PHYS 4270 / 5390 A 4.0 2020 - 21

Astronomical Techniques

Short Course Description: An introduction to modern astronomical instrumentation, observational methods, data analysis and numerical methods. In addition to weekly lectures, the course provides students with hands-on experience with both observational and theoretical techniques of modern astronomy.

Evaluation Scheme:

|  |  |  |
| --- | --- | --- |
| **Components of Final Grade** | | |
| **Item** | **Undergrad (%)**  **PHYS 4270 4.0** | **Grad (%)**  **PHYS 5390 4.0** |
| Observing assignment (1 per term) | (2 × 15) 30 | (2 × 15) 30 |
| Pre-lecture (unit) and in-class quizzes | 20 | 20 |
| In-class/take-home problems | 35 | 30 |
| In-class presentation (1 ugrad, 2 grad) | 7.5 | (5, 7.5) 12.5 |
| Essay | 7.5 | 7.5 |
| **Total** | **100** | **100** |

There will be a single major (observing) assignment each term. Students are expected to complete several problem sets throughout the year, as well as present (individual and group) solutions to assigned problems. Developing skills – both observational and theoretical – is of fundamental importance in science. Communication is an equally essential skill for professional scientists, and so graduate students will be required to give one 10-15 min oral presentation per term, while undergraduate students will give an oral presentation in the winter term. Finally, students will be expected to write one several-page essay in a relevant area of investigation. *There will be no exams or in-class tests in this course, though in-class quizzes are possible.*

All course lectures will be delivered online. Some course lectures will be delivered in a partially “flipped” classroom style: i.e., students must complete a pre-lecture/unit quiz prior to each unit, while the lecture itself will be devoted primarily to developing and discussing important concepts and solving problems in the relevant areas.

Instructor:

(Professor) Michael De Robertis (Course Director)   
Room 326 Petrie, (416) 736-2100 × 77761

Physics & Astronomy Office: (416) 736-5249

Course and Instructor email address: [**mmdr@yorku.ca**](mailto:mmdr@yorku.ca)

Eclass (online) URL: <https://eclass.yorku.ca/eclass/course/view.php?id=8310>

Class Schedule:

Lectures: Thursdays

14:30 – 16:00

[Online by ZOOM in both the fall and winter terms:

URL: https://yorku.zoom.us/j/98126347019?pwd=Z0lsZGthb1ZKaDg3TExTR2tqeTZ5dz09

Meeting ID: 981 2634 7019]

Office Hours:

Any time by e-mail

Important Dates:

For a list of the important sessional dates, refer to: <https://registrar.yorku.ca/enrol/dates/fw20>

The following dates should be noted, however:

|  |  |
| --- | --- |
| **Event** | **Date(s) 2020-21** |
| First Class (F term) | Sep 10 |
| Fall Reading Week (no classes held) | Oct 10-16 |
| Last Class (F term) | Dec 03 |
| First Class (W term) | Jan 14 |
| Reading Week (no classes held) | Feb 13-19 |
| Last Class (W term) | Apr 08 |
|  |  |
| Last date to enroll *without* permission of instructor | Sep 22 |
| Last date to enroll *with* permission of instructor | Oct 27 |
| **Last date to drop course without receiving a grade** | **Feb 05** |
| **Course Withdrawal Period (“W” on transcript)** | **Feb 06 – Apr 12** |

Academic Policy Issues:

Students must be aware of University policies regarding:

1. Academic honesty: For the Senate policy on academic honesty, refer to: <http://www.yorku.ca/secretariat/policies/document.php?document=69> [You may not claim credit for someone else’s work/ideas without proper attribution.]
2. Religious Observances. For the Senate policy on religious observance, refer to: <https://w2prod.sis.yorku.ca/Apps/WebObjects/cdm.woa/wa/regobs> and http://registrar.yorku.ca/sites/registrar/files/pdf/exam\_accommodation.pdf . [You must give your instructors no fewer than 14 days’ notice if you cannot hand in work or sit a test/exam due to a religious observance.]

Suggested Text:

### No text will be required. Detailed course notes incorporating reference materials for in-class discussions will be provided for each unit/chapter covered. These notes, with other supporting materials, will be accessible from the course (Eclass) website.

### A list of reference materials, including (reference) books and web links, will be provided throughout the course.

Other General References:

### *Observational Astronomy,* 2nd edition by D. Scott Birney, Guillermo Gonzalez and David Oesper (Cambridge U.)

[Not applicable in 2020-21: A copy of this text is on one-day hold in the reference section of the Steacie Science and Engineering Library. The “text” will be regularly and extensively supplemented with in-class material that can be found on the class website.]

### Astrophysical Techniques, 5th edition (2009)

### By C.R. Kitchin (CRC Press).

### [Not applicable in 2020-21: A copy of this text is on three-day hold in the reference section of the Steacie Library.]

### General Astronomical References:

### 2000*. Allen’s Astrophysical Quantities*, New York: Springer (ed. A.N. Cox).

### Lang, K.R. 1999. *Astrophysical Formulae* (3/e), New York: Springer.

### 2020, 2021. *The Astronomical Almanac*, Washington: U.S. Government Printing Office

### 2020, 2021. *The Observer’s Handbook*.

### Other Astronomical Instrumentation and Techniques:

### Birney, D.S., Gonzalez, G., & Oesper, D. 2006. *Observational Astronomy,* Cambridge: Cambridge U. Press.

### Budding, E. 1993. *An Introduction to astronomical photometry,* Cambridge: Cambridge U. Press.

### Henden, A.A. & Kaitchuck, R.H. 1990. *Astronomical Photometry,* Richmond, VA: Willmann-Bell.

### Howell, S.B. 2006. *Handbook of CCD Astronomy,* 2nd ed., Cambridge: Cambridge U. Press.

### Lena, P. 2012. *Observational Astrophysics,* 3rd ed.,Berlin: Springer-Verlag.

### Smart, W.M. 1977. *Spherical Astronomy*, 6th ed., Cambridge University Press.

### Sterken, Chr. & Manfroid, J. 1992, *Astronomical Photometry – A Guide,* Dordrecht: Kluwer Academic Publishers

### Tyson, R.K. & Frazier, B.W. 2004. *Field Guide to adaptive optics,* SPIE.

### Wall, J.V. & Jenkins, C.R. 2003. *Practical Statistics for Astronomers,* Cambridge: Cambridge U. Press.

### Some helpful links:

### W. Keel <http://www.astr.ua.edu/keel/techniques/>

### C. Mihos <http://burro.cwru.edu/Academics/Astr306/index.html>

### R. O’Connell <https://faculty.virginia.edu/rwoclass/astr511/ALL-Lec.pdf>

### M. Richmond <http://spiff.rit.edu/classes/phys445/phys445.html>

Astronomy Picture of the Day (APOD): <https://apod.nasa.gov/apod/astropix.html>

Canadian Astronomy Data Centre (CADC): <http://www.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/>

NASA/IPAC Infrared Science Archive (IRSA): <https://irsa.ipac.caltech.edu/frontpage/>

SAO/NASA Astrophysics Data System (ADS): <https://ui.adsabs.harvard.edu/>

Set of Identifications, Measurements, and Bibliography for Astronomical Data

(SIMBAD) <http://simbad.u-strasbg.fr/simbad/>

VIZIER: <https://vizier.u-strasbg.fr/>

[York University links to note:

Allen I Carswell Observatory website: <https://observatory.info.yorku.ca/>

Allen I. Carswell Observatory videos: <https://www.youtube.com/user/YorkUObservatory/>

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### Course curricula and outcomes:

1. Radiation (Photometry)

* Review relevant radiation quantities and units used in modern astrophysics, including luminosity, (integrated) flux, (monochromatic) flux, spectral energy distribution, the magnitude system and the concept of atmospheric extinction.
* Describe the most common photometric systems, including Johnson-Kron-Cousins and SDSS (AB).
* Ability to determine the first- and second-order extinction coefficients, transformation coefficients and zero points for a photometric system using photometric data
* Familiarity with techniques of aperture photometry, curve of growth analysis and aperture corrections, as well as differential photometry.

2. Detectors (CCDs)

* Describe CCDs from both an Engineer's (physics and construction) and an Observer's (calculation of signal-to-noise ratios and exposure times for arbitrary background and source signal) perspective.
* Familiarity with the acquisition – including taking calibration and science frames/images – and the reduction of CCD data using utilities in IRAF.
* The ability to reduce a dataset from a cryogenically cooled CCD camera.
* Ability to write a queue-observing proposal for acquiring imaging data for an open cluster in multiple filters using the 1 metre telescope of the Allen I. Carswell Observatory and the reduction of the data

3. Telescopes

* Describe the optics and relevant parameters for both refracting and reflecting telescopes, including their advantages and disadvantages, and the different foci of reflecting telescopes including the Cassegrain and Nasymth foci.
* Discuss the parameters inherent in the measurement of image quality of point-spread functions for ground-based (seeing) and space-based (diffraction-limited) images.
* Familiarity with the equatorial and alt-az mounts, their advantages and disadvantages.
* Identify the important factors used to site world-class ground-based telescopes in the 21st century

4. Positional Astronomy

* Aware of the nature of the Celestial Sphere
* Ability to calculate quantities using spherical trigonometry / to solve spherical triangles
* Familiarity with most common coordinate systems, including alt-az (horizon) and equatorial (RA, Dec), as well as hour angle
* Ability to convert positions between different coordinate systems.
* Appreciation of role of time (synodic and sidereal) in observational astronomy, how it is measured and used to point a telescope to a point on the celestial sphere.
* Familiarity with the various errors associated with an object's position as a result of the atmosphere and various motions, including refraction, airmass, aberration, proper motion, parallax, precession, nutation, and Earth's orbital motion

5. Adaptive Optics

* Review image quality parameters for diffraction-limited imaging
* Discuss the role turbulence plays in distorting plane-parallel wave-fronts
* Describe the difference between active and adaptive optics
* Awareness of the critical parameters: coherence length and time-scale, isoplanatic angle and Strehl ratio
* Describe the nature of the wave-front sensor and the Zernike modes (polynomials) that are used to correct wave-fronts on kHz time-scales through a deformable secondary mirror
* Describe the theory behind laser/artificial guide stars and the concept of multi-conjugate AO
* Discuss the most recent A.O. instrumentation on the world's largest telescopes, including ground-layer AO systems

6. Spectroscopy

* Review principle of refraction
* Describe the construction and properties of diffraction gratings (and grisms), including slit width, the grating equation, spectral orders, cross-dispersion, the line-spread function and theoretical spectral resolution
* Discuss the design of typical spectrographs, especially the dispersive element and the camera
* Familiarity with the advantages and disadvantages of the long-slit and fibre-fed spectrographs (including wide- and integral-field spectrographs)
* Describe the process used to reduce long-slit CCD spectroscopic data and employee these techniques on a spectroscopic dataset

7. Goodness of Fit Tests

* Describe the concept of a probability distribution function, both differential and cumulative
* Discuss the Maximum Likelihood Estimator method and the Chi-squared parametric methods
* Discuss the Kolmogorov-Smirnov (K-S) non-parametric test (and the Kuiper variant)

8. [Time permitting] Data (Monte Carlo) Simulation of Astronomical Data

Important Things to Note:

* *Developing and sharpening astronomical skills is the focus of this course.*
* *Both individual and group work will be required, though all assignments must be unique, reflecting your own effort.*
* *Night-time observing (with one or more partners) is a requirement, though for only a couple of nights in each term.\**
* *The ability to write either simple computer programs or to use a spreadsheet (e.g., Excel) will be important; the use of a program like PowerPoint will be helpful for oral presentations; the use of a word processing program (e.g., Word) will also be necessary for formal write-ups (such as the essay). Elementary image-processing techniques will be developed in this course (e.g., using IRAF).*

\* hands-on observing will not be required in 2020-21 due to the pandemic. Students will, however, be required to submit observing proposals to acquire data with the assistance of technical staff using the 1 metre telescope at York University’s Allen I. Carswell Observatory.

Course Content:

1. Radiation and Photometry:

* Radiation
* Magnitude systems
* Atmospheric extinction
* Photometry & Photometric Equations
* Absolute Photometry
* Differential Photometry
* Measuring Instrumental Magnitudes
* Statistics and Uncertainties

1. Detectors: CCDs and NIR arrays:

* Basic CCD – physics
* CCDs – general construction (mosaics)
* CCDs – Readout
* CCDs – Future
* CCDs – Observer’s Perspective
* CCD Calibration
* Noise, Signal-to-Noise Ratio

1. Telescopes:

* Types
* Mounts
* Siting a Large Telescope
* Seeing

1. Positional Astronomy and Atmospheric Challenges:

* Co-ordinate systems
* Refraction, Air Mass, Aberration, Proper Motion, Parallax, Precession & Nutation
* Time
* Precession & Nutation, Proper Motion and Parallax

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1. Adaptive Optics:

* Image Quality
* Active Optics
* Adaptive Optics
* Theory
* Laser Guide Stars
* Multi-Conjugate Adaptive Optics

1. Spectroscopy:

* Spectrographs
* Diffraction gratings
* Slits and Sampling
* Observing Techniques and Data Reduction
* Wide-field, multi-object spectroscopy
* Data Reduction Techniques

1. Statistics:

* Goodness-of-fit
* Parametric and Non-parametric Tests (e.g., χ2 and K-S)
* Application to astronomical problems/contexts

1. Monte Carlo (Stochastic) Modelling/Simulations:

* Selection of random variate from arbitrary distributions
* Application to astronomical problems

Computing Requirements:

Students will be required to submit some assignments prepared using a word processor (e.g., WORD), as well to perform some calculations using a spreadsheet (e.g., EXCEL). Access to intensive computing facilities will not be required for this course.

Students will be required to have access to an X-windows environment in order to use IRAF – Image Reduction and Analysis Facility – software which operates primarily in the unix/linux environments. Access to IRAF will be provided on some machines accessible from campus; details will be provided on how to run IRAF from any Windows machine connected to the network (e.g., from off campus).

Observational Projects:

Students will be required to undertake one observing project each term. Given precautions resulting from the pandemic, the precise nature of each of the observing projects is still to be determined. There will likely be a photometric project in the fall term and a spectroscopic project in the winter term. Data reduction and analysis will be undertaken using IRAF. It is hoped that some data will be acquired with the new one-metre class telescope and CCD camera associated with Allen I. Carswell Observatory.

Communications’ Skills:

A professional astronomer must be able to share her research in a variety of contexts, including in written and oral formats. Students will gain experience in scientific writing through submission of solutions to problems and of a final-term essay. Students will gain experience in composing and giving a scientific oral presentation in the format used in major scientific conferences.