ASTR-450 “Experimental Space Science”
Instruments & Methods in Astrophysics and Related Areas
Spring 2009
http://www.owlnet.rice.edu/~astr450/
Jan/18/2009

Course Instructor: Dr. Uwe Oberlack
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Lectures: Tuesday/Thursday 1:00 pm - 2:20 pm
Room HB 254
Start: Jan. 6, 2009

Office Hours: Come see me for questions or any concerns. As I share my time between office and lab, it is most efficient if you send me email to set up a time to meet.

Course Description:
This 3 credit hour course deals with instruments and methods used for measurements and observations in the areas of astrophysics, particle astrophysics, as well as solar and space physics. Instruments provide us with the means to learn about nature beyond what our senses can tell us. Even if you won't build instruments yourself, a good understanding of measurement processes, and the performance and limitations of instruments, is crucial for sensible conclusions when analyzing or interpreting data. We will discuss a selection of detectors and telescopes, and their operating principles. A module of this course will introduce statistical data analysis techniques necessary to fully exploit the wealth of data produced by modern instruments.

Prerequisites:
This course aims at advanced undergraduate students majoring in astrophysics or physics, as well as at graduate students in these research areas. Introductory physics courses and calculus are required. You also need (or you will need to acquire) basic programming skills in one of the data analysis packages IDL, Matlab, C++ with the *root* analysis package (CERN), or C/C++ with *gnuplot*.

Textbooks: (required)
1. *Statistical Data Analysis* by Glen Cowan, Oxford University Press.
   Edition: 1998 (reprinted 2002) ISBN**:** 0198501552 (paperback). Also available as hardcover.
2. *Astrophysical Techniques* by C. R. Kitchin, Taylor & Francis / CRC Press
   Edition**:** 5 (2008) ISBN**:** 978-1-4200-8243-2

Assessment:
Your grade will be based on:
Homeworks: 40%
2 exams: 40%
Project with presentation: 20%
You will typically have to read a section in one of the books or a handout before class. Participate actively in class. Don't shy away from questions or an answer you are not sure about.
Project: Every students has to research a topic defined at the beginning of the course, and present it in class (~30 min. + 10 min. discussion) together with a write-up to be distributed to class-mates. The grade is based on thoroughness of research, presentation, and write-up.
Homeworks must be done individually.

Due dates are strict!
Requests for extensions must be cleared with me by email **before** the due date, and you need valid reasons for them to be accepted.

Websites:
Course website: http://www.owlnet.rice.edu/~astr450/
We will also use the owl-space website for specific tasks: http://www.owlspace-ccm.rice.edu/
Here you will find homeworks, course notifications, updates of the syllabus, etc. Please check frequently!

Emails:
Please send course-related email to astr450@rice.edu . This will make sure your email gets proper attention.

Special Needs:
Any student with a documented disability needing academic adjustments or accommodations is requested to speak with the professor during the first two weeks of class. All discussions will be confidential. Students with disabilities should also contact Disability Support Services in the Ley Student Center.

Outline of the Course:
(This outline is likely to change during the course of the semester. Some topics may be covered by you – see Research Project)

1. Statistical Data Analysis (8 lectures)
    1.1. Definitions: probability (“frequentist”, “Bayesian”), random variables, pdf
    1.2. Error Propagation
    1.3. Distributions: Poisson, Gaussian
    1.4. Monte Carlo method
    1.5. Hypothesis testing
    1.6. Goodness-of-fit
    1.7. Maximum Likelihood estimators
    1.8. Least-Squares fit
    1.9. Confidence Intervals
    1.10. Rank Correlation
    1.11. A primer to Bayesian Statistics

2. Light as Information Carrier (1)
    2.1. Electromagnetic Spectrum & Earth's Atmosphere
        a) Seeing, Speckles, Scintillation (radio)
    2.2. Radiation Measurements
        a) Flux, Intensity, Brightness, etc.
        b) Measurements of radiation using wave, particle, or quantum properties
    2.3. Timing
    2.4. Directional Information: Imaging
    2.5. Energy Information: Spectroscopy
    2.6. Phase
        a) Coherent vs. Incoherent Measurements
        b) Interferometry
    2.7. Polarization/Spin
        a) Stokes Parameters
        b) Faraday Rotation

3. Telescopes and Basic Optics (2)
    3.1. Refraction (how does a lens form an image?)
        Snell's Law, Power, Magnification, Thick Lens, Thin Lens
    3.2. Reflection
    3.3. Two-Mirror Telescopes
    3.4. Stops and Pupils
    3.5. Fermat's Principle
    3.6. Aberrations
    3.7. Diffraction Pattern, Transfer Function, Point Spread Function
    3.8. Optical Telescope Zoo

4. Detectors, Signal-to-Noise, and Detection Limits (1)
    4.1. Detector Characteristics
        Position / energy / time resolution, efficiency, effective area, response function
    4.2. Signal-to-Noise Ratio
    4.3. Detection Limits

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5. Instrumentation in Infrared / Optical / UV (4)
    5.1. CCDs
    5.2. Spectrometers
    5.3. Adaptive Optics
    5.4. Interferometry

6. Instrumentation in Radio Astronomy and CMB Measurements (2)
    6.1. Receivers
    6.2. Antennas
    6.3. Interferometers and Aperture Synthesis
    6.4. Observation Methods

7. Instrumentation in High-Energy Astrophysics (6)
    7.1. Imaging Concepts / Apertures:
        a) Soft X-ray Mirrors, Wolter Telescopes
        b) Hard X-ray Multi-Layer Mirrors; Lobster Eye Telescope
        c) Laue Lens/Concentrator
        d) Coded Masks
        e) Rotation-Modulation Technique
        f) Compton Telescope
        g) Pair Telescope
        h) Air Cherenkov Telescope

    7.2. Detectors:
        a) Gas Proportional Counters
        b) X-ray CCDs
        c) Bolometers
        d) Scintillation Detectors (incl. PMTs, photodiodes)
        e) Semiconductor Detectors (Ge, Si, CZT)
        f) Liquid Noble Gas Detectors

8. Instrumentation in Particle Astrophysics (3)
    8.1. Cosmic Ray Detectors
    8.2. Neutrino Detectors (underground / space-borne)
    8.3. Dark Matter Detectors

9. Gravitational Wave Detectors (1)

10. Other topics ?
    - Virtual Observatories: Large Datasets
    - Electronics
    - Instrumentation in Space Physics and Planetary Sciences
        - Electric and Magnetic Fields
        - Isotopic Abundance Measurements
        - etc.

Topics for Research Project	***Date***	***Name***
Solar Telescope Missions: Trace, RHESSI, Stereo		
Cassini/Huygens: Mission & Instrumentation		
Mars Missions: rovers, orbiters, etc.		
Cosmic Microwave Background Telescopes: WMAP, Planck, etc.		
Infrared Telescopes: Spitzer, SOFIA, Herschel		
Large Optical / IR Sky Surveys (SDSS, Supernova surveys, etc.)		
Adaptive Optics for Ground-Based Telescopes		
Hubble Space Telescope: Current and Future Instrumentation		
UV Space Telescope: GALEX		
Swift Gamma-Ray Burst Telescope		
Fermi (GLAST) Pair Telescope (High Energy Gamma-Rays)		
TeV Gamma-Ray Telescopes: H.E.S.S., Veritas, MAGIC, Milagro		
Cosmic Ray Detectors: Ultra-high Energy - Pierre Auger Observatory, Low energy – PAMELA, ATIC		
Dark Matter Detectors: CDMS, XENON, etc.		
Gravitational Wave Detectors: LIGO, GEO, LISA		
High Energy Neutrino Detectors for Astronomy: Amanda/IceCube, Antares, Anita, etc.		
Solar Neutrino Detectors: Super-K, SNO, Borexino, future detectors		
Other topics you might suggest ...		