AST 309L Review sheet for Exam 2

This document assumes you have completed all the reading and have looked over the suggested questions at the end of each chapter. This review first outlines the material you are supposed to read, then gives some sample questions from each part of the exam, and finally gives a long narrative review document that goes over the material from chapters 5 and 6 in more detail and with commentary.

Material on Chapter 11: detection and properties of exoplanets and biosignatures. This is ONLY sec. 11.2, lecture notes, and Wikipedia "Extrasolar planets.

11.3 (The possibility that the Earth is rare) and 11.4 (the Hertzsprung-Russell diagram) are not on the exam. We may cover 11.3 after the exam.

In Wiki: Link to page on "Methods of detecting extrasolar planets" up-to-date of notable exoplanet discoveries, with links. See **Gliese 581c,d**. Link to separate article on **"superearths"** .

- Read "Cosmic Calculations 11.1" p. 377. Understand implications of Figure 11.17. Section on "Life detection" is brief but was covered in more detail in class.
- Know something about Kepler, GAIA, SIM, Terrestrial Planet Finder/Darwin, especially what technique each will use.

The topics in 11.2 are straightforward (if technical in places), so you should let the suggested end-of-chapter questions and the review and sample questions given here be your guide. Also notice that we covered this in more detail in class, especially the material on direct detection and biomarkers. Nearly all of this can be condensed into three areas:

1. The different techniques used for exoplanet detection. The only topic in the text *not* covered in class or on the exam is the technique of "gravitational microlensing," although I do expect you to have a simple idea of what that phrase means—but you don't have to know any of the advantages or disadvantages of the technique.
2. Properties of exoplanet systems discovered so far—e.g. surprising differences or similarities to our solar system.
3. Strategies for detection of biomarkers in exoplanet absorption spectra (what molecular bands are we searching for and why?) and reflection light curve and spectrum.

- End of chapter questions RQ 3-13, QQ30-34.

Material on Chapters 5 and 6: Life, origin of life.

The material on origin of life is in some ways more challenging and intricate than that on extrasolar planets. I wanted to go a little deeper than the textbook, and so we have not caught up yet with the syllabus. For those reasons:

- I am restricting the exam to cover material in Chapter 5 up to but NOT including 5.5 (extremophiles), and will postpone sec. 6.1.
- In Sec. 6.2, the assigned reading has been reduced to a part of "How did life begin?" on pp. 198-200, only the subsections "The Miller-Urey experiment," "Other sources of organic molecules," and "The transition from chemistry to biology," because I have been including these topics repeatedly as part of the lectures so far. I will include a few extra slides on Miller-Urey in the pdf online, but will not have time to discuss in class. Do read "RNA World" which we will pick up again after this exam.

It turns out that most of the material that we intended to cover in this part of the course (Ch.5 and 6) actually fit better with the material for Part IV of the course, evolution of life and Earth, since most of it is about the history of life, not the origin of it:

- For that reason I want you to look through sec. 5.5 (life in extreme environments), but I will not question you about it on the exam. You should only realize why this topic may have nothing to do with the origin of life, only its later adaptations. Past experience shows me that it is difficult to ask multiple choice questions about extremophiles anyway.
- **Wiki entry on "Abiogenesis."** Many of the entries are short, but link to their own entries in Wiki. Most of these are for your own interest, and just to get an idea how long your textbook would be if they discussed all the ideas for the origin of life. Specific topics you should read are mentioned in the long review below.
- Be sure to try the review questions at the end of chapters 5 and 6. They are (slightly altered to reflect altered reading list):

Chapter 5: RQ 3-6, 9-12 (not 3-14 as on original reading sheet), QQ 34.
Chapter 6: RQ 4-7 (not 1-3), QQ 33-36 (not 37).
A long narrative review follows after sample questions.

AST 309L review sheet (continued):

Review and sample questions. You should be able to give clear answers, in your own words, without relying on notes or jargon, to the questions listed below. I will be glad to discuss the material with you, either on the phone or at my office or in class, but please do not ask for answers to any of the questions on this handout. If you can't answer them, you need to study more.

Part I. Extrasolar planets.

A. Some review questions. Be sure you can give clear, and in some cases concise, answers. Some of these are similar to questions occurring on the exam, although they will be encountered in the form of multiple-choice questions.

List and describe various observational methods for searching for planets, including their advantages and limitations. (The answer to this would be fairly lengthy.) Explain why it is so difficult observationally to directly detect a planet orbiting another star.

Which of the proposed methods for detecting invisible planets around nearby stars can best or only be used in cases where our line of sight to the star lies perpendicular to the plane of the planet's orbit (i.e. planet's orbit is in the plane of the sky)? How about the parallel case?

What are "free-floating planets" and how might one be discovered?

What is the current status of detections of extrasolar planets? Discuss the masses and orbital characteristics. What are the selection effects that cause us not to be able to reach definitive conclusions about, say, the fraction of stars with planets? Why is it that the confirmed detection of extrasolar planets around a pulsar might not be very useful, or at least ambiguous, for answering the planet formation questions of most interest for our course?

Describe a few of the major proposed space missions (SIM, Kepler, TPF/Darwin) designed to detect extrasolar planets, and the techniques they will employ.

What is the fundamental reason why Kepler will be able to detect smaller-mass planets than ground-based programs?

Certain elements have recently been discovered in the atmosphere of an exoplanet. What elements? What property of this exoplanet system allows astronomers to see these elements? What do these observations tell us about the eolution of the exoplanet?

Discuss which spectral or other "biosignatures" are expected to be useful in searching for life around extrasolar terrestrial-like planets.

B. Multiple choice

a. direct imaging   b. radial velocity method   c. astrometric method   d. transits

Which of the above methods
1. Can only be used for almost exactly edge-on planetary orbits (i.e. orbit parallel to line of sight)?
2. Can be used to infer the size and hence density of a planet?
3. Requires the longest time to establish the presence of a planet.

4. .Which of the following extrasolar planets would be the most difficult to detect using the Doppler shift method?
   A) a low mass planet far from its parent star
   B) a massive planet close to its parent star
   C) a low mass planet close to its parent star
   D) a massive planet far from its parent star

5. If a star has an extrasolar planet, the symmetry of its radial velocity curve is related to the planet's
   A) orbital shape   B) mass   C) radius   D) orbital period

6. How do we know that a “hot Jupiter” is not a “hot Earth,” i.e. a giant rocky planet?
a. A rocky planet would evaporate at such high temperatures.
b. We can see spectral lines of hydrogen in most of these planets’ atmospheres.
c. Because one exoplanet was detected using two methods, which allows us to determine its mass and size, so its density.
d. A giant rocky planet would move around its parent star more slowly than observed.

7. Why is this so? That is, why was this method so much more successful than others?

a. Planets at very small distances from their star have very large orbital speeds.
b. Most exoplanets turn out to be massive, providing an advantage for this method.
c. As in our solar system, giant planets tend to be at large distances from their parent stars.
d. It is the motion of the center of mass that is being observed, and this can only be detected easily using the successful method.

8. What is one surprising result of the planet detections made so far?
a. Most of the orbits are so nearly circular. b. The planets are so much more massive than Jupiter.
c. So few of the planets are much smaller than Jupiter. d. The orbital sizes (semimajor axes) of many of the planets are so small.

9. Except for a small number of exceptions, nearly all detected and confirmed extrasolar planets around solar-type stars were detected using which method?
a. astrometric b. radial velocity d. transits (eclipses) e. infrared emission
→***Why?***

<u>Sample questions for chapters 5 and 6</u>

Why do some elements make molecules more easily, and in different ways, than others?
What makes carbon especially suited to serve as the basis for life?
What are some properties of water that make it seem ideal or unique as the liquid medium for life?
What is peculiar about the amino acids that make up proteins?
What kinds of monomers make up nucleic acids? Describe how these are arranged into nucleotides and the corresponding polymer.
Explain the four levels of structure in proteins, beginning with thefirst level, the polypeptide polymer.
What is a codon? Describe the gene-protein mechanism. The genetic code has a lot of “redundancy;” what might this suggest about the earliest life forms (see discussion in text)?

Explain what was severely incorrect with the view that the Miller-Urey experiment has "solved" the problem of the origin of life? What kind of molecules do these and subsequent experiments make? How else might these molecules be made? Why might these experiments still turn out to be relevant? What sites on Earth might give an environment that resembles their assumed conditions?
What are the arguments in favor of an "exogenous" delivery of prebiotic organics to the Earth by comets or meteorites?
Until recently, most "primordial soup" theories about the origin of life could be separated into those that think self-replicating biological molecules came first (like short RNAs) and those that think proteins came first. Today there are proponents of a “membranes first” or “metabolism first” picture—what is the motivation for this?
What was the major breakthrough that resulted in the popularity of the "RNA World" picture? What are some of the problems with RNA as the first life on Earth?
What might be a function of clay minerals for the origin of life?

Sample multiple choice questions (some of which will be on the exam).

1. That carbon atoms can form rings allows for the formation of all the

a. proteins b. cell membranes c. amino acids **d**. nucleic acids

2. The Archaea *Sulfolobus* live in volcanic hot springs where they obtain energy from chemical reactions and carbon from their environment. Given this, they can be classified metabolically as

A) photoheterotrophs B) chemoautotrophs C) photoautotrophs D) chemoheterotrophs

3. Only 20 different amino acids make up proteins found in life on Earth. Why only 20?

a. Only twenty are chiral, a crucial property for life.

b. We have only four bases in our genome, and we use them three at a time.

c. These 20 comprise a sufficient range of variety of properties to allow the full spectrum of protein folding.

d. A significantly larger number would mean that DNA would have to be much longer, making it impossible to "pack" into chromosomes.

4. Which of the following biological polymers are the easiest to produce in the laboratory?

a. nucleic acids b. proteins c. lipid bilayers d. RNA

5. The key feature of DNA that allows it to reproduce is

a. the bases must be paired with complementary bases. b. its helix structure.

c. it uses a four-letter code. d. it is protected within the cell nucleus in most organisms.

6. Why is it unlikely that the earliest life forms had four bases but used only one-base "words"?

a. There could be no base pairing, so it's hard to see how replication could occur.

b. There could be no "start" and "stop" words that are crucial in gene expression and replication.

c. It would only be able to code for four amino acids, which might severely limit the complexity of proteins it could use.

d. Every organism's genome would be identical, i.e. there would be no genetic diversity.

7. Which of the following is probably *not* a problem for gene-first theories for the origin of life?

a. If you start with a short RNA-like molecule, errors will multiply rapidly during reproduction.

b. The primitive RNAs would require something like a protein to function as enzymes.

c.. It is hard to see how RNA arose initially, since it's difficult to make in the laboratory under the best of conditions.

8. What is a major implication of the existence of such a wide variety of extremophiles for understanding extraterrestrial life?

a. It shows that life may have originated in a huge variety of different environments, suggesting that our experiments so far may have been too restricted.

b. Life on Earth may not have some single "common ancestor" as was previously thought, since many of the extremophiles have very different biochemistries, use different bases, proteins, etc.

c. We should be more optimistic about finding life even on planets with seemingly harsh uninhabitable conditions because extremophiles demonstrate the extreme adaptability of life.

d. We should not be so convinced that extraterrestrial life will be carbon-based.

The LONG review of 5 and 6 follows.

Long section-by-section review of Chapters 5 and 6

A narrative review of this material seems like the clearest way to describe what I expect you to know for the exam. I stress again that this review assumes you have already read the material in the textbook, have been coming to class (or at least looking seriously at the lecture slides online), and ready to "dig in" for a more intense review. Terms that are important to know for the examine are ***italicized in bold*** when they first arise.

5.1 Properties of life on Earth. Your textbook summarizes what the authors think are seven key features of living things, but end up *defining* life in terms of reproduction and capability for evolution.

Students should understand how difficult and subjective it is to think generally about a process for which we have only one example. Also notice how some of the listed items may not even be relevant for the origin of life. For example, reproduction could not have taken place unless there is some kind of non-biological reproduction. Otherwise, how could there be a "first" organism? Similarly, evolution in the sense intended by the authors (involving reproduction, mutation, natural selection, etc.) cannot have arisen before there was life (since no one has thought of a nonbiological process that can evolve in the sense used by the authors). *So some of these items must be considered "potential for…"*

I like the authors' emphasis on "***necessary,*** but not ***sufficient***" for all the items on their list. (Make sure you understand this, since it is the reason why very few interesting things can be defined.) It is easy to give examples of things that exhibit these traits yet are obviously not living. Examples are a mule (for reproduction; a child is another example in this case), thermostat (reacts to environment, self-regulates accordingly), and electrical appliances (or automobiles, or …; utilization of energy source for functional purpose).

The item "growth and development" in contemporary living things involves (as authors say) inherited traits, i.e. they are mixing "evolution" with "development."

If some of these are not only necessary but *sufficient* for life, then it would seem like there could not be life before ***DNA***, or some other molecule that could undergo replication with error (i.e. mutation), most likely ***RNA*** (***ribozymes***). But then the obvious question is "How could something as complex as an RNA molecule arise naturally from chemical evolution?" This is the part of the material in Ch. 6 that we are postponing.

● Besides showing how elusive the entire question of "origin of life" is [notice the problematic examples of ***viruses***, ***prions***, and ***artifical life***, discussed in the text but only briefly in class], it also gets us closer to the main scientific question that underlies all the material in Ch. 5 and 6: How can chemical evolution lead from small organic molecules to the monomers used in living things (e.g. amino acids, a certain sugar, bases, … there could be others in extraterrestrial biochemistries of course), and, most seriously, to the ***polymers*** used in life—proteins, nucleic acids, etc.

● In class we combined "Order" with "Energy utilization" as a "system that decreases its entropy (increases order) by utilizing external energy," a common characterization of life. We discussed that this applies to numerous, non-living, things, and then focussed on the *kind* of order as being key: For life this order is ***modular*** and, especially, ***hierarchical***.

[If these words are not clear yet, look them up. Try to give some examples from everyday life, and among biomolecules. Several visual examples are in lecture pdfs, and for the present topics we are primarily interested in the several levels of structures in the main biological polymers.]

Your textbook sees "enegy utilization" with an eye out for sec. 5.3 on metabolism, because one candidate for the origin of life involves sets of chemical reactions (possibly within a ***lipid bilayer*** or ***vesicle***) that can be considered primitive ***metabolic networks***. Instead, we are focussing on *structure.*

In that case the problem can be stated, without any reference to reproduction or evolution, as: We are searching for ways to understand the origin of this hierarchical kind of polymer structure, starting with the singular properties of carbon-based (organic) molecules and probably a special substance, liquid water.

● Now on to sec. 5.2. It is titled "Cells," but the main point is not that life needs cells (although it might) or the structure of cells (which is anyway to complicated for this course), but the probable uniqueness of carbon as a basis for life (the possibility of ***silicon-based life*** is discussed on p. 162), and then, most importantly, the major molecular components: ***carbohydrates, lipids, proteins, and nucleic acids*** (which get their own section, 5.4). Like the textbook, we are skipping carbohydrates, but unlike the textbook we discussed "lipids" in detail (see below), and will do the same for proteins.

● This is a good point at which to go over the list of "key biological definitions" on pp. 152-153 of your textbook. There are more, but this is a good way to check if you understand some of the material.

In order to avoid any confusion, the terms in that list that are relevant for the material on this exam are the following: evolutionary adaptation, heredity, gene, genome, genetic code, DNA, RNA, organic molecule, amino acid, protein, catalysis, metabolism. Other terms you should know are italicized and in bold throughout this review.

● In sec. 5.2 (cells) the clearest example of hierarchical polymer structure, discussed in more detail in lecture, is the ***levels of structure of proteins***, and how the 3D folded structures are determined by the *specific* properties of twenty ***amino acids***. (You don't have to be able to name a single one, only understand their significance and how they join together by ***peptide bonds***.) You should also be able to explain the levels of structure in ***nucleic acids***—4 (or 5 if you include RNA) ***bases***, a ***sugar***, a ***phosphate*** → ***nucleotide*** → chain of four types of nucleotides, giving a sequence → organization of this chain into a helical (and then double-helical) structure → packing of this *very* long polymer into chromosomes (or equivalent for prokaryotes).

● Water, hydrogen bonding. Before discussing each biopolymer specifically, we surveyed the structure and special properties of water. This is covered concisely in assigned reading pp. 239-240 in text, but in more detail in lecture notes, where we emphasized how a molecular-level interaction, ***hydrogen bonding***, is behind most of these properties of water. (Can you explain what is meant by "Water is a highly ***polar*** molecule"?) These "special properties" first arises in the textbook reading in sec. 5.3 on metabolism, where the authors list three major roles of liquid water in metabolism (they were solvation, i.e. ***polar*** chemicals dissolve in water; transport to and within cells; and necessity of water for many metabolic chemical reactions). Of course there are many more, but you will see that the authors are expressing one view on the origin of life that thinks that some primitive metabolic network was needed before you could have anything as complicated as RNA or proteins.

It is somewhat ironic that water, for all its beneficial and unique properties, is probably a *hindrance* to the polymerization process, because water *hydrolyzes* biological mononers, i.e. the monomers don't associate into chains—instead the chains break up into monomers. [Just take this on faith for now—it is in sec. 6.2.]

● Hydrophobic effect, lipid membranes. Among water's special properties is one that is responsible for the structure of all biological compartments, by which I mean cell membranes (but also the boundaries of organelles in more evolved eukaryotic cells): The ***hydrophobic effect***, yet another result of hydrogen bonding. (Can you explain how?)

This leads to the first example of a biological polymer that is of great interest for origin of life: ***lipid bilayers*****,** which represent the amazing yet very simple and common tendency of *non-polar* molecules to avoid water, and polar molecules to interact with molecules (through partial charges), so that ***amphiphilic molecules*** (one end polar, the other non-polar) aggregate into a sandwich layer (***bilayer***) or else close up into a spherical layer (***micelles***= sheet of amphiphilic molecules folded in a way that the non-polar molecules avoid water), ***vesicles***=bilayer folded into a sphere). This process happens very easily, and the formation of vesicles and other related structures has been seen when chemicals from meteorites are put into liquid water (see slide in notes). For this reason, many people think *encapsulation* (formation of a permeable boundary that allows chemicals to stay in proximity and sustain their reactions) was an early, or even the first, step in the origin of life. Your textbook returns to this idea in the section on RNA world, because of recent experimental reports suggesting how lipids could have led to the polymerization of RNA.

● Other bio-polymers: Proteins.

By this point most of the ideas needed to understand why we are interested in the structure of the other biopolymers should be clear: We see in their current structure a historical development, pointing the way (we hope) toward the answer to the main question of origin of life: the formation of **hierarchical polymers** (that are ***functional***).

So we quickly proceed to the structure of ***proteins***, the astonishing way in which 20 simple molecules called amino acids, each with its own characteristics, not only link up to produce the ***primary level*** of structure of proteins (a string of amino acids), but encode in their characteristics the specific 3D structure that this chain can take, i.e. the complex process of ***protein folding*** is given completely by the sequence of amino acids along the primary structure, the famous "protein folding problem" (interesting enough to look up). Proteins are discussed concisely on p. 164 of your textbook.

Remember that this sequence of aminos, in today's life, is a translation of the sequence of bases in DNA which was the "instruction" on how to produce the sequence of aminos in the first place; i.e. the DNA sequence is turned into a functioning 3D structure (protein) by way of an amino acid sequence. Clear? (If not, you have not yet read, or at least understood, sec. 5.4 on DNA and the genetic code.) The point, which will come back to haunt us in sec. 6.2, is that it is hard to see how this could have occurred for the earliest life, since there probably were no proteins, certainly none that could code for DNA. Perhaps you already know the answer to this major dilemma, one of the few origin of life questions that has a fairly clear resolution.

● Nucleic acids, genetic code. This section begins with the structure of nucleic acids, especially DNA; this gets a paragraph on p. 164, but really has its own subsection in 5.4, which you should read in detail (see also below).

● YOU MAY SKIP THE SECTION "What are the major groupings of life on Earth?" on pp. 165-167, except to realize that there are two basic types of organisms according to the complexity of their cells (Fig. 5.10): ***prokaryotes and eukaryotes***, and that eukaryotes only developed fairly late in the history of the Earth, so this is of no relevance to origin of life, only another confusion between evolutionary matters and origin of life matters.

● I think the presentation in sec. 5.3 on ***metabolism*** is clear and does not require a parallel lecture, so you should read it on your own; it *will* be on the exam. The only difficult part is remembering the difficult-sounding ways in which organisms are categorized according to their metabolic use of ***carbon sources*** and ***energy sources***, so you end up with "chemoautotrophs", "photoheterotrophs," etc. Just remember that "chemo-" and "photo-" are just what they sound like. You don't have to memorize the full name of ATP or the energy-production cycles in which it is used, only that it is possible, or likely, that some key molecule like this was needed in order to get a sustainable metabolism going in the ancient world; also not the crucial importance of the *phosphate* group in this molecule—the energy basically comes from repeatedly making and breaking the bond with the phosphate group. This is the first time an element other than HCNO has seemed potentially necessary, maybe even sufficient.

At this point the textbook is using the fact that all life on Earth uses ATP for its energy needs as evidence that all life evolved from a ***common ancestor***, evidence that you already know of, from the fact that all life uses the same genetic code, same 20 amino acids (with a few exceptions), etc. You *should* think about which of the metabolic classes the earliest life on Earth might have belonged.

● Sec. 5.4, "DNA and heredity" is the last part of chapter 5 that will be included on this exam. Although I will cover the basic structure of DNA and its functioning as the key part of the ***genome*** in class on Tuesday, the material is well-presented in your book, so if you have read and understood the textbook version, it is unimportant whether we complete that material in lecture. In particular, the details of the genetic code will probably be skipped in class, but is well-explained in the textbook. You do NOT have to memorize that complicated-looking table (Fig. 5.15 on p. 175) showing the ***genetic code***, but it is really easy enough to understand if you sit with it for a few moments. You SHOULD be able to think about things like the "Think about it" on p. 175—what if there were only two bases, how many "words" (***codons***) would you have? Enough? Think about organisms that use *more* bases than life on Earth does. They could be *much* more complex! Or they could be impossible.

● Read through the subsection "The role of RNA," but **don't read the rest of this chapter, from p. 176 to the end.**

Now skip 6.1, and go to 6.2 The origin of life. There are basically three parts.

1. The first has to do with where the monomers for life (amino acids, etc.) came from. We have already discussed "***The Miller-Urey experiment***," "Other sources of organic molecules," and "The transition from chemistry to biology," so you should just read those sections for a coherent review of the topic.

The corresponding section in the assigned reading in Wikipedia, "Abiogenesis," is 3.1 "Origin of organic molecules".

2. The second part is the subsection on "***The RNA world***" pp. 200-202. The key points here are the primary motivation for the model, namely the discovery of "***ribozymes***," types of RNA that can act as their own catalysts; and the ideas about how this early RNA-type molecule could have been produced—the leading model, which now has some experimental support, is polymerization in pre-cell lipid membranes on the surfaces of clay minerals. This is illustrated in the cartoon at the bottom of p. 202. Wikipedia has a very concise summary of RNA World topics in the "Abiogenesis" article; you can link to a much more detailed discussion on RNA World (it has its own listing at Wiki), but I think your textbook's version is much clearer, if not as long. Notice the problems with the model and suggestions that there must have been some earlier, different molecule marking the transition to RNA.

3. Finally, read the next section, "Could life have migrated to Earth?" on your own—it is a very interesting subject, with a lot of recent work. (This migration of life is usually called "***panspermia***.") A quick search at Wiki or elsewhere will turn up a huge range of writings on this subject, so I suggest you stick to the textbook version, which is as authoritative as can be expected for this topic.

I had originally included **6.6 Artificial Life** (pp. 226-228) in the reading, but I am leaving it off the test, which already has a very large range of material. However I urge you to read it if interested, since there are some exciting (to some) new developments, especially in laboratory experiments.