Paper Abstract: Due Monday, October 9
First Draft: Due Monday, October 25
First Draft Comments: Due Monday, November 1
Second Draft: Due Monday, November 8
Final Paper: Due Monday, November 27

This paper/project is an opportunity to research a topic which particularly interests you, and which we have not had much time (perhaps any time) to pursue in class. The paper should be about 10 pages in length, with up to 5 pages for a cover page, figures, tables, and bibliography, and written using a LaTeX template that is on the course website (`template.tex`). The paper should contain an introduction that you yourself would have been grateful for when you began to research the topic, and should include material drawn from current journal articles.

Technical/scientific writing is an essential skill, that requires practice. Although the final paper is due Monday, November 27th, there will be several deadlines preceding turning in the final paper, including draft revisions based on comments by your fellow students and myself. First, a draft title and abstract (<300 words) are due on Monday, October 9th. Two copies of a complete, i.e., at least two-thirds finished, first draft are due on Monday, October 25th. These will be read by two of your fellow students and returned to you by Monday, November 1st. A second draft, at least 90% finished, (along with the two commented copies of your first draft) will be due to me on Monday, November 8th. My comments will be returned to you on Monday, November 15th, and the final draft will be due Monday, November 27th.

Part of your paper/project assignment is a presentation of about 12 minutes (plus 3 minutes of questions) to the class. The presentations will be scheduled during class on Monday, November 8th, 15th, 27th, and December 4th.

Below is a sampling of possible subjects for your paper/project. You may choose one of the following topics, modify or focus on a subsection of one of them, or come up with a subject all your own. Those of you writing theses may choose a related topic and perhaps incorporate some of this text into your thesis. Those of you that have done some research in an exoplanet-related area, may choose to build on that expertise and write a paper associated with the same area. But, most importantly, choose a topic that you find interesting. All text must be original and written this semester.

There are two categories below (computational and observational projects) that go beyond simply researching a topic and reporting on it. If you choose one of these topics, the expectation for the length of the paper text will be 5 pages, instead of 10, with the remainder used for additional figures and tables.

Possible Subjects for Papers/Projects

Detection

1. **Pulsar Planets:** Pulsar planets were the first definitely planet mass objects ever found around another star. What was the technique used to find them? What are the observational biases for this technique? What do these planets tell us about the fate of our own planet?

2. **Microlensing:** Gravitational microlensing of distant stars by a foreground star (the lens) can be modified by the presence of a planet orbiting the foreground star. However, this encounter will only occur once. What can we learn from a microlensing survey that cannot be learned from the other detection techniques? What telescopes are currently being used for this purpose and how are the observations carried out?

3. **Moons, Rings, and Nonspherical Objects:** Most planets have moons, some have rings, and maybe there are nonspherical objects orbiting stars. Are these objects detectable? How?

4. **Detection Future:** Numerous detection techniques are currently being used, each with their own strengths and weaknesses. Summarize these, and detail the parameter space currently being searched by these techniques. Discuss future prospects for exoplanet detection, given the development of these methods over the last decade from the ground and space.

5. **Kepler:** The *Kepler/K2* telescope is proving to be a highly successful mission, and its launch will likely be considered a watershed moment in the development of the field of exoplanets. What are the major discoveries that it has made since its launch, and what can we expect in the coming years? Discuss the long term impact that *Kepler/K2* will have on astronomy.

Formation

1. **Disk-Planet Interactions:** As planets are forming, they will coexist with a substantial gas and dust disk. These disks are much easier to detect that the planets themselves. Detail the interactions between planet and disk, and comment on planet-induced observables in the disk that might be used to indirectly detect an exoplanet embedded in a disk.

2. **Multiple Planet Systems:** We live in a planetary system with at least 8 planets. However, most known exoplanets are singletons. How common do we expect multiple planet systems are? What do multiple planet systems tell us about planetary formation and the individual history of those systems?

3. **Free-Floating Planets:** Given the dynamical nature of planetary systems, it is quite likely that planets are ejected from forming or nearly formed planetary systems. Can we detect these planets? Could life develop on such a planet?

Characterization

1. **Planetary Surfaces:** Surface features provide invaluable information on the current and past conditions on a planet. For example, for most of the solar system planets, these types of observations have driven the entire field of planetary science. What kinds of observations could we hope to get for surface features for exoplanets?

2. **Exospheres:** Close-in giant exoplanets have been observed to be losing mass, that is, they have unbound, upper atmospheres that extend beyond the Roche Lobe of the planet. What are the mechanisms for mass loss? What are the long-term implications for the planet?

3. **Exometeorology:** As demonstrated by the difficulty in predicting Earth's weather, despite an abundance of data, planetary atmospheres are dynamic, variable, and nonlinear. What are the prospects for measuring this temporal variability (e.g., winds speeds, phase variations)?

4. **Life on Another Planet:** Arguably, the greatest scientific discovery of the modern era would be the discovery of life on another planet. Detail the most likely path to this discovery. What will be the largest sources of error or controversy?

Observing Projects

1. **Known Transiting Exoplanets:** Identify a recently discovered transiting exoplanet. Observe at least two transits with the 24-inch Perkin Telescope. Reduce the data and fit the transit light curve.

2. **Implement Your Own Transit Search Program:** Design a program to detect new transiting exoplanets. This could be a blind search (i.e., HAT) or a targeted search (e.g., MEarth). Use the 24-inch Perkin Telescope to initiate a pilot study of your program.

3. **Kepler/K2 Data:** Download and search publicly available *Kepler/K2* data and search for exoplanet signatures. Describe your search methodology. Discuss the data quality and astrophysical variability not due to exoplanets.

4. **Exoplanet Transits of White Dwarfs:** Since white dwarfs are about the same size as planets, a transit of an exoplanet around a white dwarf will produce an easily identifiable photometric signal (see Gänsicke et al. 2016). Use the 24-inch Perkin Telescope to search for (or in the case of WD1145+017, observe) transits around nearby white dwarfs.

5. **Microlensing:** Gravitational microlensing by a star with a planet can occur over several days to weeks. Monitor microlensing alerts (see the website of a current microlensing collaboration, such as MicroFUN). Provide follow-up observations with the 24-inch Perkin Telescope. Reduce the data and characterize the microlensing event.

Computing Projects

1. **Long-Term Stability of Multiple Planet Systems:** Test the long-term stability of a wide range of orbits (perhaps habitable zone orbits) for some multiple planet systems. Use planetary system integration software (e.g., SWIFT; Levison & Duncan 1994) to test whether a low mass planet in such an orbit is dynamically stable.

2. **Transit Prediction:** Develop software to predict when a transit is likely to occur, given the orbital information derived from a radial velocity detection. Test on radial velocity data for known transiting systems, and then make predictions for some recently discovered radial velocity exoplanets.

3. **Global Climate Models:** Explore exoplanet parameter space (vary mass, waterworlds versus arid worlds, M star stellar hosts versus O stars, etc) with a GCM (MIT and NASA both have free GCM software). Discuss the sensitivity of observables (e.g., atmosphere scale height or spectral lines) to these parameters.

4. **A Solar-Gravity Lens Exo-Earth Image:** Using concentrated light at the solar gravity focus, a resolved image of an exo-Earth may be possible. Simulate observations of an exo-Earth from this position and explore the logistical challenges and the image reconstruction.

5. **Transit Timing Variation Sensitivity:** The presence of additional (undetected) exoplanets can cause variations of tens of minutes in the timing of the transit of the detected exoplanet. Develop software to calculate the timing variations (see Agol et al. 2005). Make timing variation predictions for some recently discovered systems.

6. **Simulate Planet Formation:** Much about the process of planet formation, from molecular cloud collapse to a cleared planetary system, remains unknown. Develop your own algorithm for the growth and formation of planets. While not from first principles, motivate your choices physically. Run several simulations, explore parameter space, and comment on the results.