PROGRAM OF THE POSTGRADUATE STUDIES IN ASTROPHYSICS

Academic Coordinator

André de Castro Milone

Board of Postgraduate Studies

André de Castro Milone, Academic Coordinator (President)
João Braga, Deputy Academic Coordinator (Vice-President)
Cláudia Vilega Rodrigues
José Carlos Neves de Araujo
Fernando Falkenberg Marques, Students Representative
Helissa Helen da Costa, Deputy Students Representative

Faculty Members

Permanent Members

1. Alberto Rodriguez Ardila - Doctor, UFRGS, 2000
2. André de Castro Milone - Doctor, USP, 1996
3. Carlos Alexandre Wuensche de Souza - Doctor, INPE, 1995
4. Cláudia Vilega Rodrigues - Doctor, USP, 1997
5. Diego Antônio Falceta Gonçalves - Doctor, USP, 2005
6. Flavio D'Amico - Doctor, INPE, 1997
7. Francisco José Jablonski - Doctor, USP, 1989
8. Grzegorz Kowal - Doctor, Uniwersytet Jagielloński, Polonia, 2006
9. João Braga - Doctor, USP, 1990
10. Joaquim Eduardo Rezende Costa - Doctor, INPE, 1990
11. José Carlos Neves de Araujo - Doctor, USP, 1990
12. Odylio Denys de Aguiar - Doctor, Louisiana State University, USA, 1990
13. Oswaldo Duarte Miranda - Doctor, USP, 1997

Collaborator Members

14. Camila Paiva Novaes - Doctor, INPE, 2015
15. Jaziel Goulart Coelho - Doctor, ITA, 2013
16. Massimo Tinto - Doctor, University College, Wales (UK), 1987
17. Rafael da Costa Nunes - Doctor, UFJF, 2018

COURSES

OBLIGATORY COURSES

AST-200-3	Stellar Evolution I
AST-202-3	Stellar Evolution II
AST-203-4	Observational Techniques in Astrophysics
AST-204-4	Radiative Processes I

ELECTIVE COURSES

AST-300-3	Gravitational Wave Astrophysics
AST-301-4	Plasma Astrophysics
AST-302-4	Experimental Technicques in Radioastronomy
AST-305-3	Current Problems in Astrophysics
AST-306-3	Radiative processes II
AST-307-4	Quantum Mechanics I
AST-308-4	Extragalactic Astrophysics
AST-402-4	Introduction to General Relativity
AST-404-4	High Energy Astrophysics
AST-405-4	Infrared Astrophysics
AST-406-3	Solar radiophysics
AST-409-3	Physics of the interstellar medium
AST-411-3	Time series in Astrophysics
AST-412-3	Cataclysmic Variables
AST-413-4	Fundamentals de Cosmology
AST-414-3	Stellar populations
AST-415-3	Special Topics in Astrophysics
AST-416-3	Fundamentals of Astrobiology
AST-417-3	Astrostatistics
AST-408-4	Computational Astrophysics

DESCRIPTION OF THE GRADUATE COURSES

OBLIGATORY COURSES

AST-200-3	Stellar Evolution I

Prerequisites: none.

Observational properties of stars. Equations of the stellar structure. The equations of the gas state. Physical conditions, thermodynamics, transport of energy and nuclear processes in the stellar interior. Polytropic stellar models.

Bibliography

BÖHM-VITENSE, E. Introduction of Stellar Astrophysics - Volume 3 Stellar Structure and Evolution. Cambridge University Press, 1989.

CLAYTON, D.D. Principles of Stellar evolution and nucleosynthesis. University of Chicago Press, 1983.

HANSEN, C.J., KAWALER, S.D. & TRIMBLE, V. Stellar Interiors - Physical Principles, Structure, and Evolution. Springer, 2004.

KIPPENHAHN, R., WEIGERT, A. & WEISS, A. Stellar Structure and Evolution. Springer – A&A Library, 2012.

MACIEL, W. J. Introdução à Estrutura e Evolução Estelar. Editora da Universidade de São Paulo, 1999.

NOVOTNY, E. Introduction of Stellar Atmospheres and Interiors. Oxford University Press, 1973.

ROSE, W. K. Advanced Stellar Astrophysics, Cambridge University Press, 1988

AST-202-3	Stellar Evolution II

Prerequisite: AST-200-3

Stellar formation, evolution prior to the main sequence with different masses; main sequence; evolution post-main sequence with different masses; later stages of stellar evolution; final stages: white dwarfs, neutron stars, black holes; stellar evolution in binary systems.

Bibliography

CAMENZIND, M. Compact Objects in Astrophysics. Springer, 2007.

CARROL, B. W. & OSTLIE, DALE A. An introduction to Modern Astrophysics. Addison-Wesley,

1996

CLAYTON, D.D. Principles of stellar evolution and nucleosynthesis. University of Chicago Press, 1983.

HANSEN, C.J.; KAWALER, S.D. & TRIMBLE, V. Stellar Interiors – Physical Principles, Structure, and Evolution. Springer, 2004.

HARWITT, M. Astrophysical Concepts, Springer-Verlag, 4th Ed., 2006.

KIPPENHAHN, R.; WEIGERT, A.; WEISS, A. Stellar Structure and Evolution. Springer-Verlag, 2nd Ed., 2012

LEBLANC, F. An Introduction to Stellar Astrophysics. Wiley, 2010

MACIEL, W.J. Introdução à estrutura e evolução estelar. EDUSP, 1999.

PRIALNIK, D. An introduction to the Theory of Stellar Structure and Evolution (2nd ed). Cambridge, 2010

ROSE, W. Advanced Stellar Astrophysics. Cambridge, 1998

SHAPIRO, S. & TEUKOLSKY, S. Black Holes, White Dwarfs, and Neutron Stars: the physics of compact objects. Wiley (2004).

AST-203-4	**Técnicas Observacionais de Astrofísica**

Prerequisites: none.

Astronomical coordinates. Earth atmosphere: structure and radiative processes. Astronomical detectors. Telescopes. Photometry. Polarimetry. Spectroscopy. Data analysis.

Bibliography

BEVINGTON, P. R. & ROBINSON, D.K. Data reduction and error analysis for the physical sciences. 3a. ed., McGraw-Hill Inc., 2002

BRADT, H., Astronomy Methods: A Physical Approach to Astronomical Observations, Cambridge Univ. Press, 2004.

GRAY, D. F. Observation and analysis of stellar photospheres. 3a. ed., Cambridge Univ. Press, 2008.

HOWELL, S. B., Handbook of CCD Astronomy, 2a. ed., Cambridge, 2006

KITCHIN, C.R. Astrophysical Techniques. 5a. ed., CRC, 2008.

LÉNA, P., LEBRUN, F., MIGNARD, F. Observational Astrophysics. 2a. ed., Springer-Verw, 1998.

MCLEAN, I. S. Electronic imaging in astronomy: detectors and instrumentation. Springer & Praxis. 2008.

WALKER, G. Astronomical observations: an optical persperctive. Cambridge Univ. Press, 1987

AST-204-4	Radiative processes I

Prerequisites: none.

1. Fundamental concepts of radiative transfer: the specific intensity and its moments; the radiative transfer equation; thermal radiation; blackbody radiation; Einstein coefficients; scattering; radiative diffusion.
2. Basic theory of radiation fields: electromagnetic waves; radiation spectrum; polarization.
3. Radiation from moving charges: the Liénard-Wiechart potentials; radiation fields; Larmor's formula; Thomson scattering; radiation from harmonically bound particles.
4. Radiation from relativistic particles: four-vectors and tensors; the electromagnetic tensor; fields of a uniformly moving relativistic particle; emission from relativistic particles.
5. Bremsstrahlung
6. Synchrotron radiation: total emitted power, spectrum; polarization.
7. Radiation by inverse Compton scattering: Comptonization

Bibliography

RYBICKI, N., LIGHTMAN, S. Radiative Processes in Astrophysics. Wiley, NY, 1979.

SHU, F. The Physics of Astrophysics. Univ. Science Books, 1992

JACKSON, J.D. Classical Electrodynamics (2nd Ed.). Wiley, 1975

ELECTIVE COURSES

AST-300-3	Gravitational Wave Astrophysics

Prerequisites: none.

Gravitational waves (GW): Nature, introduction to general relativity (GR), mathematical derivation from GR, generation, propagation, principle of detection;

GW Sources: man-made, astrophysical, cosmological;

Detectors/observatories: resonant-mass (bars and spheres, Schoenberg), laser interferometers, pulsar timing arrays, EM CMB detectors, high frequency detectors, other detectors;

Instrumentation: noise sources, quantum noise, thermal noise, seismic noise, Newtonian gravitational gradients forces, vibrational isolation, scattered light, laser intensity and frequency noises, coupling of angular fluctuations to displacement, diagnostic and noise minimisation techniques, cryogenics, core optics, coatings, laser sources, quantum enhancements, SAS & SUS, auxiliary optics, simulation and controls, and calibration;

Data acquisition and processing: data acquisition, digital filtering, noise analysis, quantum limiting and performance prediction, detections/observations already performed, physics and astrophysics learned from those detections/observations;

Future detectors/observatories: ET, Cosmic Explorer, AIGO, LIGO-India and SAGO.

Bibliography

MAGGIORE, M. Gravitational Waves: Volume 1: Theory and Experiments. Oxford, 2007.

MAGGIORE, M. Gravitational Waves: Volume 2: Astrophysics and Cosmology. Oxford, 2018.

REITZE, D., SAULSON, P.; and GROTE, H. Advanced Interferometric Gravitational-Wave Detectors, two volumes in "100 Years of General Relativity – vol. 5", World Scientific, 2019.

MISNER, R.; THORNE, K.; and WHEELER, J.C. Gravitation. Freeman, San Francisco, 1973.

THORNE, K.S. Gravitational Radiation. In 300 Years of Gravitation, ed. by HAWKING, S; ISRAEL, W.. Cambridge, 1987.

WEBER, J, General Relativity and Gravitational Waves. Interscience, NY, 1961.

BLAIR, D.G. The Detection of Gravitational Waves. Cambridge, 1991.

WEINBERG, S. Gravitation and Cosmology. Wiley, NY, 1972.

WILL, C.M. WAS EINSTEIN RIGHT. Basic Books, NY, 1986 HAWKING, S; ISRAEL, W. 300 Years of Gravitation. Cambridge, 1987.

AGUIAR, O.D. Parametric Motion Transducer for Gravitational Wave Detectors. INPE-5238- TAE/ 002, 1991.

DAVIES, P.C.W. The Search for Gravity Waves. Cambridge, 1980.

Papers on the above topics.

AST-301-4	Plasma Astrophysics

Prerequisite: AST-204-4

Interaction of electron beams with plasmas, Langmuir wave generation. Wave to radiation conversion: linear and nonlinear mechanisms. Collisions, "Landau damping". Propagation of waves in cold plasmas. Shocks, discontinuities and solution. Gyrosincrotron and syncrotron radiation. Emission of ultra-relativistic particles in a plasma. Solar X-ray sources. Solar and non-solar gamma radiation.

Bibliography

CHEN, F. Introduction to Plasma Physics. Plenum Press, 1974.

RAMATY, R. Journal of Geophysical Research A: Space Physics. vol. 73, nº 11, June 1, 1968 pp.3573.

RAMATY, R. The Astrophysical Journal. vol. 158, nov., 1969. pp. 753.

WILD, J.P.; SMERD, S.F.; Weiss, A.A. Anual Review of Astronomy and Astrophysics. pg. 291, 1963.

KAPLAN, S.A. and TSYTOVICH, V.N. Plasma Astrophysics. Pergamon Press, 1973.

ZHELEZNYAKOV, V.V. Radio Emission of the Sun and Planets. Pergamon Press, 1970.

GEORGE BEKEFI Radiation Processes in Plasmas Hardcover. Wiley, 1966.

ARNAB RAI CHOUDHURI The Physics of Fluids and Plasmas: An Introduction for Astrophysicists. Cambridge University Press, 1998.

AST-302-4	Experimental technics in radioastronomy

Prerequisites: none.

Installation of a Radio Observatory. Earth atmosphere propagation. Antennas for radio astronomy. Wave polarization. Parabolic Antenna Calibration. Feeders and illumination effects. Resolution and sensitivity. Analysis of efficiency parameters. Radiometry: radiometers, amplifiers, mixers, oscillators, waveguides, generators. Radio astronomical parameter settings. Radiometers used in radio astronomy. Spectral analysers. Antennas and interferometers. Data acquisition systems. Observational methods.

Bibliography

KRAUS, J.D. Radio Astronomy. Wiley, NY, 1965.

KRAUS, J.D. and CARVER, RK Eletromagnetics. McGraw-Hill, 1973.

MEEKS, M.L. Astrophysics - Part C - Methods of Experimental Physics. Vol. 12, Academic Press.

BAARS, J.W.M. Dual Bean Parabolic Antennas in Radio Astronomy.

AST-305-3	Current problems in astrophysics

Prerequisites: AST-200-3, AST-204-4, AST-203-4 and AST-202-3.

An open course aimed to discuss the main current problems in astrophysics. The course is mainly based in seminars of specific topics.

Bibliography

BAHCALL, J.; OSTRIKER, J. Unsolved Problems in Astrophysics. Princeton University Press, 1997.

AST-306-3	Radiative processes II

Prerequisites: AST-204-4

1. Plasma effects on radiation: dispersion; Faraday rotation; Cherenkov radiation; the Razin effect.
2. Review of atomic structure: Shrödinger equation; Hydrogen atom; many-electron atoms; level splittings, term diagrams, L-S coupling, Spin-orbit interaction; Zeeman effect; hyperfine structure; thermal distribution of energy levels and ionization: the Saha equation.
3. Radiative transitions: the transition probability; the dipole approximation; oscillator strengths; selection rules; transition rates; line broadening mechanisms.
4. Molecular transitions: the Born-Oppenheimer approximation; electronic binding of the nuclei; pure rotation spectra; rotation-vibration spectra; electronic-rotation-vibration spectra.

Bibliography

RYBICKI, N.; LIGHTMAN, A. Radiative Processes in Astrophysics. Wiley. NY, 1979.

SHU, F. The Physics of Astrophysics. Univ. Science Books, 1992.

DOPITA, M.; SUTHERLAND, R. S. Astrophysics of the Diffuse Universe. Springer, 2003.

OSTERBROCK, D. Astrophysics of Gaseous Nebulae and Active Galactic Nuclei. University Science Books, 1989.

GRAY, D. Observation and Analysis of Stellar Photospheres. Willey, 1992

NOVOTNY, E. Introduction to stellar atmospheres and interiors. Oxford, 1973.

AST-307-4	Quantum Mechanics I

Prerequisites: none.

I. Fundamental Concepts

I.1 The Stern-Gerlach Experiment
I.2 Kets, Bras, and Operators
I.3 Base Kets and Matrix Representations
I.4 Measurements, Observables, and the Uncertainty Relations
I.5 Change of Basis
I.6 Position, Momentum, and Translation
I.7 Wave Functions in Position and Momentum Space

II. Quantum Dynamics
II.1 Time-Evolution and the Schrödinger Equation
II.2 The Schrödinger Versus the Heisenberg Picture
II.3 Simple Harmonic Oscillator
II.4 Schrödinger's Wave Equation
II.5 Elementary Solutions to Schrödinger's Wave Equation
II.6 Propagators and Feynman Path Integrals
II.7 Potentials and Gauge Transformations

III. Theory of Angular Momentum
III.1 Rotations and Angular-Momentum Commutation Relations
III.2 Spin 1/2 Systems and Finite Rotations
III.3 S0(3), SU(2), and Euler Rotations
III.4 Density Operators and Pure Versus Mixed Ensembles
III.5 Eigenvalues and Eigenstates of Angular Momentum
III.6 Orbital Angular Momentum
III.7 Schrödinger's Equation for Central Potentials
III.8 Addition of Angular Momenta
III.9 Schwinger's Oscillator Model of Angular Momentum
III.10 Spin Correlation Measurements and Bell's Inequality
III.11 Tensor Operators

IV. Symmetry in Quantum Mechanics
IV.1 Symmetries, Conservation Laws, and Degeneracies
IV.2 Discrete Symmetries, Parity (or Space Inversion)
IV.3 Lattice Translation as a Discrete Symmetry
IV.4 The Time-Reversal Discrete Symmetry

Bibliography

SAKURAI, J.J. & NAPOLITANO, J. Modern Quantum Mechanics, Cambridge University Press: 2nd Edition, 2017.

COHEN-TANNOUDJI, C.; DIU, B. & LALOË, F. Quantum Mechanics, Volumes I and II, Wiley -VCH Verlag: 2nd Edition, 2020.

BRANSDEN, C.J. & JOACHAIN, P.H., Quantum Mechanics, Pearson: 2nd Edition, 2012.

ZETTILI, N., Quantum Mechanics: Concepts and Applications, Wiley: 2nd Edition, 2010.

SHANKAR, R. Principles of Quantum Mechanics, Plenum Press: 2nd Edition, 1994.

MAHON, J.R.P. Mecânica Quântica - Desenvolvimento Contemporâneo com Aplicações, LTC Editora - Grupo GEN, 2011.

AST-308-4	Extragalactic astrophysics

Prerequisite: AST-204-4

Presentation - Introduction to Extragalactic Astrophysics
Galaxies: classification and morphology; global properties
Galaxies: stellar and gaseous content; scaling relationships
Galaxies: internal movements and dynamics; Black holes in the center of galaxies
Luminosity function
IMF and Stellar Population Synthesis
Peculiar galaxies. Radio extragalactic sources: types, demography and luminosities
Structure of radio galaxies; evolution of radio sources.
Hubble's Constant and Distance Indicators: Introduction to Friedmann Models
Quasars and active galactic nuclei: introduction; fundamental properties; quasars as radio sources; AGN zoology; the central engine; accretion of matter
Quasars and active nuclei: components of an AGN; the IR, optical and UV continuum; the broad line region; the narrow line region; x-ray emission; Unified models.
Large-scale structure: galaxy counts and structure mapping.
Local supercluster; peculiar movements; galaxy clusters; the intergalactic environment.
Big Surveys

Bibliography

Peter Schneider: Extragalactic Astronomy and Cosmology, Springer

Bradley M. Peterson: Introduction to Active Galactic Nuclei, Cambridge Univ. Press

Steven Phillips, The Structure & Evolution of Galaxies, Wiley

Whittle, M – Classroom notes - http://www.astro.virginia.edu/class/whittle/astr553

Keel, W. – Classroom notes - http://www.astr.ua.edu/keel/galaxies/

AST-402-4	Introduction to General Relativity	

Prerequisites: none.

Tensor algebra. Vector fields in spaces with affine connection. Particularization for Riemannian spaces. Tensor analysis. Differential forms. Application of Tensor Calculus to Physics (Electromagnetrism, Relativistic Mechanics, Gravitation and Special Relativity). Curvature tensor. Gravitational field equations in empty space and with source term. Schwarzschild's solution, including black holes.

Bibliography

(Basic Textbook) D'INVERNO, RAY Introducing Einstein's Relativity. Clarendon Press, 1992.

(Supplementary textbook) ADLER; BAZIN; SCHIFFER Introduction to General Relativity. Mc Graw-Hill, 2nd ed., 1975.

(Supplementary textbook) WEINBERG Gravitation and Cosmology. Wiley, 1973.

Recommended additional reading:

MISNER; THORNE; WHEELER Gravitation. Freeman, 1973.

STEPHANI General Relativity. 2nd ed., Cambridge University Press, 1992.

SCHUTZ, A first course in General Relativity. Cambridge U.P., 1985.

LIGHTMAN; PRESS; PRICE; TEUKOSKI Problem Book in Relativity and Gravitation. Princeton U.P., 1975.

BERMAN; GOMIDE Cálculo Tensorial e Relatividade Geral: uma introdução. Mc Graw-Hill, 2a. ed., 1987.

AST-404-4	**High Energy Astrophysics**

Prerequisites: AST-204-4 and AST-202-3

Introduction and Historical Grounds/Observations. X and Gamma-ray observations: their origin and interaction processes. X and Gamma-ray detectors; observational techniques. White Dwarfs, Neutron Stars and Black Holes. Accretion onto compact objects: binary systems; accretion disks; accretion onto white dwarfs: cataclysmic variables; accretion onto neutron stars and black holes: X-ray binaries. Transient phenomena: bursts in X-ray binaries; gamma-ray bursts. Quasars and Active Galactic Nuclei. Diffuse X and Gamma-ray sources: X-ray and Gamma-ray background. Hands-on activity: spectral modeling of an X-ray binary using standard techniques: Ftools and Xspec.

Bibliography

FRANK, J.; KING, A., RAINE, D. Accretion Power in Astrophysics (Third Edition). Cambridge University Press, 2002.

COURVOISIER, T. High Energy Astrophysics. Springer, 2013

LONGAIR, M.S. High Energy Astrophysics (Third Edition) Cambridge University Press, 2011.

LEWIN, W. H.G. & van der Klis, M. (eds.). Compact Stellar X-Ray Sources. Cambridge University Press, 2006

KNOLL, G. F. Radiation Detection and Measurement (Fourth Edition). Wiley, 2010.

AST-405-4	**Infrared astrophysics**

Prerequisites: AST-204-4, AST-202-3

Astrophysical infrared sources: interstellar dust; astrophysical molecules; planetary atmospheres; sun; HII regions; stars; planetary nebulae; Galactic center; extragalactic sources. Infrared

instrumentation and catalogs.

Bibliography

GLASS, I. S.; Handbook of Infrared Astronomy, Cambridge University Press,1999, ISBN 0521633117

McLEAN, I. - Infrared Astronomy with Arrays: The Next Generation Astrophysics and Space Science Library, Vol. 190. ISBN 0792327780

AST-406-3	Solar radiophysics

Prerequisites: AST-204-4

The solar atmosphere in radio. Fundamentals of Radioastronomy. The quiet sun and the coronal plasma. Methods of study of active regions and models. Explosive activity, metric and decimeter eruptions. Centimeter and millimeter solar eruptions. Solar and X-ray and gamma activities and association with radio diagnostics. Temporal evolution of the transient emission and spectra. Recent models of transient interpretation in hot plasmas.

Bibliography

KRUEGER, A. Introduction to solar radio astronomy and radio physics. Dordrecht, D. Reidel, 1979.

STURROCK, J. Solar flares. Boulder, Associated University Press, 1960.

TANDBERG-HANSEN, E. Solar activity. Waltham, Blaisdell, 1967.

ZIRIN, H. The solar atmosphere. Waltham Blaisdell, 1966.

AST-409-3	Physics of the interstelar medium

Prerequisites: AST-204-4 and AST-202-3

Interstellar Medium: general properties. Gattering of information: thermal and non-thermal spectral lines; continuum emission. Microscopic processes: ISM gas heating and cooling, molecular reactions. Radiatively excited regions: hydrogen nebulae; heavier elements contaminated nebulae; nebulae structure. Gas dynamics: basic equations (conservation laws); mechanical waves and propagation in gases; shocks. Dynamical processes in the ISM: nebulae expansion, stellar winds and the ISM. Current knowledge of the ISM and star formation.

Bibliography

SPITZER, L. Diffuse Matter in Space. Wiley, NY, 1977.

J. E. DYSON & WILLIAMS, D.A. "The Physics of the Interstellar Medium", Institute of Physics Publishing 1997.

BALLY, J. The Structure and Kinematic of Star Formfing Clouds. Proc. of ESO Workshop, 1989.

ELITZUR, M. Physical Characteristics of Astronomical Masers. Rev. of Modern. Phys., 1982.

BOWERS, R.L.; DEEMING, T., Astrophysics I, II, "Jones and Bartlett Publishers Inc., Boston, 1984.

W. J. MACIEL, "Astrofísica do Meio interestelar", EDUSP, 2002.

AST-411-3	Time series in astrophysics

Prerequisites: none.

Regular and irregular sampling of astrophysical time series. Periodic signals in astrophysics: orbital period; radial and non-radial pulsation; rotation period; pulsars; quasi-periodic oscillations. Fourier transform: properties, convolution, correlation, Fourier series and Sampling Theorem. Discrete Fourier Transform: convolution and discrete correlation. Fast Fourier Transform. Power spectrum. Spectral window. Power spectrum statistics. Significance levels. Sensitivity to periodical signals. Lomb-Scargle periodogram. Phase diagram. Methods of phase dispersion minimization (PDM). PDM in IRAF. Clean method. Maximum entropy method.

Bibliography

MAOZ, D.; STERNBERG, A.; LEIBOWITZ, E., Astronomical Time Series, Kluwer Academic Pub., 1997.

BLOOMFIELD, P., Fourier Analysis of Time Series, John Wiley & Sons, 1976.

BRACEWELL, R. The Fourier Transform and its Applications, McGraw-Hill Int. Eds., 1986.

BRIGHAM, E., The Fast Fourier Transform, Prentice-Hall Inc., 1974.

PRESS, W.; TEUKOLSKY, S. AND VETERLING, W. Numerical Recipes in Fortran, Cambridge Univ. Press, 1992.

VAN DER KLISS, M., Fourier Techiniques in X-Ray Timing, in Timing Neutron Stars, Eds. H. Ogelman e E.P.J. van den Heuvel, Kluwer Academic Pub., 1989.

AST-412-3	Cataclysmic variables

Prerequisites: AST-200-3, AST-202-3, AST-203-4, and AST-204-4

Cataclysmic variables (CV) observations. Binary system components and the orbital cycls. Spectral properties. CV evolution. Accretion disk and eruptions. Phenomenology of CV variability and possible origins. Magnetic CVs. Flickering and oscillatipons. Nova eruptions. Phenomena related to the secondary star.

Bibliography

HELLIER, C. Cataclysmic variable stars. Praxis, 2001.

WARNER, B. Cataclysmic variables stars. Cambridge. 1995

AST-413-4	Fundamentals of Cosmology

Prerequisites: none.

Introduction to cosmology. Theoretical background: the homogeneous Universe, cosmic inventory, baryogenesis, thermal history, beyond the standard model, inflation. The non-homogeneous Universe: cosmological perturbations, evolution of perturbations, the non-linear Universe. Cosmological observations: large scale structure, baryon acoustic oscillations, the cosmic microwave background, 21 cm cosmology.

Bibliography

LIDDLE, A. An Introduction to Modern Cosmology. Cambridge, 2015

SCHNEIDER, P. Extragalactic Astronomy and Cosmology: An Introduction. Springer, 2014

WEINBERG, S. Cosmology. Wiley, 2008

MUKHANOV, V. Physical Foundations of Cosmology. Cambridge, 2005

L. BERGSTRÖM E A. GOOBAR. Cosmology and particle astrophysics. Springer, 2004

S. DODELSON. Modern Cosmology. Academic Press, 2003
PADMANABHAM, T. Theoretical Astrophysics: Volume 3, Galaxies and Cosmology, Cambridge, 2002

LONGAIR, M. Galaxy Formation. Springer, 1998.

PEACOCK, J. A. Cosmological Physics (Cambridge Astrophysics), 1998.

PEEBLES, P. J. E. Principles of Physical Cosmology. Princeton University Press, 1993.

KOLB, E., TURNER, M. The early Universe. Addison-Wesley Press, 1994

PADMANABHAN, T. Formation of Structure in the Universe. Cambridge, 1994.

MOSHE, C. Classical Fields, General Relativity and Gauge Theory, World Scientific, 1982

WEINBERG, S. Gravitation and Cosmology. Wiley, 1972

DURRER, R. The Cosmic Microwave Background, Cambridge, 2008

NASELSKY, P., NOVIKOV, D. The Physics of the Cosmic Microwave Background. Cambridge, 2006.

AST-414-3	Stellar Populations

Prerequisites: AST-200-3 and AST-202-3

Stellar populations concept: history and current status. Stellar populations in the Galaxy and other galaxies. Models of simple stellar populations. Stellar populations synthesis: methods and tools. Stellar kinematics in the Galaxy and other galaxies. Chemical evolution of galaxies: stellar and primordial nucleosynthesis, star formation rate, initial mass function and analytical models.

Bibliography

BINNEY, J. & MERRIFIELD, M. Galactic Astronomy. Princeton University Press, New Jersey, 1998.

MATTEUCCI, F. Chemical Evolution of Galaxies. Springer – A&A Library, Berlin, 2012.

MO, H., VAN DEN BOSCH, F. & WHITE, S. Galaxy Formation and Evolution, Cambridge University Press, Cambridge, 2010.

PAGEL, B. E. J. Nucleosynthesis and Chemical Evolution of Galaxies. Cambridge University Press, Cambridge, 2009.

TINSLEY, B. M. Evolution of the Stars and Gas in Galaxies - Fundamentals of Cosmic Physics. Gordon and Breach Science Publishers Ltd., Great Britain, 1980.

Seminal and/or recent papers.

AST-415-3	Special topics of astrophysics

Prerequisites: none.

In this course, a special topic in astrophysics is thoroughly discussed.

Bibliography

Specific book and papers.

AST-416-3	Fundamentals of Astrobiology

Prerequisites: none.

Fundamental questions: what is life? Conditions in the Universe: formation of chemical elements, basic physical and chemical conditions for life appearance, stellar evolution. Planetary

habitability: habitable zone, atmospheres, biochemistry of the interstellar medium, the necessity of water. Evolution of Earth and of life on Earth: prebiotic Earth, first stages of life, the need of oxygen, long-term cycles, formation and evolution of atmosphere, extremophiles and implications of their existence, evolution and biological diversity. The search for life beyond Earth: exploration of the solar system, Mars, Europa, Ganimedes, Titan, terraformation, exoplanets. Extraterrestrial intelligence: the SETI project.

Bibliography

DAVID A. ROTHERY & IAIN GILMOUR. An Introduction to Astrobiology, Cambridge, 2018.

RICHARD GORDON & ALEXEI SHAROV (Eds.). Habitability of the Universe before Earth, Volume 1: Astrobiology: Exploring Life on Earth and Beyond (series), Academic Press, 2018

Astrobiologia: uma ciência emergente. D. Galante, E. P. da Silva, F. Rodrigues, J. E. Horvath, M. G. B. de Avellar (orgs.), Tikinet/USP (2016) – Livro-texto eletrônico

COCKEL, C. Astrobiology: Understanding Life in the Universe, Wiley-Blackwell, 2015 Wiley-Blackwell

IAN W. M. SMITH; CHARLES S. COCKELL & SYDNEY LEACH (Eds.). Astrochemistry and Astrobiology (Physical Chemistry in Action), Springer, 2013

CHRIS IMPEY; JONATHAN LUNINE & JOSÉ FUNES (Eds.). Frontiers of Astrobiology 1st Edition, Cambridge, 2012

IMPEY, C. O Universo vivo. Larousse, 2009

SHAW, A. M. Astrochemistry: from astronomy to astrobiology. Wiley, 2006

WARD, P. Life as we DO NOT know it. Viking, 2005

LUNINE, J. Astrobiology: a multi-disciplinary approach. Benajmin Cummings, 2004.

AST-417-3	**Astrostatistics**

Prerequisites: none.

Probability theory. Probability distribution functions. Bayesian probability. Random numbers and Markov chain Monte Carlo (MCMC). Fisher information. Parameters Estimation. Confidence intervals. Statistical hypothesis testing and upper limits. Practices in Astronomy. The art of scientific computing. Introduction to the Gaussian Process and Machine learning. In addition to these basic topics, an individual planning with the student can be done.

Bibliography

WASSERMAN, L. All of Statistics: A Concise Course in Statistical Inference. Springer Texts in Statistics, 2004.

LIST, L. Statistical Methods for Data Analysis in Particle Physics. Springer Lecture Notes in Physics 909, 2016.

PRESS, W. H; TEUKOLSKY, S. A. & Vetterling, W. T. Numerical Recipes 3rd edition: The Art of Scientific Computing. Cambridge University Press, 2007.

WALL, J. V. & JENKINS, C. R. Practical Statistics for Astronomers. 2rd edition, Cambridge University Press, 2013.

ALPAYDIN, E. Introduction to Machine Learning Third Edition. The MIT Press, 2014.

AST-408-4	Computational Astrophysics

Prerequisites: none.

Module I: Introduction to Python. Introduction and overview of the Python language. Access to Python; forms of execution of Python programs. Basic commands: expressions and attributes; text and number formatting; reserved words. Types. Control structures. Introduction to the modules SciPy, NumPy, Matplotlib, Astropy, Pandas and others. Computing with formulas and data exhibition. Functions. Computing with arrays and matrices. Basic Data I/O. Exceptions, numerical errors, overflow. Matplotlib examples.
Module II: Numerical Methods for astrophysics I. Interpolation and extrapolation. Curve fitting. Roots of a function. Numerical integration and differentiation: practical aspects; methods. Fourier analysis. Histrograms. Data modeling; distributions. Applications of this module to astrophysics.
Module III: Numerical Methods for astrophysics II. Numerical solution of differential equations: introduction. Numerical solution of differential equations: applications.
Module IV: Modern Computational Astrophysics. Overview of Computational Statistics. Overview of Astronomical Data Analysis. Overview of Machine Learning and Neural Networks.
Module V: Mini-Projects. Preparation, discussion and presentation of the students' mini-projects.

Bibliography

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GÉRON, A. Mãos à obra: aprendizado de máquina com Scikit-Learn, Keras & TensorFlow: Conceitos, ferramentas e técnicas para a construção de sistemas inteligentes. 2a. edição, Alta Books, 2021.

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PRESS, W. H.; TEUKOLSKY, S. A.; VETTERLING, W. T. & FLANNERY, B. P. Numerical Recipes: The Art of Scientific Computing. 2nd. Edition, Cambridge University Press, 1992.

SCHERER, P. O. J. Computational Physics: Simulation of Classical and Quantum Systems. 3rd. Edition, Springer, 2017.

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STICKLER, B. A. & EWALD SCHACHINGER, E. Basic Concepts in Computational Physics. 2nd. Edition, Springer, 2016.

Os trabalhos auxiliares ou finais do programa de Pós-Graduação serão identificados na forma abaixo indicada:

AST-730	**Master Research in Astrophysics***

0 credit

AST-750	**Master Dissertation in Astrophysics**

12 credits

AST-780	**Doctorate Research in Astrophysics***

0 credits

AST-800	**Doctorate Thesis in Astrophysics**

36 credits

*Mandatory activity in every single academic period, in which the student develops scientific research.

São José dos Campos, 23th November 2023

Catálogo aprovado pelo CPG em 27 de novembro de 2023.