SYLLABUS

OPTI 495B / 595B — Information in a Photon

3 units · Fall 2026 · James C. Wyant College of Optical Sciences, University of Arizona

Meetings	Mondays and Wednesdays, 3:30 – 4:45 PM · Meinel 307
Instructor	Daniel Soh · GCRB 441 · danielsoh@arizona.edu
Office hours	By appointment only. Email the instructor to request a meeting. There is no teaching assistant for this course.
Required text	D. Soh, Photonic Quantum Information Processing: From Classical Waves to Quantum Technologies (2026)
Course site	D2L (Brightspace). Lecture materials are posted in advance of every meeting; assignments, readings, and announcements are posted there as well.
Final assessment	Project presentations Dec 2, 7, and 9; written report due Fri Dec 11. No final examination.

Description of Course

This course asks a single question and follows it to the bottom: how much can a measurement on light possibly tell you, and what sets the ceiling? A gravitational-wave interferometer must resolve a fractional arm-length change of order 10^{-21}. Something decides whether that is achievable, and the answer is not the cleverness of the engineering alone — it is a property of the quantum state of the light itself.

The organizing object of the course is the quantum Fisher information: the quantity that converts a quantum state and a parameter to be estimated into a hard bound on how precisely that parameter can ever be known. We build it from the ground up. We begin with the quantum states of light — coherent, squeezed, thermal, entangled — and the phase-space and covariance-matrix methods that make them calculable. We then develop the measurement apparatus: interferometers, photon counting, homodyne and heterodyne detection, and the universal role of optical loss. With states and measurements in hand, we turn to the information measures themselves: Shannon and von Neumann entropy, relative entropy, trace distance, fidelity and the Bures geometry of state space, and the Holevo bound. The quantum Fisher information emerges from that geometry, and the quantum Cramér–Rao bound converts it into a limit on precision.

The course closes where it began, with sensing. We derive the standard quantum limit and the Heisenberg limit for interferometric phase estimation, show what squeezed light and entangled probes buy, and then confront the result with reality: optical loss caps Heisenberg scaling and returns the ceiling to standard-quantum-limit form. Applications appear throughout — gravitational-wave detection, sub-Rayleigh imaging by mode sorting, transmittance and displacement estimation, optical communication capacity.

The course does not assume prior background in optics, quantum mechanics, information theory, or estimation theory. It does assume comfort with undergraduate mathematics: complex numbers, probability, and linear algebra. Students who have seen quantum mechanics will find the first two weeks familiar, though treated from a more information-theoretic angle than is conventional.

Course Prerequisites or Co-requisites

- Complex numbers
- Basic probability theory
- Elementary linear algebra (vectors, matrices, eigenvalues)

This course should be accessible to most senior undergraduate and graduate students. Exposure to quantum mechanics at the level of an undergraduate modern physics course is helpful but not required. If you are unsure, please contact the instructor before registering.

Course Format and Teaching Methods

Two 75-minute lectures per week, on campus, for fourteen weeks, followed by student presentations.

Lectures follow the textbook closely and derive results at the board. Roughly the last third of each meeting is reserved for open discussion and questions, and three sessions during the semester carry no new material at all and are given over entirely to questions, worked problems, and consolidation. Students are asked to post one question on the reading before each meeting; these set the agenda.

Course Materials and Preparation

All class material is distributed on D2L in advance of the lecture it supports. For each meeting you will find, posted no later than 24 hours beforehand:

- The reading assignment, identified by specific sections of the text.
- Lecture notes or slides for that meeting, including a skeleton of the derivations to be worked at the board.
- Any figures, tables, or reference sheets used in class.

The derivation skeletons exist for a reason. This course works through the mathematics at the board, equation by equation, and a student who spends the hour transcribing is not a student who is following. Print or download the notes, bring them, and annotate them. Your attention is better spent on the steps than on the copying.

You are expected to have read the assigned sections before class. You do not need to have understood all of it — that is what the lecture is for — but you should arrive knowing where you got stuck. This is also what makes the pre-class question possible: having read the material, post one sentence on D2L identifying something that did not land. Those questions are read before each meeting and shape what gets emphasized, and they count toward the participation grade.

Office Hours

Office hours are by appointment only, and there is no teaching assistant for this course. To meet with me, send an email proposing a few times that work for you, and include a sentence on what you would like to discuss so that I can come prepared. I will normally reply within one business day.

Please do use this. A course of this kind rewards individual conversation, particularly around the final project, and an appointment system means we meet when you actually need it rather than at a fixed hour that may suit neither of us.

Because there is no teaching assistant, questions of general interest are best raised in class or posted to the D2L discussion board, where the answer reaches everyone. Three sessions during the semester carry no new material and exist precisely for accumulated questions; the pre-class questions you post also shape what gets covered. Between those channels, most difficulties can be resolved without an individual meeting.

Course Objectives and Expected Learning Outcomes

This course straddles all four tracks at the College of Optical Sciences and introduces photonic quantum information to students in optical physics, photonics, image science, and optical engineering. Its purpose is to provide a starting point for research in quantum-enhanced photonic sensing, communication, and imaging.

Upon completion of this course, students will be able to:

1. Compute the quantum Fisher information of a parametrized family of optical states, and interpret it physically as the variance of a generator.
2. State and apply the quantum Cramér–Rao bound, and determine whether a given measurement saturates it.
3. Compute and interpret the von Neumann entropy, quantum relative entropy, and Holevo information of photonic states and channels, and explain what each one bounds.
4. Explain the standard quantum limit and the Heisenberg limit in interferometric phase estimation, and quantify how optical loss constrains both.
5. Analyze photon counting, homodyne, and heterodyne detection as POVMs, and determine what information each discards.
6. Represent Gaussian states by their covariance matrices and extract purity, entropy, and entanglement from the symplectic spectrum.

Graduate students (595B) will additionally:

7. Typeset a technical report in LaTeX using the REVTeX/PRX article class — a core professional skill.
8. Independently develop an advanced research question and deliver formal results to a scientific audience.
9. Give a professional-level conference-style talk and defend the work under questioning.

Scheduled Topics and Approximate Order

Topics follow the required text. Week counts are approximate; the detailed lecture schedule is posted separately on D2L and may be adjusted with advance notice.

Unit	Topics	Text	Approx.
I	Quantum states of light — from classical waves to quantization; density operators and the photon-number ladder; coherent states, Poisson statistics, and the Poisson point process; quadratures and the uncertainty relation; homodyne detection and the standard quantum limit; squeezed states, their generation, fragility under loss, and squeezed-vacuum injection for phase sensing	Ch. 1, 2, 3, 5	Weeks 1–5
II	Phase space and Gaussian methods — the Wigner function, marginals, and homodyne tomography; Gaussian states and the covariance matrix; symplectic transformations, Williamson's theorem, and the von Neumann entropy of a Gaussian state	Ch. 6 (selected), 7	Weeks 6–7
III	Linear optics and detection — beam splitters, Hong–Ou–Mandel interference, and the Mach–Zehnder	Ch. 8, 9, 10	Weeks 7–9

Unit	Topics	Text	Approx.
	interferometer; mode sorting and sub-Rayleigh imaging; photon counting, homodyne, and heterodyne as POVMs; loss as a beam splitter; two-mode squeezing, EPR correlations, and entanglement entropy		
IV	Information measures — Shannon entropy, mutual information, classical Fisher information and the Cramér–Rao bound; trace distance, fidelity, and Bures geometry; quantum relative entropy and the quantum Chernoff bound; quantum state discrimination and the Helstrom limit; quantum channels, von Neumann entropy, and the Holevo bound	App. E, App. F, Ch. 11, 12	Weeks 9–12
V	Quantum parameter estimation and sensing — estimation as local discrimination; the quantum Fisher information; the quantum Cramér–Rao bound; phase estimation with coherent, squeezed, and NOON probes; the standard quantum limit and the Heisenberg limit; loss as the ultimate ceiling	Ch. 13	Weeks 12–15
VI	Student presentations of final projects	—	Weeks 15–16

No class Monday September 7 (Labor Day), Wednesday November 11 (Veterans Day), or Wednesday November 25. The November 25 meeting is cancelled so that students may travel for the Thanksgiving recess.

Assignments and Examinations: Schedule and Due Dates

There are six homework assignments, drawn from the exercises in the required text. Assignments are posted on D2L and are due by 11:59 PM on the stated date.

Set	Material covered
HW 1	Chapter 1; coherent states (§2.1–2.3)
HW 2	Coherent states (§2.4–2.9); quadratures and homodyne (Ch. 3)
HW 3	Squeezed states (Ch. 5); Wigner function (Ch. 6); Gaussian states (Ch. 7)
HW 4	Linear optics (Ch. 8); detection (Ch. 9); two-mode squeezing (Ch. 10)
HW 5	Classical information theory (App. E); distinguishability and the QFI (App. F)
HW 6	State discrimination (Ch. 11); channels and entropy (Ch. 12); quantum estimation (§13.1–13.4)

Late work

Deadlines matter. Work submitted between 0 and 72 hours after the deadline receives a 50% grading penalty. Work submitted more than 72 hours late receives no credit.

Each student has one extension token, usable once during the semester on any single homework set, granting five additional days with no penalty and no explanation required. Notify the instructor by email before the original deadline.

Final Project

This course has no final examination. In its place, each student completes a final project on an advanced problem drawn from the semester's material, producing both a written technical report and a conference-style presentation.

The report

Six to eight pages in APS two-column format, prepared in REVTeX 4.2 using the PRX article class. Required elements: an abstract of no more than 150 words, an introduction establishing the physical stakes, a framework section, results including at least two original figures of your own making, a discussion of limitations, references in APS style, and a short appendix containing any code used.

The presentation

Fifteen minutes plus three minutes of questions. State your result on a single slide before presenting the derivation.

Grading Scale and Policies

Component	Weight	Basis
Homework	**60%**	Six sets, 10 points each
Class participation	**20%**	See breakdown below
Final project	**20%**	Report 12, presentation 8
Total	**100%**	

Participation, in detail

Participation in this course is not a synonym for attendance. Because roughly a third of each meeting is discussion, and because three sessions are given over entirely to questions, participation is the mechanism that makes the format work.

Letter grades

80–100% = A · 60–79% = B · 40–59% = C · 20–39% = D

Requests for a grade of Incomplete (I) or Withdrawal (W) must be made in accordance with University policy: catalog.arizona.edu/policy/grades-and-grading-system

Undergraduate (495B) and graduate (595B) students

	495B	595B
Advanced homework problems	Required; counted	Required; counted
Project team	Individual	Individual
Report	Individual, REVTeX/PRX format	Individual, REVTeX/PRX format

	495B	595B
Presentation	Optional	15 minutes, individual

Use of Generative AI in this Course

Each instructor at the University of Arizona sets the AI policy for their own course. This is the policy for this course. It is also posted on the Course AI Policy page in the Start Here module on D2L. If anything below is unclear, or if you want to discuss a use not covered here, please ask me before you submit — I would much rather have that conversation in advance.

Two lanes

The work in this course falls into two categories, and they have different rules. The distinction is not about trust; it is about what each piece of work is for.

Lane	What it covers	Rule
Assured	Homework problems and their written solutions; board work in class; the physical reasoning, analysis, and conclusions of your final project; your presentation and its question period	**No generative AI. This is where I verify that you can do the physics.**
Developmental	LaTeX and REVTeX formatting, bibliography management, figure production code, and language polishing of prose you have already drafted yourself	**AI permitted, with acknowledgment.**

Specifically permitted

- LaTeX and REVTeX formatting, debugging, and bibliography management for the final report.
- Generating code examples and explaining library functions for your project figures.
- Polishing the language of prose you have already written yourself.
- Explaining background concepts, or checking your own algebra after you have worked a problem through.
- **Generating practice questions for yourself from the reading, and answering them with feedback.** This is an actively encouraged use. Recent work, including research in UA's own Educational Psychology department, finds that answering AI-generated practice questions with feedback outperforms rereading on delayed tests — even though students believe the opposite.

Specifically not permitted

- Producing solutions, derivations, or written answers to homework problems — including bonus and advanced problems.
- Generating the physical reasoning, analysis, or conclusions of your final project report.
- Drafting the substance of your presentation.
- **Generating code solutions.** Following the line drawn by MIT EECS: AI may be used for conceptual understanding and for generating code examples, but not for generating the code that produces your result. In this course the figure often is the result.

Why the homework rule is where it is

Two reasons, and I want you to know both.

The first is specific to this text. The exercises in the required book were written to be answerable by reasoning within the chapter's physical picture rather than by outsourcing the work to a language model. They are designed to build intuition, not to drill mechanical calculation. A solution you did not reason through teaches you nothing, and it will not survive questions during your presentation.

The second is evidence. In a 2025 randomized study of nearly a thousand students published in PNAS, students given an unrestricted AI tutor substantially outperformed a control group while practicing — and then scored 17 percent worse than students who never had access when tested without it. A guardrailed version removed the harm but produced no gain. Students in both AI groups judged their own learning too favorably. The pattern is that unrestricted assistance feels like learning while it is happening and is not.

Acknowledging AI use

Where AI use is permitted, it must be acknowledged. Include a short statement in the appendix of your report, in this form:

> *I acknowledge the use of [name of AI system] to [describe the specific use]. Prompts used included [prompt text or link].*

Failing to acknowledge permitted AI use, or using AI in the assured lane, is a violation of the Code of Academic Integrity — specifically, the prohibition against submitting work that is not your own. See the UA Libraries guide on citing AI: libguides.library.arizona.edu/students-chatgpt/citing

Which tools to use

Where possible, use tools covered by a University of Arizona agreement, and sign in with your U of A credentials so that your work stays in a secure, FERPA-compliant environment: U of A GenAI (genai.arizona.edu), Microsoft Copilot, Google Gemini, and Adobe tools with AI features. Consult the AI Tools and Data Use Guide at responsibleai.arizona.edu/ai-tools-guide before entering any data you are unsure about.

Additional rules for the final project

Your project is a piece of scientific writing in the format of a published paper, and professional norms apply to it.

- **Authorship.** An AI system cannot be listed as an author, because it cannot take intellectual responsibility for the work. This is the standard position of the Committee on Publication Ethics and of Optica, SPIE, IEEE, and APS.
- **Citations.** Every reference in your report must be one you have personally verified exists and says what you claim it says. Fabricated citations are not a technicality: under NSF policy effective December 2025, fabrication, falsification, and plagiarism committed through the use of AI-based tools fall squarely within the definition of research misconduct, and the author owns that responsibility. You will be writing proposals under this rule within a few years.
- **Data you do not own.** Do not paste unpublished data, results, or figures from your research group into any AI tool. Beyond the courtesy issue, export-controlled technical data placed into a commercial cloud service may constitute a deemed export, and unpublished invention disclosures should route through

Tech Launch Arizona first. If your project draws on your group's work, talk to your advisor — and to me — before using any tool on it.

How suspected violations are handled

I do not use AI detection software. University guidance does not recommend it: these tools are unreliable and biased, and they misidentify writing by non-native English speakers as AI-generated at elevated rates. Turnitin's AI detection feature has been disabled campus-wide since 2023. In a course with a substantial international cohort, running such a tool would do more harm than good.

If I have a concern, I will begin by talking with you directly. Most issues are resolved in that conversation. If a violation is confirmed and warrants escalation, I will tell you before reporting it, consistent with the University's recommended tiered approach.

Attendance and Class Participation

Participating in the course and attending lectures are vital to the learning process, and attendance is expected at all meetings. Because the course format depends on discussion, absence has a real cost to you and to the room.

The University's policy on Class Attendance, Participation, and Administrative Drop is available at catalog.arizona.edu/policy/courses-credit/courses/class-attendance-participation.

Absences for any sincerely held religious belief, observance, or practice will be accommodated where reasonable (policy.arizona.edu/human-resources/religious-accommodation-policy). The calendar of religious holidays is at registrar.arizona.edu/calendar-religious-holidays.

Absences pre-approved by the UA Dean of Students, or a Dean designee, will be honored: deanofstudents.arizona.edu/absences. If you miss class due to illness or emergency, please contact me; documentation may be requested for extended absences.

Course Communications

Course communication takes place through D2L and your official University of Arizona email address.

Code of Academic Integrity

Students are encouraged to share intellectual views and to discuss freely the principles and applications of course materials. Working through problems together is welcome and encouraged. However, graded work must be the product of independent effort unless otherwise instructed, and the write-up you submit must be your own.

Students are expected to adhere to the UA Code of Academic Integrity: deanofstudents.arizona.edu/policies/code-academic-integrity. The University Libraries offer guidance on avoiding plagiarism at new.library.arizona.edu/research/citing/plagiarism.

Selling class notes or other course materials to other students or to a third party for resale is not permitted without the instructor's express written consent. Violations are subject to the Code of Academic Integrity and may result in course sanctions, and may also constitute copyright infringement.

University Policies

The University's required syllabus policies are collected at catalog.arizona.edu/syllabus-policies. The provisions most likely to matter to you are summarized below.

Classroom Behavior

A positive learning environment is a shared responsibility. Our focus is on the work at hand rather than on extraneous activity. Please refrain from disruptive conversation during lecture. Students who continue to disrupt class after being asked to stop may be asked to leave and may be reported to the Dean of Students.

Threatening Behavior

The UA Threatening Behavior by Students Policy prohibits threats of physical harm to any member of the University community, including to oneself: policy.arizona.edu/education-and-student-affairs/threatening-behavior-students.

Accessibility and Accommodations

The University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability or pregnancy, please let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at 520-621-3268 or drc.arizona.edu to explore reasonable accommodation. Accessible seating in the classroom should remain available for students who need it.

Nondiscrimination and Anti-harassment

The University is committed to creating and maintaining an environment free of discrimination: policy.arizona.edu/human-resources/nondiscrimination-and-antiharassment-policy. Our classroom is a place where everyone is encouraged to express well-formed views and the reasons for them, in an environment free of bullying or discrimination.

Additional Resources for Students

Academic policies and procedures: catalog.arizona.edu/policies. Student Assistance and Advocacy: deanofstudents.arizona.edu/student-assistance/students/student-assistance. Confidentiality of student records (FERPA): registrar.arizona.edu/personal-information/family-educational-rights-and-privacy-act-1974-ferpa.

Subject to Change

Information contained in this syllabus, other than the grade and absence policies, may be subject to change with advance notice, as deemed appropriate by the instructor.

Calendar dates verified against the University of Arizona 2026–27 academic calendar and the Registrar's Fall 2026 final examination schedule. AI policy language adapted from the UCATT Instructor AI Policy Guide (ucatt.arizona.edu/ai-teaching/instructor-ai-policy-guide).