in the planetarium?

What conclusion could Galileo draw by observing the phases of Venus through a telescope?

Why is diagram (f) shown at 19.2 months? What is special about this time?

Part 2: The Moons of Jupiter

The diagrams on the third page of the graph handout are inspired by drawings that Galileo made when he discovered the moons of Jupiter with a telescope. He observed four points of light very close to Jupiter and all in a line with Jupiter, and he noticed that the positions of these points of light changed from night to night, and even during the course of a night, but that they always stayed close to Jupiter. (We now know that Jupiter has other moons besides these four, but they are too faint to be seen with a telescope like Galileo's.)

In each diagram, the solid circle marks the position of Jupiter, and the asterisks mark the positions of the moons. The angular scale is marked in degrees – e.g., in the first observation, the third moon is separated from Jupiter by an angle of about 0.1 degrees.

Each diagram shows an observation at a different time, separated by intervals of 0.5 days, as marked to the left or right. For your convenience (nature is usually not so kind), the first observation in the upper left shows a time when each moon is at its maximum angular separation from Jupiter. From inner to outer, the moons are Io, Europa, Ganymede, and Callisto.

1. *What are the angular separations of the four moons from Jupiter, in degrees?*

Io: Europa: Ganymede: Callisto:

2. These observations correspond to the time when Jupiter is closest to the Earth, a distance of 6.3×10^8 km. Use the equation $L = d \times (\theta / 57.3 \text{ degrees})$ to *compute the radii of the moons' orbits around Jupiter, in km.*

Io: Europa: Ganymede: Callisto:

3. *From the diagram, determine the orbital periods of the four moons (i.e., how long they take to go around Jupiter), in days.* Try to estimate the period to at least the nearest half day, and more accurately than that if you can. **Hint:** It is easiest to start with Callisto and work inwards, ending with Io.

Io: Europa: Ganymede: Callisto:

4. *Are your measurement uncertainties for the orbital radii and the orbital periods closer to 1%, 10%, 25%, or 50%?*

5. You have conveniently been given observations separated by regular intervals of 0.5 days, which makes it easier to determine the orbital periods. *Why would it have been impossible for Galileo to obtain a set of observations with a regular 0.5-day spacing?*

6. Assume that the moons are orbiting Jupiter on circular orbits. (This assumption is very accurate.) *Use the formula $v = 2\pi r / P$ to compute the orbital speeds of the four moons, in km/s.* **Important:** Remember to convert the period from days to seconds, using the fact that there are $60\times60\times24$ = 86,400 seconds in a day.

Io: Europa: Ganymede: Callisto:

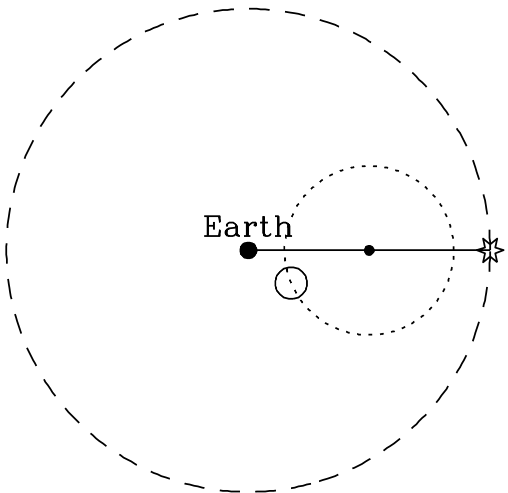
7. The final page has the graph that you made in the last take home assignment, of orbital velocity of planets vs. their distance from the Sun. All the planets have been filled in for you. *Using the numbers you have calculated above, add the moons of Jupiter to this graph*, now using the separation *from Jupiter* instead of the distance from the Sun on the *x*-axis and using the orbital velocity *around Jupiter* instead of the orbital velocity around the Sun on the *y*-axis.

Comment on your results in the space below:

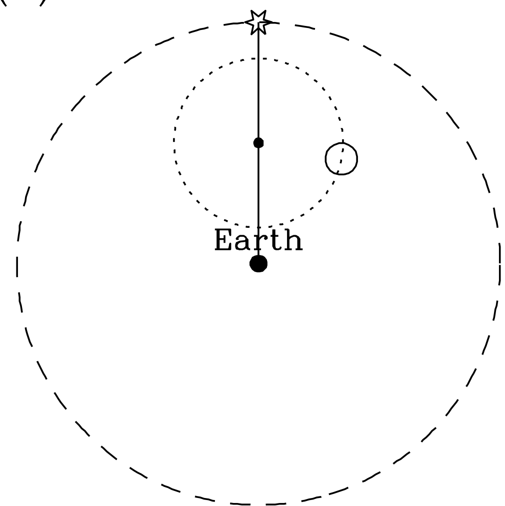
Student Name: *Lab TA Name:*

Earth, Sun, Venus: Ptolemaic System

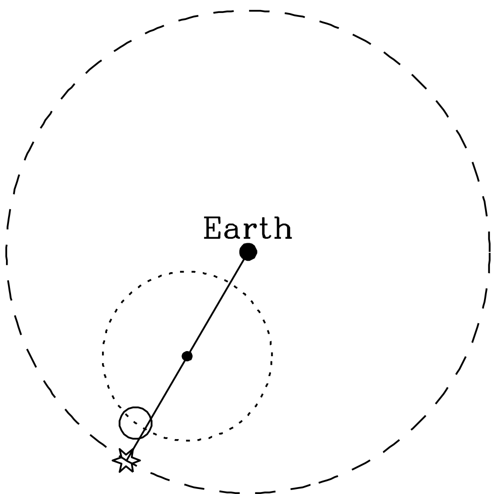
(a) 0 months



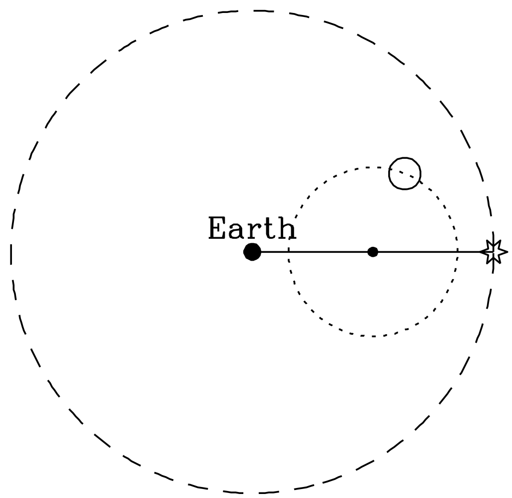
(b) 3 months



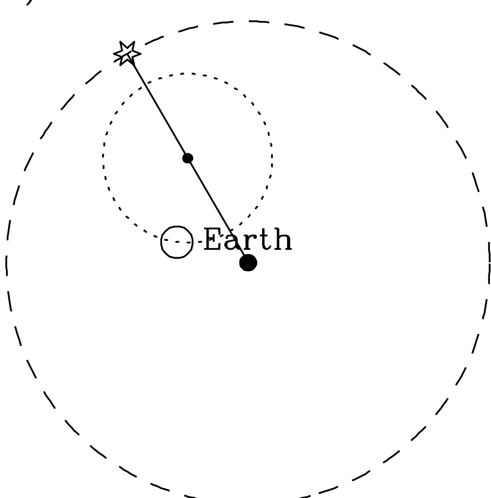
(c) 8 months



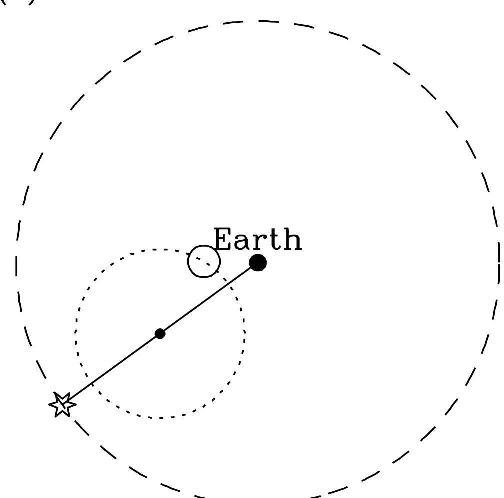
(d) 12 months



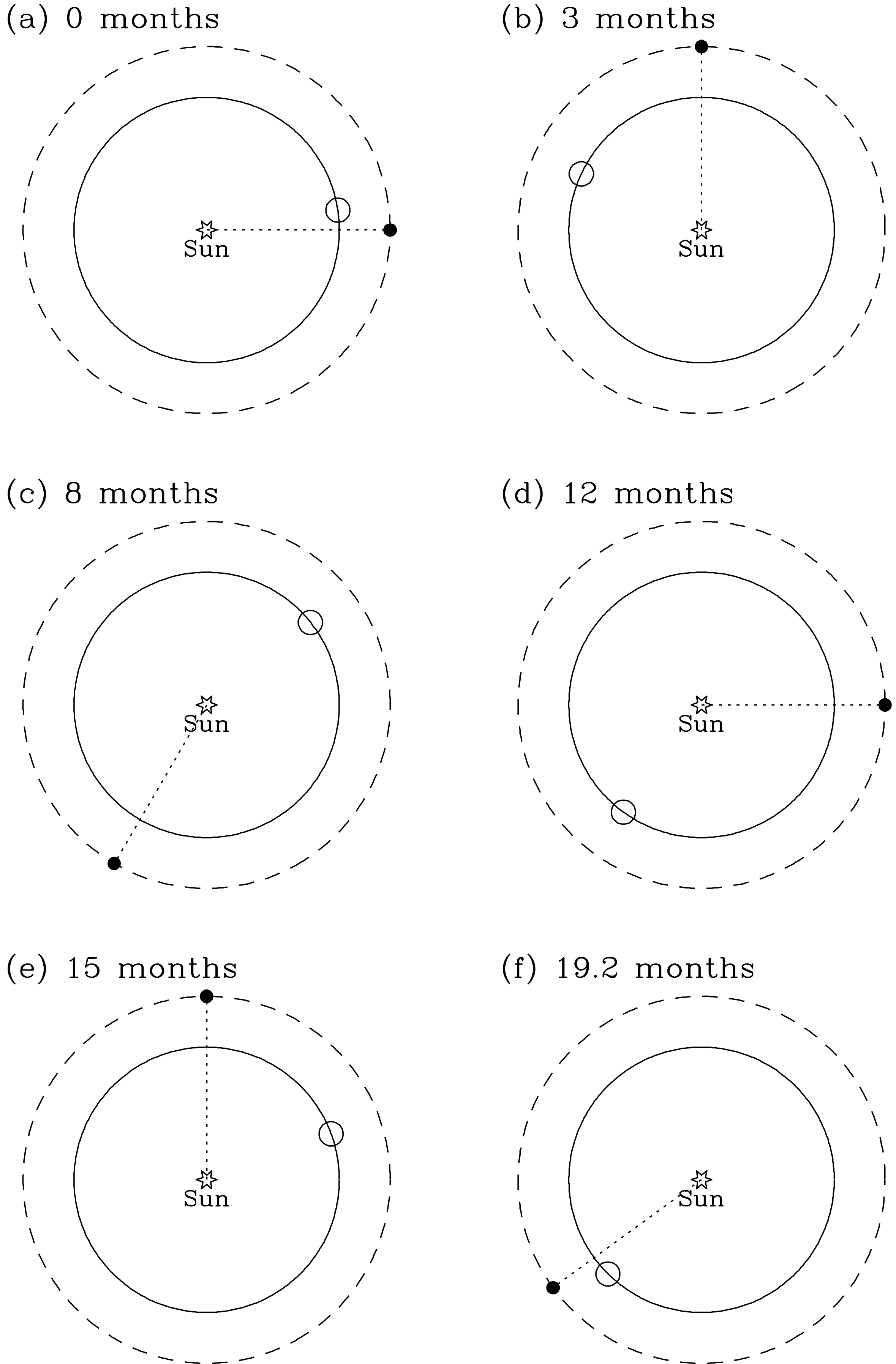
(e) 15 months



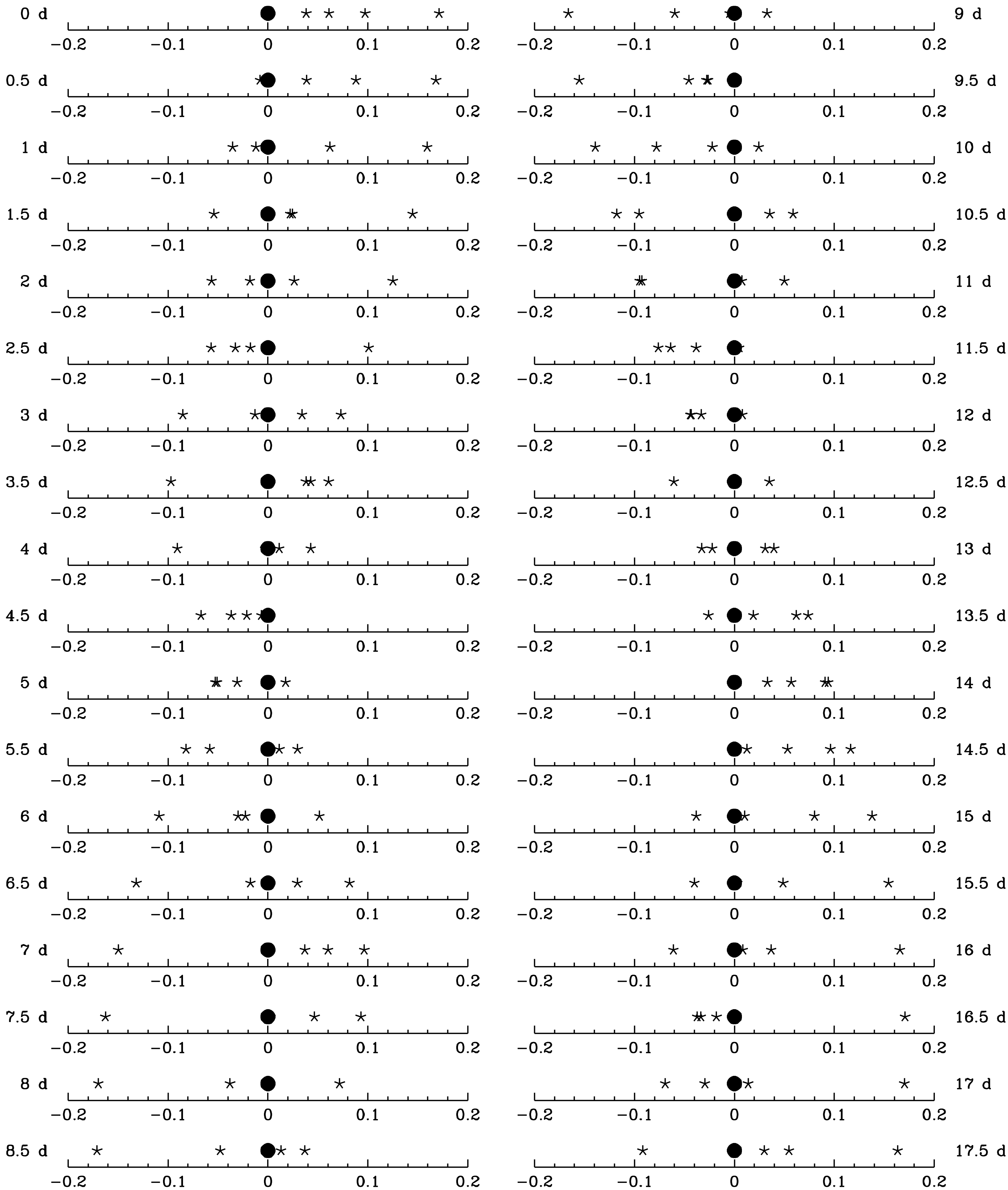
(f) 19.2 months

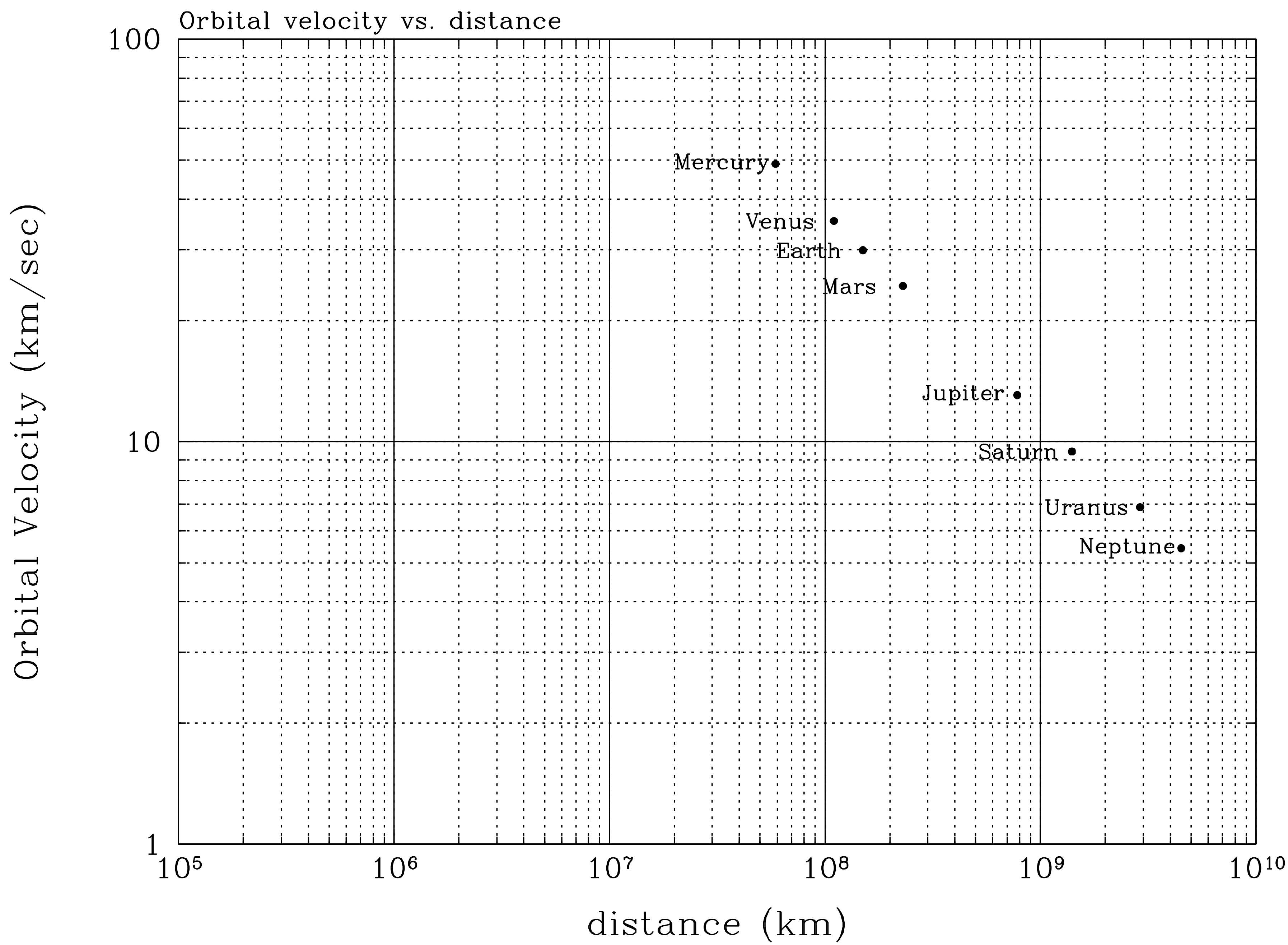


Earth, Sun, Venus: Copernican System



Moons of Jupiter





Orbital velocity vs. distance
100
10
1
Orbital Velocity (km/sec)
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
10^5
10^6
10^7
10^8
10^9
10^10
distance (km)

Student Name: *Lab TA Name:*

A1101, Lab 3: Exploiting Galileo's Discoveries
Take Home Worksheet

Part 1: Venus

Why was Galileo the first person to observe the phases of Venus?
[I.e., why couldn't anyone see them before Galileo?]

How did Galileo's observations of Venus help distinguish the Ptolemaic and Copernican theories of the solar system?
[I.e., which theory failed to explain Galileo's observations, and why?]

Part 2: Jupiter

Based on your measurements in Lab 3, *fill in the first two columns of the table below,* listing the orbital radius (around Jupiter) and orbital speed (around Jupiter) of the four moons.

Moon	Orbital Radius (km)	Orbital Speed (km/sec)	Inferred M_{Jup} (kg)
Io			
Europa			
Ganymede			
Callisto			

If you are worried that any of the numbers you got in Lab might be far off, you can check them against values listed in the back of an astronomy textbook (most of them have tables like this in the appendices) or by doing some internet research. If you correct any of your numbers, explain which ones you corrected and why. Put corrected numbers here, but don't change the numbers on your Lab worksheet.

Continue on other side

As you will learn in lecture, if one body is orbiting in a circle around a much more massive body, you can infer the mass of that central body from the formula

$$M = v^2 r/G$$

where v is the orbital speed, r is the orbital radius, and

$$G = 6.67\times10^{-11}\ \mathrm{m^3\,kg^{-1}\,sec^{-2}}$$

is Newton's gravitational constant. With this mass, the central body exerts the gravitational force needed to hold the orbiting body in its circular orbit.

Important: Because the value of G given above uses meters rather than km, you have to convert your orbital radii r from km to m and your orbital velocities from km/sec to m/sec before applying the formula, using the fact that 1 km = 1000 m. The formula will then give you the mass of Jupiter in kg.

Use this formula to estimate the mass of Jupiter from the orbital velocity and orbital radius of Callisto. Show your calculation in the space below – i.e., write down the numbers that you are multiplying or dividing, and give the result.

Use the same method to estimate the mass of Jupiter using each of the other three moons. List your four inferred value of Jupiter's mass in the fourth column of the table.

Are the mass values that you determined separately from the four moons consistent given your measurement uncertainties?

What is the ratio of the mass of Jupiter to the mass of the Earth, $M_{earth} = 6.0\times10^{24}$ kg?

What is the ratio of the mass of Jupiter to the mass of the Sun, $M_{sun} = 2.0\times10^{30}$ kg?

(Note: The mass formula comes from setting the acceleration provided by the gravity of a mass M at distance r, $a_{\mathrm{grav}}=GM/r^2$, equal to the acceleration of a body in a circular orbit of radius r and speed v, $a_{\mathrm{circ}}=v^2/r$.)

Student Name: *Lab Instructor Name:*
Lab Partner Name:

A1101, Lab 4: The Astronomical Unit and Parallax Laboratory Worksheet

In this Lab, you will first apply your understanding of the Doppler effect to observations of another star to determine the size of the Astronomical Unit (AU), which is the distance from the Earth to the Sun. You will then make measurements of stellar parallax to determine the distances to stars. In between, you will do an experiment to better understand how parallax works.

The data you will work with are idealized, but they do illustrate the kinds of data that astronomers use to make these measurements.

Part 1: Determining the AU from the Doppler Effect

For this section, you will make use of the Doppler formula, which says that if a body is moving towards you or away from you with velocity v, then light that the body emits at wavelength λ_{emit} is observed by you at a wavelength λ_{obs}, where

$$\lambda_{obs} = \lambda_{emit} \times (1 + v/c).$$

Here $c = 3.0\times10^5$ km/sec ($= 3.0\times10^8$ m/sec) is the speed of light, so, for example, $v = 30$ km/sec corresponds to $v/c = 30/3.0\times10^5 = 10^{-4}$.

In this formula, a positive v means that the body is moving away from you, and a negative v means that the body is moving toward you, so depending on the direction of motion light can be shifted to longer (redder) wavelength or shorter (bluer) wavelength. Also note that the Doppler effect depends on the motion *along the line of sight*; the light from a body that is moving side-to-side, across your line of sight, is not shifted in wavelength.

To go from measurements of wavelength to inferred velocity, it is useful to solve the above equation for v:

$$v = 3.0\times10^5 \text{ km/sec} \times (\lambda_{obs} / \lambda_{emit} - 1).$$

For example, if $\lambda_{obs} / \lambda_{emit} = 1.0001$, then $v = 30$ km/sec.

To measure the Doppler shift of a star, we must first measure its spectrum by spreading out its light (with a prism or similar to device) to measure the intensity at different wavelengths. Because of the internal physics of atoms, different kinds of atoms absorb or emit light at very specific wavelengths, so they imprint the overall "glow" of the star's hot surface with a thicket of narrow lines that can be used to measure even tiny Doppler shifts.

The graphs on the next page show the spectrum of the Sun. The top graph shows the entire wavelength range of visible light, and the one below it shows approximately the range of yellow light. The subsequent graphs zoom in on narrower and narrower wavelength ranges so that you can see finer details, with the lowest graph showing the tiny range 633.38 – 633.81 nano-meters (billionths of a meter). In this range there are two prominent absorption lines, each produced by iron atoms in the outer layers of the Sun. In these graphs, a value of 1.0 corresponds to no absorption.

The first page on the graphs handout shows observations of the spectrum of another star, similar to the Sun but far more distant, over the course of a year, as seen from the Earth. The wavelength range shown is the same tiny portion of the spectrum shown in the bottom panel of the earlier figure, and the same two prominent iron lines are seen. From laboratory measurements of such atoms, it is known that the wavelengths of these two lines are
λ_{emit} = 633.53 nm for the shorter wavelength (bluer) line and
λ_{emit} = 633.68 nm for the longer wavelength (redder) line
Here nm stands for nano-meter, or 10^{-9} m.

Measure the observed wavelength of the bluer line in each of the eight panels. Record your answer to the nearest 0.01 nm:

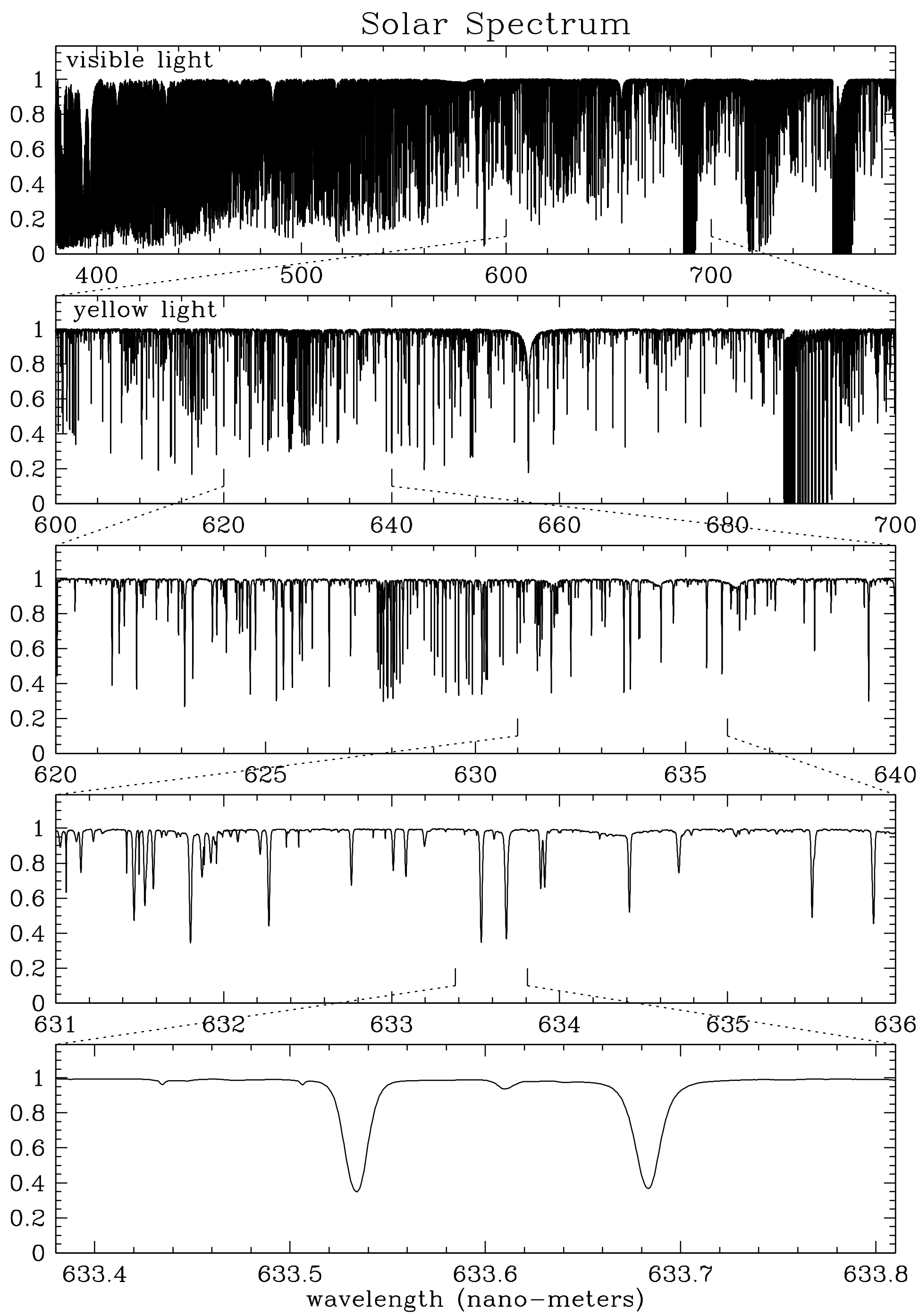
t = 0 months:
t = 2 months:
t = 3 months:
t = 4 months:
t = 6 months:
t = 12 months:

As you can see, at t=3 months, the observed wavelengths are equal to the emitted wavelengths, so the line-of-sight velocity of the star as seen from Earth is zero. Based on your measurements and the Doppler formula:

What is the line-of-sight velocity of the star at t = 0 months, in km/sec?

At t = 6 months?

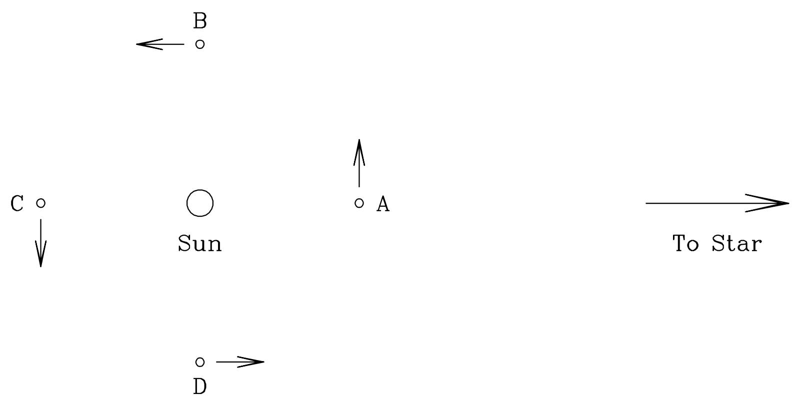
At t = 12 months?



Solar Spectrum
visible light
yellow light
wavelength (nano-meters)

Part 1, continued:

The diagram below (not to scale) shows the position and direction of motion of the Earth at four points in its orbit around the Sun. The star whose Doppler shift you are measuring is off to the right of the diagram, a very, very, very long way, in the same plane as the Earth's orbit.



Which Earth position (A, B, C, D) corresponds to
t = 0 months:
t = 3 months:
t = 6 months:

Why is the Doppler shift of the star zero at t = 3 months?

Why would you be unable to get an observation of the star when the Earth is in position C?

Based on your measurements, what is the speed at which the Earth moves in its orbit around the Sun, in km/sec?

Final Result: Using the equation

$$2\pi r = vt$$

for the circumference of the Earth's orbit, where v is the orbital speed you have inferred above and t = 1 year = 3.16×10^7 sec, *compute the size of an AU (r in the above equation) in km.*

Part 2: Parallax in the Lab

The Lab Instructor will set up tape marks that, from a marked distance, are separated by 4, 8, and 12 degrees. (For a distance of 3 meters, the separations are 21, 42, and 63 cm.) Closing or covering your left eye, hold your index finger up at arm's length and line it up with the first tape mark. Without moving your finger, change from looking with your right eye to looking with your left eye.

By how much (in degrees) does the apparent position of your finger shift?

Now bend your arm to hold your finger at half the previous distance and repeat the experiment. *By how much does the apparent position of your finger shift?*

Have your lab partner measure the distance between your eyes, in cm.
Record the answer here:

Using the formula

$$L = s_{eyes} \div (\theta/57.3 \text{ deg})$$

where θ is the shift in angle and s_{eyes} is the separation of your eyes, *compute the length of your arm in cm:*

Is your answer reasonable?

Part 3: Parallax distance to a star

The other three pages of the graph sheet show three images of a field of stars taken at six-month intervals. The dates of each observation are indicated at the top. Each star is represented by a shaded circle with a diameter of 1.5 arc-seconds. (1 arc-second is 1/3600 of a degree.) Each image is 50 arc-seconds on a side. All but two of these stars are too distant for you to detect the parallax on these images.

Which two stars show parallax?

Which of those two stars is closer to the Earth?

What is the parallax shift θ_{arcsec} *of these two stars in arc-seconds?*

Using the formula $d = (2\ \text{AU}) \div (\theta_{\text{arcsec}} / 206{,}265)$ *compute the distances to the two stars in AU.*

Using your result from part 1 for the length of an AU in km, what is the distance to the stars in km?

For the closer star, how long did light have to travel to reach the Earth, in years?
Hint: Look back to page 1 for the speed of light.

Concluding Comments:

Determining distances to objects in the sky is hard. For objects beyond the solar system, parallax is the most direct method to determine distance. For objects that are too distant to have a measured parallax, we typically infer their distances by comparing them to objects whose distance has been measured with parallax.

To determine distances via parallax, we have to know the size of an AU. There are various ways to do this, with Doppler shift being one of them. The most accurate modern methods use radar ranging to planets.

Doppler shifts are a crucial tool in astronomy for measuring how fast objects are moving, toward or away from us, though they don't measure side-to-side motion.

Even "nearby" stars are a long way away.

Student Name: *Lab TA Name:*

A1101, Lab 4: The Astronomical Unit and Parallax
Take Home Worksheet

This take-home assignment is not a follow-on to Lab 4 but a distinct assignment. It is due at the beginning of Lab 5.

As we have discussed extensively in class, many aspects of the solar system were uncertain or poorly understood 2,500 years ago. We have traced the development of competing theories of the solar system's structure and the development of Newton's theory of universal gravitation as an explanation for the motions of planets and moons.

List five properties of the solar system or the properties of gravity that are now so well established by observations and theoretical understanding that they can be taken as "facts." Choose facts that are distinct from each other; avoid repeating the same fact in different words.

Use complete sentences. For example,

0. Planets orbit the Sun on elliptical paths.

1.

2.

3.

4.

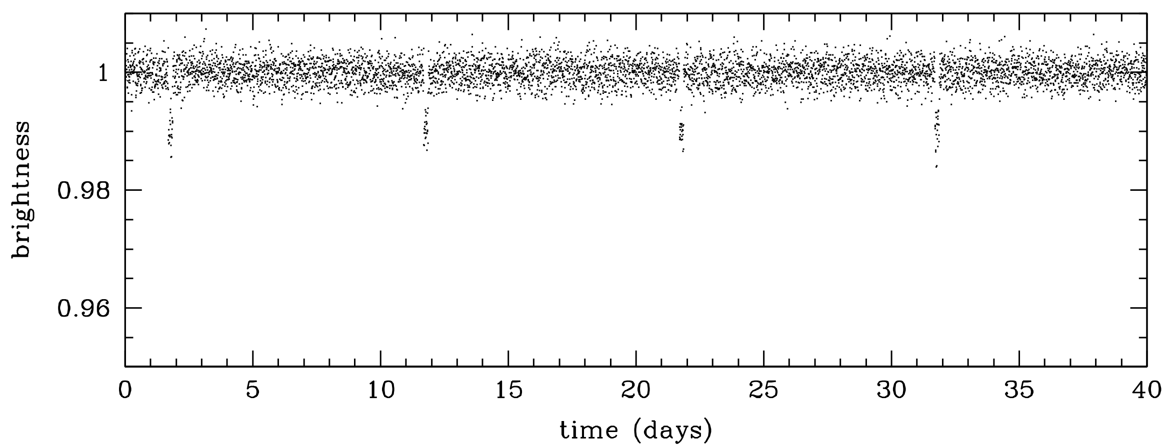
5.

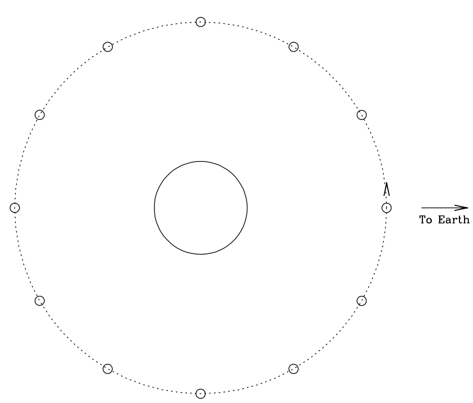
Student Name: *Lab TA Name:*
Lab Partner Name:

A1101, Lab 6: A Transiting Planet
Laboratory Worksheet

Part 1: Discovery and Orbital Period

Using a network of small telescopes at different locations around the globe, you obtain observations of a star every 10 minutes for 40 days straight. At the end of these 40 days you make the following plot of your observations. Here the vertical axis shows the measured brightness of the star relative to its average value. Thus, a "brightness" of 0.99 means that the star appears 1% (= 0.01) fainter than average. Individual points scatter up and down because there is inevitably some noise in your measurements, since you only collect a finite amount of light in your 10 minute exposures. Nonetheless, you conclude with enthusiasm that you have discovered a transiting planet!





The diagram above illustrates an "overhead" view of the system: when the planet (small circle) passes in front of the star (large solid circle) it blocks a small portion of the star's light. An "edge-on" diagram appears on the separate handout.

1. *What is the orbital period of the planet around its parent star, in days?*

2. *To get a data set like the one shown, why would you have to have a network of telescopes around the globe instead of using a single telescope in one location?*

(Astronomers really do collaborate internationally to create such telescope networks, for just this reason.)

Part 2: Properties of the Parent Star

3. Conveniently, you find that this star has a measured parallax, from which you determine that the distance is d = 10.0 light years = 9.48×10^{16} meters.

Your own observations show that the brightness of the star is
Brightness = 3.39×10^{-9} watts/m^2 (watts per square meter).

Using the same equation that you used in Lab 5,

$$\text{Luminosity} = \text{Brightness} \times (4\pi\, d^2)$$

What is the luminosity of the star in watts?

How does this compare to the luminosity of the Sun, 3.83×10^{26} watts?

4. In class, you have discussed the equation Luminosity = $(4\pi R^2) \times \sigma T^4$, which relates a star's luminosity to its radius and surface temperature. For two stars of the *same* surface temperature, the luminosity is just proportional to the star's area, and thus to R^2.

The radius and mass of the Sun are: $R_{\text{sun}} = 7.0 \times 10^5$ km, $M_{\text{sun}} = 2.0 \times 10^{30}$ kg.

You measure the color of the star and find that it is exactly the same color as the Sun.
What is the radius of the star in km (one decimal place of precision is sufficient)? Explain your reasoning
Hint: You do not need to use a calculator or solve an equation to get the answer.

R_{star} =

5. *Based on your answers to questions 3 and 4, what do you expect the mass of the star to be, in kg? Explain your reasoning.*

M_{star} =

Part 3: A Detailed Transit Light Curve

Now that you can predict when the transits are going to occur, you get time on Hubble Space Telescope to get better observations of your star during one transit. You now get one exposure every 100 seconds, and because Hubble is a bigger telescope it collects more light and gives you more precision on each measurement.

The light curve (plot of brightness vs. time) on the separate handout page shows the result of your observation, where time is now marked in seconds rather than days. Several times are marked on this diagram, t_1 through t_7.

The second diagram on the next page shows a schematic view of the transit, with the planet moving from left to right as it transits the star. This is the "edge-on" view of the system, in contrast to the "overhead view" on the previous page.

6. *Which time on the top diagram corresponds to each lettered location on the lower diagram?* (Give your answers as, e.g., "t_1" or "t_5", not a time in seconds.)

A:
B:
C:
D:
E:
F:
G:

7. *What is the distance that the planet travels between times t_2 and t_5, in km?*
Hint: Use your value of R_{star} from question 4, and remember that the diameter of the star is twice the radius.

8. *What is the orbital speed of the planet, in km/sec? Show your calculation.*

9. *What is the radius of the* ***planet****, in km? Briefly explain your reasoning.*

Hints: Use your orbital speed from question 8 and figure out from the light curve how many seconds it takes the planet to move a distance equal to its own diameter (which is twice its radius). Measure carefully; it may help to draw straight lines through the points to pinpoint where the light curve turns down or flattens out.

R_{planet} =

10. *Based on the accuracy of your light-curve measurements, do you think the accuracy of your determination of the planet radius is closer to 1%, 20%, or 50%? What is the basis for your answer?*

11. *How does the planet radius you found in question 9 compare to the radius of the Earth, R_{earth} = 6400 km? How does it compare to the radius of Jupiter, R_{jup} = 70,000 km?*

12*. Do you think the planet is likely to be composed mainly of rock or mainly of gas? Explain your reasoning.*

Part 4: The Mass of the Star

13. *Assuming that the planet is in a circular orbit, what is the orbital radius, in km? Show your calculation.*
Hints: Convert the orbital period from question 1 into seconds, recalling that there are 60 × 60 × 24 = 86,400 seconds per day. If the orbit is a circle, then the orbital speed you found in question 8 should be $v = 2\pi r / P$, where r is the orbital radius and P is the orbital period. This equation can be rewritten as $r = v \times P / (2\pi)$.

14. Just as you determined the mass of Jupiter from the orbital speed and orbital radius of its moons in Assignment 3, you can determine the mass of this star using the formula from Newtonian gravity,

$$M = v^2 r/G$$

where v is now the orbital speed, r is the orbital radius, and

$$G = 6.67\times10^{-11}\ \mathrm{m^3\ kg^{-1}\ sec^{-2}}$$

is Newton's gravitational constant. You need to convert v from km/sec to m/sec and r from km to m before you use this value of G.

What is the mass of the star in kg? Show your calculation.

M_{star} =

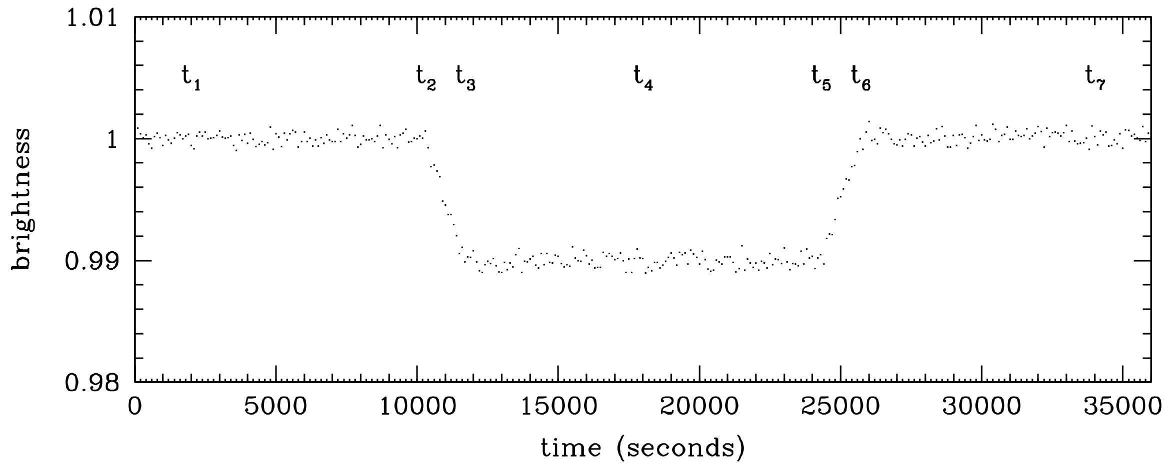
How does this compare to mass of the Sun (2.0×10^{30} kg)?

15. *Does this answer, based on Newtonian gravity and the orbit of the planet, agree with the value that you predicted in question 5, based on the luminosity, radius, and temperature of the star?*

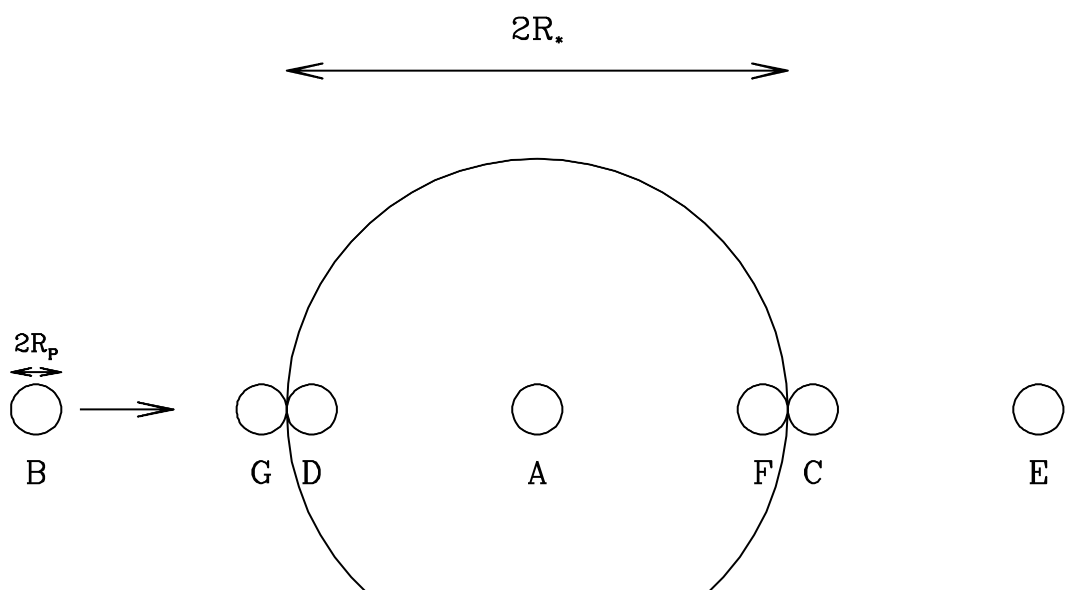
Concluding Comments

Transit searches are one way of discovering planets. Only a small fraction of planets will produce transits because they have to be fortuitously aligned to pass between us and their parent star. To find planets via transits you have to monitor a large number of stars for a long time, with enough precision to pick out the small change in light that a transit produces.

Once you discover a transit, you can use the detailed transit light curve to learn about both the planet and the star, as you have done in this Lab. When you do this you are making some assumptions, in particular that stars obey the usual relationship between surface temperature, area, and luminosity, and that Newton's laws of gravity also apply to other planetary systems. With sufficiently good measurements, you can *test* these assumptions by using different methods to infer the same quantity (like the mass of the star) and seeing whether you get the same result.



Note: The smallest tick marks on the horizontal axis show intervals of 200 seconds.



Student Name: *Lab TA Name:*

A1101, Lab 6: A Transiting Planet
Take Home Worksheet

This take-home assignment is due at the beginning of Lab 7.

Part 1: On the Universality of Physical Laws

In Lab 6, you applied several different physical principles or “laws” to infer the properties of the star orbited by the transiting planet.

First, you inferred the star’s luminosity from its brightness and its distance.
Then you inferred that the star had the same temperature as the Sun because it had the same color.
Then, using the relation between luminosity, temperature, and surface area, you inferred that the star must have the same radius as the Sun.
Then you inferred that the star should have the same mass as the Sun, because it has the same radius, temperature, and luminosity.

In the last section the Lab, you used the relation $M = v^2r/G$ to infer the mass of the star from the orbital speed and orbital radius of the transiting planet. If all went well, you found that the mass of the star was equal to the mass of the Sun.

This equation for mass is based on Newton’s theory of gravity, which was originally derived using observations of the solar system. Your analysis implicitly assumed that gravity in this star system 10 light years away works the same way as gravity in the solar system, and that the strength of gravity (i.e., the value of the constant G) is the same in both places.

If gravity were actually 100 times weaker (smaller G) in this other star system, how would your results have come out differently? Explain why your result– in particular the fact that you concluded that the mass of the star was equal to the mass of the Sun – provides *evidence* that gravity in this distant star system works the same way that it does in our solar system.

Your answer should be a short paragraph, in complete sentences.

OVER ➔

Part 2: Exoplanets and Our Place in the Universe

How has the discovery of exoplanets changed the way we (i.e., humans) think about the solar system or the place of humanity in the universe?

Your answer should be a two-paragraph essay, in complete sentences. You can use the space below or attach a separate sheet (please write your name on it and staple).

GENERAL EDUCATION ASSESSMENT FOR
ASTRON 1101 "FROM PLANETS TO THE COSMOS"

Astronomy 1101 is an overview of astronomy from our solar system to the universe as a whole. It is a General Education (GE) Physical Science course in the Natural Science category that is intended for BS and BA students. An integral laboratory component distinguishes Astronomy 1101 from other GE courses in astronomy. Astron 1101 is not intended to be a comprehensive survey of astronomy, but will instead cover a limited number of astronomical topics to illustrate general principles of physical science and the scientific method.

An outline of our assessment plan is appended to this document.

We will employ rubrics to assessing student understanding of laboratory exercises as articulated in their lab write-ups and homework. In the Table below, we give sample rubrics that we might use to evaluate the lab exercise on the Hubble Law (given as a lab example in the accompanying "GE Rationale" document) and another set of rubrics for a lab on the Sun-Earth-Moon system and the nature of eclipses. We will carefully evaluate student lab reports to assess student understanding of the material.

We will also use pre- and post-assessment short quizzes to determine how student understanding has changed as a result of the course.

Another direct method of assessment that we will employ is embedded testing. The final examination will include multiple-choice questions that address specific concepts that were emphasized in certain of the laboratory exercises. Examples of embedded questions that address the specific GE goals appear in the assessment plan below. This course was offered for the first time in Autumn 2014 and a small-scale pilot study of our assessment plan was carried out: the limited goal of the pilot study was to determine the effectiveness of the laboratory exercises. The assessment consisted of embedded questions in the final exam that were included in the final exams for Astron 1101, 1140, and 1144. The embedded questions included some material learned in laboratory exercises and, as a control, questions on material covered only in lecture. On the control questions, the students in all three courses performed comparably. On the laboratory-related questions, the Astron 1101 students outperformed the Astron 1140 and 1144 students, who did not have the benefit of a laboratory experience.

As an indirect method of assessment, we will employ exit surveys that will include the specific course objectives and the GE learning objectives and students will be asked whether they strongly agree, agree, disagree, strongly disagree, or neither agree nor disagree that these goals were met. Narrative responses also will be sought.

Feedback from all sources will be examined to determine which parts of the course and which individual laboratory exercises were effective or ineffective and whether or not some of the exercises were too complicated/difficult or trivial/too easy. Laboratory exercises that are deemed to be ineffective will be either redesigned or replaced.

Feedback from all these sources will also be used to evaluate the topical content of the course to determine whether or not the areas of selected emphasis are achieving the goals outlined in our GE rationale documents.

Student performance evaluation will be carried out as described in the sample syllabus, with components of the grade including examination and laboratory performance and participation.

Table: Sample Rubrics for Assessing Laboratory Exercises

Evaluation Laboratory Exercise	Does Not Yet Meet Expectations	Minimally Meets Expectations	Fully Meets Expectations	Exceeds Expectations
Eclipses (part of week 2)	Can explain eclipse phenomenon, but not eclipse conditions	Correctly explains solar/lunar eclipses and conditions where they occur	Can articulate why there are “eclipses seasons” rather than eclipses every month	Understands precession and why interval between eclipses seasons is less than half a year
Hubble Law (week 11)	Understands correlation between distance and recession velocity, but cannot explain clearly underlying assumptions and the correlation between luminosity and redshift	Can correctly explain variables used in the Hubble diagram, underlying assumptions, and their implications	Can correctly explain implications of the Hubble diagram for the age of the universe	Can correctly connect with Copernican principle and implications of homogeneity and isotropy.

GE Natural Science—Physical Science Assessment Plan for Astron 1101

a) Specific Methods used to demonstrate student achievement of the GE expected learning outcomes

GE Expected Learning Outcomes	Direct Methods (*assess student performance related to the expected learning outcomes. Examples of direct assessments are: pre/post test; course-embedded questions; standardized exams; portfolio evaluation; videotape/audiotape of performance*)	Indirect Methods (*assess opinions or thoughts about student knowledge, skills, attitudes, learning experiences, and perceptions. Examples of indirect measures are: student surveys about instruction; focus groups; student self-evaluations*)
1. Students understand the basic facts, principles, theories and methods of modern science.	Embedded questions on exams[1] Pre- and post testing.	Opinion survey [3]
2. Students understand key events in the development of science and recognize that science is an evolving body of knowledge.	Embedded questions on exams[1] Pre- and post testing	Opinion survey
3. Students describe the inter-dependence of scientific and technological developments.	Embedded questions on exams [1] Pre- and post testing	Opinion survey
4. Students recognize social and philosophical implications of scientific discoveries and understand the potential of science and technology to address problems of the contemporary world.	Embedded questions on exams [1] Pre- and post testing	Opinion survey

[1] On each lecture exam and the final, several questions will be written specifically to assess student achievement of each GE expected learning outcome. The scores on these questions will be included in the totals for the exam but will also be analyzed separately so that the data can be used in revising the course and for GE assessment reporting purposes.   Examples of *specific* embedded questions follow.

GE Goal 1: "A Cepheid variable with a pulsation period of 10 days is observed in a galaxy at a distance of 50 Mpc. Another Cepheid with the same period is observed in another galaxy, but is 10,000 times fainter. What is the distance to the second galaxy?" Multiple choice: correct answer is 0.5 Mpc = 500 kpc.

GE Goal #2: "Give an example of a historically important observation that supported the Copernican picture of our solar system." Multiple choice: correct answers include "Phases of Venus" and "Orbital motions of the moons of Jupiter."

GE Goal #3: "The telescope was a key technological development that enabled experimental confirmation that the Earth orbits the Sun by detection of what effects?" Multiple choice: correct answer includes "parallax of stars, aberration of starlight, and stellar radial velocities."

GE Goal #4:"Observations have shown that:" Multiple choice: correct answer is "there are no special places or directions in the universe."

[2] At the end of the semester, each student will be asked to fill out an opinion survey comprised of specific questions asking to what extent each student has achieved the four GE expected learning outcomes in this course.

b) **Explanation of level of student achievement expected:**
In general, for exams, success means that students will answer 75% of the embedded GE questions correctly. For laboratories, success means that >75% of the students will achieve "minimally meets expectations", >50% will "full meet expectations, and >10% will "exceed expectations."

c) **Description of follow-up/feedback processes:**
At the end of the course, we will use an analysis of the embedded exam questions to identify problem spots and how we might change the course and the presentation of materials to insure better fulfillment of the four GE Natural Science-Physical Science expected learning outcomes. We will also analyze the self-evaluation questions carefully to judge how students evaluated their own progress and to determine whether student perception meshed with performance. There will be weekly meetings of faculty and GTAs in the course to assess the effectiveness of the previous week's lab assignment and to prepare for that of the coming week.