Syllabus: ASTR 634: Instrumentation

Prof. Klaus W. Hodapp

This course will offer an in-depth look at the key technologies involved in astronomical instrumentation. The goal is for the students to develop an understanding on 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. While primarily intended for astronomy graduate students, the course might also be of interest for graduate students in physics and mechanical and electronics engineering.

There will be some overlap with the subject matter of the ASTR 633 "Techniques" course, hopefully only in important areas that are worth repeating. My 634 course will concentrate on the more advanced technologies and also introduce you to the process of designing instruments.

I am planning on 12 sessions of nominally 2.5 hours (with a break) duration plus 2 sessions where students are expected to give reviews of SPIE papers in conference-style presentations (20 min + 10 min for questions). Adjustments to this schedule may be made depending on the number of students enrolled and to work around my travel plans. I will teach some sessions remotely from Hilo, via Polycom and Powerpoint presentations. For the more interactive sessions, I will come to Manoa.

This course is for three credits. Grades for this seminar will be assigned on the basis of homework assignments, two verbal presentations of SPIE papers, and a written final exam. 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. 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.

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.

Course Schedule in Spring 2015

ASTR-634-1 (1/12/2015)
Introduction, schedule, homework policy, grading policy, student paper and presentation
Discussion of student interest and expectations
The logistics of remote teaching

Classification of detectors:
Detector Types: coherent – incoherent
photon sensitive – thermal or bolometric
photo-emissive – semiconductor
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

1/19/2015 is Martin Luther King Day

ASTR-634-2 (1/26/2015)
The solid-state physics behind detectors:
The photoelectric effect – photocathodes
Isolators – semiconductors – metals
Electron and hole propagation, mobility, effective mass

The silver-halide photographic process

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-634-3 (2/2/2015)
CCD:
History
Basic design, 3 phase and 4 phase,
CCD fabrication, signal sampling, noise sources, dual slope integration
binning, drift scan operation
Visit to CCD laboratory

Solid state physics of silicon
Quantum efficiency of CCDs
Improvements of quantum efficiency
Typical design of a data acquisition system
Data reduction procedures, Performance limits
Special CCDs: OTCCD, EMCCD

Detectors for X-rays and gamma-rays

ASTR-634-4 (2/9/2015)
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

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

Photon counting systems
Far-Infrared photoconductors
Optical CMOS imagers

2/16/2015 is Presidents Day

ASTR-634-5 (2/23/2015)
Radio and Sub-mm Instrumentation:
- Heterodyne receivers
- Bolometer arrays
- Transition-Edge detectors
- Kinetic Induction Devices

Interferometry at radio and infrared wavelengths

ASTR-634-6 (3/2/2015)
Student presentations of their review papers on detectors (15 + 5 mins each)

Discussion of special topics in detectors

ASTR-634-7 (3/9/2015)
Instrument Design Overview:
Cameras (optical and IR)
Spectrographs (optical and IR)
Fiber-linked spectrographs
Integral-field spectrographs
Polarimeters

Solar instrumentation
Vacuum technology
Thermal design of cryogenic instruments,
Cooler Technologies

ASTR-634-8 (3/16/2015)
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
- Catadioptric Designs
  - Schmidt, Maksutov, Houghton, Hamilton
- Focal reducers and field correctors
- Infrared optical systems

Optical Tolerancing
Optics Mounts and supports
Optics fabrication techniques and typical performance

3/23/2015 is spring break

ASTR-634-9 (3/30/2015)
Atmospheric turbulence and Random processes
Imaging and imaging through turbulence
Wavefront sensing techniques, Wavefront reconstruction,
and Control Theory

ASTR-634-10 (4/6/2015)
Limitations - anisoplanicity, sky coverage, and basic error budgets/performance estimates
Laser Guide stars
Advanced AO concepts: Multi-conjugate AO, Ground-layer AO

ASTR-634-11 (4/13/2015)
Visit to the machine shop, practical work on lathe and milling machine

ASTR-634-12 (4/20/2015)
Mechanical design workflow

Practical experience with Computer-Aided Design (2D, 3D)
Drawing standards
Visit to the machine shop, practical work on lathe and milling machine

ASTR-634-13 (4/27/2015)
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

ASTR-634-14 (5/4/2015)
Practical experience with project planning tool.

Student presentations of their review papers (15 + 5 mins each) on instrument design

ASTR-634-15 (5/11/2015)
final written exam