

Take-Home Final Exam

Astro 289, Winter 2020

Due by 11:59 pm on Friday March 20th (last day of Exam Period)

Your written reports on your class projects are also due at the same time.

Please email to max@ucolick.org – be sure to put AY289 in your Subject line

Exam rules and goals:

- a) The goal of this exam is to provide a strong incentive for each of you to review the lectures and your own notes. Please take this opportunity to synthesize for yourselves what you have learned in this course, so that you can make it your own.
- b) This is an open-book take-home exam. Do it **YOURSELF**, without consulting other students. But feel free to consult all the lectures and readings on the class website and in the readings on Canvas, plus your favorite reference books and your notes. I do **NOT** want you to spend time roaming the web to find answers, so the only websites you may use are our own class site, and the concept map websites linked to from our class site.
- c) There is no particular format for your responses. But please write legibly if you are submitting a scanned hand-written exam.
- d) What I am most interested in is your conceptual understanding of adaptive optics. So when you submit your answers to the exam questions, include as much explanation as possible. I want you to write down the physical reasoning you used to reach each answer, in words or equations or both. Draw sketches wherever appropriate to illustrate your ideas.
- e) Include UNITS in all equations and formulae.
- f) In the spirit of continuing your transition from classroom students to researchers, I invite you to include in your exam your musings, questions, and hypotheses about issues that arise in the course of reading the exam questions and in the course of your review of the lectures and textbook. I want to see you think about the meaning and implications of what you are doing. (There will be extra credit for your musings ...)
- g) Remember to put your name on each page of your exam.

The exam will be in three parts, which are described in the following pages:

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| Part I. | Review |
| Part II. | Exam Questions |
| Part II. | Feedback to me on how to improve this course in the future |
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Part I. Review

Before you start the rest of this exam, take at least 3 hours to go over the lectures, your notes, and the readings. If possible do this the day before you start to work on the exam itself. Write down on the front page of your exam paper the specific times and date(s) when you did this review.

This is to encourage you to step back and take time to synthesize the material in the course. I know that you could all just sit down and work on the exam, and that you're rushed with lots of other things to do. But reviewing is the best way I know to have course material "stick" after the course is over. And that's the point.

Part II. Exam Questions

1) "Concept Map" of AO

Concept maps can be a useful method to synthesize knowledge in a topic or field. They seek to lay out the important elements or concepts, show how they relate to each other, and indicate causation or dependence between them.

I would like you each to make your own concept map that pulls together the adaptive optics concepts you've learned in this course. Please use this concept-mapping exercise to review the course material and, most important, to put the various parts in relation to each other.

For a refresher on concept maps, I've placed several items on the class website, at: <http://www.ucolick.org/~max/289/ConceptMapLinkPage.html> This page includes some examples of concept maps for technical topics, to set the stage. Please read them.

It also includes a link to instructions for how to make your own concept map. Please do NOT spend a bunch of time cruising the web and reading more instructions besides these. I am not looking for any specific format.

I'm looking for a concept map that goes into a fair amount of depth about AO. You should go down at least one or two levels below each AO subsystem (e.g. 2 levels below the "wavefront sensing" or "deformable mirror" subsystems), to show what other factors influence these subsystems and how the subsystems are related to other parts of the AO system. In these concept maps the relationships are just as important as the specific subsystems. For example you might want to show how the wavefront sensor integration time influences both the measurement error and the bandwidth error.

2) Crib Sheet¹

Please prepare your own version of a Crib Sheet on Adaptive Optics. It should be no more than two pages in 12-point font. It should contain whatever you decide are the most important concepts, equations, rules of thumb, order of magnitude estimates, etc from the class. Feel free to personalize your Crib Sheet according to your own specific interests.

3) Why is r_0 so important for AO?

The atmospheric coherence length (or Fried Parameter) r_0 plays a huge role in the design of an AO system.

- Define r_0 in words (hint – in class we gave at least two different definitions); illustrate using an equation or a sketch if you'd like.
- Describe at least four specific areas in which r_0 sets the AO requirements and influences its implementation (and cost!).
- How does r_0 scale with wavelength? Give a physical description of why this is true (not of the exact scaling in a formula, but an explanation of the trend of r_0 with wavelength). Illustrate with a diagram.
- How does r_0 scale with the strength of the turbulence, and with the path length through which the light must pass? Give a physical description of why this is true. Illustrate with a diagram.

4) Point spread functions (PSF)

- Define the point spread function in at least two ways. Explain why it is important.
- Draw a rough sketch of the PSF produced by an astronomical AO system with Strehl of 70% in a long-exposure image. Label all of the important features. Indicate on your sketch expressions for the approximate dimensions of the main features in the PSF.
- Do the same for a Strehl ratio of 10%.
- Draw a sketch of the effects of image motion on the PSF in b) above.
- Actually measuring the PSF during an astronomical observation is difficult. What ways can you think of that would enable observers to have at least an estimate of what the PSF was doing during their observation?

5) Optics (draw pictures)

- What is an aperture stop? Give an example of one, for an astronomical telescope.
- What is a pupil?
- What is the significance of a pupil in the design of an AO system?

¹ A Crib Sheet is a short list of information that you can use to help you do or remember something.

6) Optical design of AO systems:

- a) What does it mean for two locations in an optical system to be “optically conjugate”? Draw a picture to illustrate your answer.
- b) In an AO system connected to a telescope, describe at least one pair of positions that are optically conjugate to each other. Describe the physical significance of having these two positions conjugate to each other.
- c) How many more pairs of conjugate positions can you think of, in an AO system?

7) Anisoplanatism

- a) Define the isoplanatic angle, and give an expression for it.
- b) Draw a rough sketch of the physical origin of anisoplanatism.
- c) What limitations does the isoplanatic angle place on the operation of astronomical AO systems?
- d) Write an expression for the mean square wavefront error due to anisoplanatism. Would this expression be different if we lived on a planet where the atmospheric turbulence was non-Kolmogorov? Why?

8) Error Budgets

- a) What is an “error budget” for an AO system?
- b) How would you use an error budget to design a new AO system?
- c) Write down a notional error budget: what are the main contributors? (You may have to specify what science you are asking your AO system to do.)

9) Laser Guide Stars

- a) Why are laser guide stars needed, for astronomy? Be quantitative. Are there astronomical science programs for which laser guide stars are not useful or not needed? What are they, and why not?
- b) Describe the two main types of laser guide stars. Draw a sketch illustrating each. Explain the physical mechanism that scatters the light back into the telescope, for each type.
- c) What are the relative advantages and disadvantages of the two main types of laser guide stars?
- d) What is the “isokinetic angle” and why does it matter for laser guide star AO?
- e) What is the “cone effect”? Draw a sketch illustrating its physical principles. What kind of limitations does the “cone effect” impose? What quantity is used to characterize the severity of the “cone effect”?

Part III. Feedback to me on how to improve this course.

This section is intended to give me your feedback on how to improve this class in the future. You do NOT have to put your name on this section of the exam, unless you want to. If you wish you may hand it in as a separate, self-contained item.

How useful and/or valuable were the following aspects of the class:

	Not very useful	Useful	Very useful	Comments: how can these be improved? (continue comments below if there isn't enough room here)
Lectures: ppt slides				
Discussions and concept questions				
Class website				
Assigned readings				
Homework (Yes I know, there was only one problem set. But what did you think of it? How could it have been improved?)				
Class project				

What aspect of the Class Project was the most useful? The least useful?	na	na	na	Please comment here or below:
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Regarding Zoom:

a) Please suggest concrete ways in which I can improve the class experience for future Zoom users.

b) What aspects of your Zoom experience worked, and what didn't work?

c) Would an on-line discussion group or chat room be attractive to you? What should it look like? Have you had good experiences with these in other classes?

Take a deep breath. You have finished your exam.

It's been fun working with you all -- you're a great class (really!). Best of luck to you all.

Claire