Announcements

• Note the introduction of assignments on the weekly handout for the next 3 class meetings: Thursday of this week, the following Tuesday, and then also for the following Thursday. The written Thursday assignments, when given, will be more mathematical/observational in nature, and are to be handed in separately (on Thursdays) from the weekly assignments that are turned in on Tuesdays. I give the assignment over a week in advance, so that you may bring questions to the next Tuesday’s class about them, should they arise.

• Note that if you are having any difficulty understanding the material presented in class, the optional readings may be very useful for you. They are specifically chosen for their coverage of the material discussed in class, as well as their clarity of presentation. They also can be more expansive on certain topics, so you will gain a broader perspective than, perhaps, is achieved through class alone. All recommended books are on reserve at the Millikan Library front desk.

• As discussed on the handout given in class, remember to email your choice of topic for your midterm project to me (leonard@astro.caltech.edu) by 9 PM Friday, April 15. As only one student may research a given topic, it is best to email me sooner rather than later, so you get the topic that you want!

Assignment for Thursday, April 14

• Contemporary Writings: Timothy Ferris, from The Dome of Heaven in Coming of Age in the Milky Way.

Although included in the handout material, I inadvertently left out assigning the reading from the first chapter in Timothy Ferris’ great little book for this week. Thus, I assign it now; this week’s additional selection completes the chapter. In this work, Ferris eloquently sketches out the “problem of the planets”, introducing us to the vexing dilemma of retrograde motion, and how humans sought to explain it. He covers a lot of historical ground, providing along the way memorable descriptions of both Plato and Aristotle.

Assignment for Tuesday, April 19

• Primary Writings: Euclid.

It’s hard to overstate the importance of Euclid’s axiomatic method in the development of science and logical thought. In this excerpt, some of the definitions, postulates (accepted, fundamental truths) and axioms (self-evident truths) that open his masterwork, The Elements, are given, followed by a typical problem: in this case, to describe an equilateral triangle upon a given line. Note how it all follows elegantly from the previously defined terms, and keep your focus on the over-arching philosophical principle: If one agrees with stated postulates and axioms, and the proof is solidly built on logic, then one must believe in the results of a Euclidean proof. This powerful idea transcends mathematics and pervades human thought.

• Primary Writings: Plato, from The Republic.

Here Plato discusses the purposes for, and methods of, astronomy in the ideal educational syllabus (believed to be followed in Plato’s Academy). Although Plato speaks through the character of Socrates, the words and many of the ideas are thought to be his own. In this excerpt, the characters (Glaucon is actually Plato’s brother’s name) agree that one must certainly learn a good deal of mathematics – in particular, plane geometry. Then Socrates raises the question of astronomy. Note how he belittles the role of observation of the heavens as a means of arriving at truth.

• Primary Writings: Plato, from The Republic.

This is the famous Simile of the Caves passage, from The Republic, in which Plato reveals his theory of knowledge. As discussed in class, men are imprisoned within a deep cave, chained so as to be incapable of
moving their heads. Behind them is a wall, and beyond that a fire. People walk back and forth beneath the wall, holding above it various objects, including statues of humans and animals, which cast shadows on the wall of the cave visible to the prisoners. The prisoners see only the shadows cast by these statues and other objects; having lived in the cave from childhood, they no longer recall any other reality. They do not suspect that these shadows are but imperfect images of objects that they cannot see, and so they mistake the shadows for real things. The analogy here, as discussed on the first day of class, is to humans’ everyday experience with the physical world of objects, which are shown to be shadowy, imperfect replicas of the perfect objects that exist in the “world of forms”. We are all souls imprisoned in bodies. The shadows of the allegory represent the world of sense experience. The soul, peering out from its prison, is able to perceive only these flickering shadows, and the ignorant claim that this is all there is to reality.

• Primary Writings: Plato, from *The Republic.*
What does Plato think about the arts or, for that matter, any form of dramatic representation? Here’s where we find out. Along the way, there are references to many of Plato’s most significant philosophical beliefs, including, most importantly, the idea of the World of Forms, that place to which the soul aspires, and in which the true essence of all objects exists. In this passage, he begins to discuss three different possible beds: the one of forms, the one of the painter, and the one of the carpenter. As with Lucretius’ reading, think, again, about what may be left out of the reading passage. Based only on what you have read, which one do you think Plato ultimately dismisses as being farthest from the true reality of a bed?

• Primary Writings: Aristotle, from *Physics.*
Reading Aristotle’s writings is tricky. As we discussed in class, the writings of Aristotle that have been handed down to us probably don’t represent anything that he would have considered to be a “book”, or even a “work”. Though during his lifetime he wrote many dialogues and books on zoology, natural history, and physics, these have been lost. What has survived (and it is a *lot*) are believed to have been either lecture notes, or possibly even notes taken by a student in the Lyceum. Thus, it may be unfair to criticize Aristotle’s writings as difficult to follow, contradictory, or too verbose: lord knows, if someone took my lecture notes and published them, future generations would have thought I couldn’t put a sentence together. So, you may find his writings difficult to understand — but that’s part of the point of having you try to read them, actually! Many later interpreters had similarly difficult times trying to figure out just what he meant. Don’t struggle too long on anything, though; just do your best with the readings, and take comfort in knowing that these are some of the hardest readings of the course.

Since Aristotle makes such difficult reading, here is a review of what we covered in class; I hope that this will help make reading his works a bit easier. Essentially, the thing to look for with Aristotle is the “why” to every question; just describing *how* something works does not satisfy him. He always goes further and delivers an ultimate cause for everything, be it motion, change, or the movement of the stars. Prior to Aristotle, it is often said that there were basically two ways of looking at Nature: Either through the use of the senses or through use of pure logic, with the senses playing a secondary role (of course we also know that with the Ionian philosophers we do seem to get an elegant *mixture* of these two ways to understand nature). Further, there were those who believed in the reality of change and those who felt that all observed change was merely the result of seeing the imperfect shadows of the World of Forms, where everything exists in a pure, essential, and unchanging state.

Aristotle took ideas from both camps, elevating the role of the senses and empirical observation but not totally rejecting the use of logic to arrive at truth. He refused to accept Plato’s world of forms: the traits that give an individual object its character do not have a prior and separate existence in a world of forms, but belong to the object itself. In his cosmology he also found a happy medium between the two rival ideas. He claimed that the Universe consisted of two distinct places: a perfect, unchanging part that exists above the lunar sphere (i.e., the sphere that contains the Moon and rotates around the Earth once per month), and an area below the lunar sphere, surrounding and containing the Earth, which is the scene of change, corruption, decay, birth, death, etc. Aristotle thus believed that change was genuine, but confined to the sublunary sphere.

The first reading selection is from the first pages of *Physics,* and opens with Aristotle’s method of scientific inquiry. Note particularly at lines 24 and 25 where he espouses that “we must advance from generalities to particulars”: this method of logic, known as *deductive reasoning,* is a dominant theme.
throughout Aristotle’s writings. (This approach is also the one taken by Euclid in his geometric proofs.)

After discussing more about his theory of knowledge, we pick up Aristotle, in a significant statement, saying that “men do not think they know a thing till they have grasped the ‘why’ of it”. This week’s thought question asks you to delve deeply into the meaning of this statement.

In book IV, Aristotle continues the theme of how all the elements have a natural place of existence. For Aristotle, place was a fundamental thing; it has properties. Heavy bodies move toward their place at the center of the universe not because of a tendency to unite with other heavy bodies located there, but simply because it is their nature to seek that central point. All places are not equal in Aristotle’s cosmology! Notice also how Aristotle refers back to Hesiod in this excerpt.

The last tiny excerpt from Book VII of Physics is very important: it says, like Plato had before him, that there must be a cause for all non-natural (violent) motion. There is no Lucretian “Doctrine of the Swerve” for Aristotle.

• Primary Writings: Aristotle, from On the Heavens.

Aristotle believed in two kinds of motion: natural and violent. In Aristotle’s universe, there were 5 elements – four (air, earth, water, fire) belonging to the sublunary sphere, and one (the “quintessence”, or “ether”, which is sometimes spelled “aither”) belonging to the region beyond the moon. If left to their own devices, earth and water would descend toward the center; because of its greater heaviness, earth would collect at the center, with water in a concentric spherical shell outside it. Air and fire ascend, but fire, owing to its greater levity, occupies the outermost region, with air as a concentric sphere just inside it (see the class overhead). In the real sublunar world, though, things are composed largely of mixed bodies, one always interfering with another, and this ideal state (of having all the elements separated) is never attained. However, objects, depending on the proportions they possess of each element, will strive towards their natural place: a rock will fall, fire will race upwards. This is called natural motion. Violent motion occurs when motion is caused by an external force, which compels the body to violate its natural tendency and move in some direction other than toward its natural place. Lifting up a rock is an example of violent motion.

In this excerpt, we read about the “natural” and “violent” motions of objects, and the natural tendencies of the four basic elements to move in straight lines, either towards or away from the center of Earth. The observed, circular motion of objects in the heavens leads Aristotle to propose that things up there beyond the lunar sphere are composed of a completely different substance, which he calls “Aither”, or “Ether”. This divorce between things in the heavens and things on Earth remains entrenched in Western thought for nearly 2000 years.

• Primary Writings: Ptolemy (Claudius Ptolemaeus), from The Almagest.

Finally done with Aristotle, we turn now to the eminently readable writings of Ptolemy. To understand the writings fully, we need to define a few terms first:

Syzygy: the straight-line configuration of three celestial bodies (as the sun, moon, and earth during a solar or lunar eclipse). Ptolemy uses this word a lot when describing the sun-moon-Earth system. The two possible types of syzygies are conjunction and opposition; when speaking of the moon with regard to the sun, conjunction occurs when the moon is between the sun and Earth; opposition occurs when the moon is on the other side of the Earth, opposite the sun. Quadrature occurs when a line from the Earth to the Sun makes a right angle with the line from the Earth to the moon (or planet).

Claudius Ptolemaeus lived from approximately A.D. 100 to A.D. 175, and worked mainly in Alexandria, the principal city of Greco-Roman Egypt. Not much else is known about his life, except that he left to us the most complete astronomical text of antiquity, The Almagest (the actual title of the work is the Mathematical Syntaxis, but was given the more familiar name by a translator during the Middle Ages. The Almagest literally means “The Greatest” which, if nothing else, shows the profound respect accorded the work by later generations. In fact, the work is so comprehensive that most earlier writings (by the likes of Hipparchus) have not been passed down to us, having been rendered obsolete by Ptolemy’s masterwork.

The Almagest is a massive work containing 13 ‘books’, each containing many individual chapters. The
first reading passage comes from the book 1, and includes selections from the first 8 “chapters”; this is followed by a brief, highly mathematical selection from book 12, and finally the last paragraphs of the work in book 13.

The original title of the work betrays its inspiration: mathematics. Indeed, in the preface to the treatise (Chapter 1 of your reading) Ptolemy announces that speculation about divine causation of celestial motion or about the material nature of things leads only to “guesswork” and that, if the goal is to achieve certainty, the mathematical way is the only way. Often in his writings he argued that astronomical models should be chosen on the basis of mathematical simplicity (with less emphasis on physical plausibility). However, we will notice that things aren’t so cut and dry – he certainly presents physical arguments for the centrality of the earth among other things. It is thus possible to see Ptolemy as advancing Aristotle’s empiricism while reducing the certainty as to the exact causes of motions in the heavens. He describes the aims of astronomy at the outset of the work, mentioning the Aristotelian distinction between theoretical and practical studies. Note that the purpose of studying astronomy is not merely to obtain knowledge, but also to appreciate the beauty and order of the heavenly bodies. The last paragraph of the preface points to the important fact that Ptolemy was summarizing all astronomical thoughts up to his day; in addition, he probably also added a great deal of information, including original observations, although the exact extent of his contributions is hotly debated.

After the Preface, the next 7 chapters of the Almagest are presented in their entirety, during which Ptolemy proceeds to formulate and justify the fundamental physical theses on which his astronomical system is based, such as the sphericity of the heavens and earth, and the doctrine that the earth is at rest in the center of the universe (note again the influence of Aristotelian doctrines). To prove the sphericity of the heavens, he refers not only to the evidence of the observed circular motion of the circumpolar stars, but also to such physical considerations as that the heavens are composed of aether (Aristotle’s quintessence), the most homogeneous element element, and since the surfaces of homogeneous bodies will themselves be homogeneous, and the most homogeneous solid figure is the sphere, we may suppose that aether is spherical in form. Ch. 5 sets out to establish that the earth is at the center of the universe by refuting all other possible positions. In Ch. 6, we see that Ptolemy understood something about the vastness of the universe in relation to the Earth – nevertheless, the Ptolemaic universe is estimated to have measured only some fifty million miles in radius, meaning that it could easily fit inside what we now know to be the dimensions of the earth’s orbit around the sun! Next, read how slickly Ptolemy disposes of the notion that the earth might have a motion: the arguments he employs will be parroted by many thinkers right up until the time of Galileo.

We next pick up in book 12, in which Ptolemy is demonstrating the retrograde motion of Mars by means of epicycles. You certainly do not need to follow all of the steps in this derivation; the main purpose here is to impress upon you the highly mathematical nature of the bulk of the Almagest, and also that Ptolemy went to great pains to make his model accurately predict the motions of e the planets in the night sky.

After that mathematical interlude, we pick up again with 2 paragraphs to conclude the Almagest. Do read these paragraphs, as they contain an influential argument for the preference of simplicity in scientific explanation.

● Primary Writings: Ptolemy, from Tetrabiblos.
I think you will enjoy the final reading selection from the Primary Writings for this week. It contains excerpts from Ptolemy’s Tetrabiblos, the ‘Bible’ of astrology. The fact that so accomplished an astronomer as Ptolemy wrote such a serious work on astrology points to the close connection between the two disciplines in antiquity. I’ve selected a particularly amusing passage on the connection of the location of the planets to a newly born child’s temperament and physical characteristics.

● Optional Reading: Lindberg, The Beginnings of Western Science, p. 35 - 68. Good coverage of Plato’s and Aristotle’s thinking, including most of the major ideas discussed in class, as well as a few that we didn’t talk about.

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• Optional Reading: Koestler, The Sleepwalkers. Chapters 4 and 5. Wonderful reading about Plato, Aristotle, and wheels within wheels (epicycles). Gives a bit more detail about how epicycles worked than we did in class.

Weekly Thought Question

From the reading excerpts this week, Aristotle writes:

Knowledge is the object of our inquiry, and men [and, presumably, women too!] do not think they know a thing till they have grasped the ‘why’ of it (which is to grasp its primary cause).

If you could choose to have either an intimate knowledge of why something occurs, or how something occurs, which would you choose?

Assignment for Thursday, April 21

Please respond to the three following questions, drawn largely from your reading of Abell’s text from last week; you will turn in your work at the start of next Thursday’s class (April 21). The questions will be graded as simply right or wrong.

1. At what time of day or night does the first quarter Moon rise? (Assume that the sun is directly overhead at 12:00 noon local time.)

2. The Earth’s diameter is about three and two-thirds times the diameter of the Moon. What is the angular diameter of the Earth as seen by an observer on the Moon?

3. You are on a strange planet. You note that the stars do not rise or set, but that they circle around parallel to the horizon. Then you travel over the surface of the planet in one direction for 10,000 km, and at that new place you find that the stars rise straight up from the horizon in the east and set straight down in the west. What is the circumference of the planet?