Syllabus: UHH ASTR 450 (F20): Astronomical Instrumentation

Prof. Klaus W. Hodapp

Goals of this course:
This course is the final course in the 3-course series on optics and astronomical instrumentation offered at UHH. We will concentrate on detector technology, the design of astronomical instruments, and practical optics design work. The goal is for the students to develop an understanding of how astronomical technology has historically evolved and how today's most common instruments are being designed, constructed and operated. Students will develop a thorough understanding of the present state of the technology of astronomical instrumentation, so that they have the background to develop plans for new instruments, or to pass judgment on such plans when working on review or funding committees. For those who plan to specialize in instrumentation, the course will give a good foundation to start on this career path, but cannot possibly teach everything there is to know about instrument development.

Logistics:

The class will be held on Tuesdays at 2:00 - 4:30 pm, once per week. Due to the COVID-19 pandemic, it will be held entirely remotely in what we call the IfA Remote Classroom 1.
This is a Zoom room reserved for this class. The zoom participation information is:

Meeting ID: 8088088301

Meeting Password: 011056

https://zoom.us/my/ifavcr1

Please join this zoom room a few minutes before the start of the class. In case of problems, I can be reached at (808) 932 2313. This is my office phone, so I will be there only shortly before the class.

Class presentations will be made available on
http://www.ifa.hawaii.edu/~hodapp/UHH-ASTR-450/ as the class progresses.

I am planning on 15 sessions of nominally 2.5 hours with a break.
This course is for three credits. Grades for this seminar will be assigned on the basis of homework assignments (40%), the student presentation (30%), and the final exam (30%). Homework assignments will be typically rather broad and sometimes open-ended questions trying to simulate the type of reports or brief conceptual studies typically required from instrumentalists. Usually, there is not a unique correct answer. Rather, you will be expected to make your own assumptions about some or most of the input

parameters, and justify your assumptions, just as you would in real life as an instrumentalist.
I encourage you to communicate and collaborate with your fellow students about the homework assignments. I insist, however, that each of you write your own version of the assignment, even if you collaborated on it. There is a significant benefit in learning to write clear, well organized technical summaries. Simply signing other people's work does not convey this benefit. Completed homework assignments should be emailed to me and be time-stamped by the UH email system before the deadline, which is the start of the next class Tuesday at 2:00 pm. Your email must be from your *@hawaii.edu account and have the subject line: ASTR 450 homework #n.

I will pre-select a number of recent papers from the biannual SPIE conferences on Astronomical Telescopes and Instrumentation, and each student will choose one paper to give a review presentation on, primarily aimed at introducing your fellow student to a specific technology or instrument. The quality of this presentation will be considered in the final grade.

The written final exam will consist of a small number of open questions, similar but not identical to homework assignments, and the answers are expected in the form of a few paragraphs of text and/or calculations with comments. The final exam will be on 12/15/20 and will be done via email. Since you will take this exam from home, it has the character of an open-book test.

This course will use the following textbook:
Electronic Imaging in Astronomy, Detectors and Instrumentation,
By Ian S. McLean
ISBN 978-3-540-76582-0 Springer Berlin Heidelberg New York or the latest edition

Course Schedule ASTR 450 in Fall 2020

ASTR-450-1 (8/25/2020)
Introduction, schedule, homework policy, grading policy
Discussion of student interest and expectations

Ground-based observations:
Atmospheric transmission
Atmospheric emission, light pollution
Turbulence and seeing
Site selection
Dome design

ASTR-450-2 (9/1/2020)
Classification of detectors:
Detector Types: coherent – incoherent
photon sensitive – thermal or bolometric
photo-emissive – semiconductor

Radio and Sub-mm Instrumentation:
Heterodyne receivers
Bolometer arrays
Transition-Edge detectors
Kinetic Induction Devices
Interferometry at radio and infrared wavelengths

ASTR-450-3 (9/8/2020)
Noise statistics : Read noise, background noise
Quantitative discussion of the human eye as an astronomical detector system
Evolution of detection systems
(catalogs, sketches, photography, electronic detectors)
Expansion of wavelength coverage over history

The silver-halide photographic process

ASTR-450-4 (9/15/2020)
The solid-state physics behind detectors:
The photoelectric effect – photocathodes
Isolators – semiconductors – metals
Electron and hole propagation, mobility, effective mass

PN junctions, diode, photodiodes, Field-effect-transistors
Typical amplifiers, source followers, operational amplifiers,
Negative feedback circuit, trans-impedance amplifier, charge integrating circuits

Detailed discussion of a simple PIN diode photometer

ASTR-450-5 (9/22/2020)
Charge Coupled Devices (CCD):
History
Basic design, 3 phase and 4 phase,
CCD fabrication, signal sampling, noise sources, dual slope integration
binning, drift scan operation

Solid state physics of silicon
Quantum efficiency of CCDs
Improvements of quantum efficiency

ASTR-450-6 (9/29/2020)
Typical design of a data acquisition system
Data reduction procedures, Performance limits
Special CCDs: OTCCD, EMCCD
Detectors for X-rays and gamma-rays

Optical CMOS imagers

Practical work with CCD camera:
flatfield, noise
simulated star photometry
data reduction (IRAF or Python)

ASTR-450-7 (10/6/2020)
IR Detector Arrays:
Basic design (hybrid technology)
Multiplexer designs and their historic evolution
Today's most common design (source follower)
Detector material choices, dark current, wavelengths, operating temperature
Infrared Photon counting systems
Far-Infrared photoconductors

Operation:
- Signal sampling, multi-sampling
- Noise sources: white, 1/f
- Reference signals and reference pixels

Typical design of a data acquisition system
ASIC operation
data reduction procedures
calculation of detector system sensitivities

ASTR-450-8 (10/13/2020)
Instrument Design Overview:
Cameras (optical and infrared)
Spectrographs (optical and infrared)
Fiber-linked spectrographs
Integral-field spectrographs
Polarimeters with emphasis on the Savart plate polarimeter
Solar instrumentation
Limitations of far-infrared instruments

ASTR-450-9 (10/20/2020)
Vacuum technology
Thermal design of cryogenic instruments
Cryogenic Technology
Cooler Technologies
Cooled space telescopes

ASTR-450-10 (10/27/2020)
Basic Optical Design (with Zemax demos):
Lens forms, basic properties
Optical aberrations
Achromatic systems
Example: designing a visual refractor
Reflective telescope designs:
Newton
Cassegrain
Ritchey Chretien

11/3/2020 Election Day
Vote for someone reasonable !

ASTR-450-11 (11/10/2020)
More optical design using Zemax or other software
Infrared optical systems:
Material selection
Transmission
Background reduction

ASTR-450-12 (11/17/2020)
Opto-mechanical design
Lens cells
Optical fabrication methods
Diamond turning
Optical Testing methods

ASTR-450-13 (11/24/2020)
Mechanical Design:
Introduction to technical drafting
Introduction to computer aided design (CAD)
Machining techniques:
- Lathe and mill work
- 3D printing

ASTR-450-14 (12/1/2020)
Student presentations based on selected SPIE papers

ASTR-450-15 (12/8/2020)
Instrumentation Project Management:
- Funding sources
- Grants vs. Contracts
- Project planning tools
- Cost estimates
- Project review
- IfA Instrumentation Division, Job order system
- Purchasing rules
- Legal issues such as International Traffic in Arms Regulations
- Instrument testing, acceptance testing
- Observatory integration and commissioning
- Maintenance
- Instrument upgrades

Final Exam (12/15/2020)