Research in Physics & Astronomy

at the

University of Louisville

The Department of Physics & Astronomy at the University of Louisville has enjoyed a 100 year history in the College of Arts & Sciences. It has long had a strong record of research by faculty and students. The research interests currently being pursued within the department are described on the following pages. For more detailed information about this research and academic programs offered visit our web site, http://www.physics.louisville.edu/.

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Astrophysics

Faculty and students in the Department of Physics and Astronomy pursue research in extragalactic, galactic, and stellar astrophysics, laboratory astrophysics, and instrumentation development. Areas of observational research include the use of quasar absorption line systems as tracers of large scale structure, the large-scale distribution of galaxies in large quasar groups, extended emission regions around proto-galaxies and the evolution of the elements in the Universe since the Big Bang. The composition and structure of the interstellar medium in the Milky Way as well as external galaxies are studied using multi-wavelength approaches from the X-rays to the radio.Multi-wavelength imaging and spectroscopic studies of proto-planetary disks are being made to determine the nature and evolution of planetary formation around other stars. Laboratory and theoretical physics are being applied to reveal the structure and evolution of brown dwarf stars. Finally, advanced technologies in optical and computer sciences are opening windows in the near infrared for high dynamic range adaptive time-resolved imaging.

We utilize both ground and space-based facilities such as the telescopes at Kitt Peak National Observatory, Apache Point Observatory, the Hubble Space Telescope, and the Gemini Observatories to pursue both galactic and extragalactic observational studies. The department also operates Moore Observatory near Louisville, Kentucky, and in collaboration with the University of Southern Queensland, Mt. Kent Observatory near Toowoomba, Australia. A 0.6-meter technically advanced research telescope at Moore Observatory is used for advanced training and research programs in instrumentation and stellar astrophysics. The observatories are home to a pair of remotely operable robotic 0.5-meter telescopes that provide nearly continuous coverage of the entire sky and permit a rapid response to transient events such as gamma ray bursts, supernovae, and exo-planet transits. Through Internet2, these robotic telescopes deliver hands-on astronomy education to undergraduate students on campus, and to schools throughout the state.

Research on the dynamics and thermodynamics of planetary atmospheres is carried out using the EPIC Atmospheric model, funded by NASA and NSF, which is a general circulation model designed for planetary applications. EPIC stands for "Explicit Planetary Isentropic Coordinate" and is the leading model for the atmospheres of the gas giants Jupiter, Saturn, Uranus, and Neptune. The model can also be used to simulate terrestial-class atmospheres. This work is carried out at the Comparitive Planetology Laboratory.

Faculty

John F. Kielkopf, Ph.D. (The John Hopkins University)
Gerard M. Williger, Ph.D. (Cambridge University)
James T. Lauroesch, Ph. D. (University of Chicago)
Timothy Dowling, Ph.D. (California Institute of Technology)

Representative Publications

1 *Study of the K-H_2 quasi-molecular line satellite in the potassium resonance line,* N. F. Allard, F. Spiegelman, and J. F. Kielkopf, Astronomy and Astrophysics, 465, 1085-1091 (2007).
2 *Impact broadening of alkali lines in brown dwarfs,* N. F. Allard, J. F. Kielkopf, and F. Allard, European Physical Journal D -- Atomic, Molecular and Optical Physics, 44, 507-514 (2007).
3 *A MIKE + UVES survey of sub-damped Lyman α systems at z < 1.5*, Meiring, Joseph D., Lauroesch, James T., Kulkarni, Varsha P., Péroux, Celine, Khare, Pushpa & York, Donald G. 2009, MNRAS, 397, 2037
4 *SOAR imaging of sub-damped Lyman α systems at z < 1*, Meiring, Joseph D., Lauroesch, James T., Haberzettl, Lutz, Kulkarni, Varsha P., Péroux, Céline, Khare, Pushpa & York, Donald G. 2011, MNRAS, 410, 2516M
5 *The Clowes-Campusano Large Quasar Group Survey. I. GALEX Selected Sample of Lyman Break Galaxies at z ~ 1*, Haberzettl, L., Williger, G. M., Lauroesch, J. T., Haines, C. P., Valls-Gabaud, D., Harris, K. A., Koekemoer, A. M., Loveday, J., Campusano, L. E., Clowes, R. G., Davé, R., Graham, M. J. & Söchting, I. K., 2009, ApJ, 702, 506.

6 *A Link Between Gas-Rich Protoplanetary Disks and Gas-Poor Debris Disks,* Collins, K.A., Grady, C.A., Hamaguchi, K., Wisniewski, J.P., Brittain, S., Sitko, M., Carpenter, W.J., Williams, J.P., Matthews, G.S., Williger, G.M., van Boekel, R., Carmona, A., van den Ancker, M.E., Meeus, G., Chen, X.P., Petre, R., Woodgate, B.E., Henning, Th. ApJ, 697, 557 (2009).
7 *The Connection between a Lyman Limit System, a very strong OVI Absorber, and Galaxies at z ~ 0.203,* Lehner, N., Prochaska, J.X., Kobulnicky, H.A., Cooksey, K.L., Howk, J.C., Williger, G.M., Cales, S.L., ApJ, 694, 734 (2009).

Atmospheric Physics

Atmospheric physics research at the University of Louisville includes modeling and data analysis of phenomena spanning mesoscale to planetary scale, the troposphere to the middle atmosphere, and includes planetary atmospheres. The EPIC atmospheric model, a general circulation model (GCM) designed for plantery applications, was developed here and funded by NASA and NSF. EPIC stands for "Explicit Planetary Isentropic Coordinate" and is the leading model for the atmospheres of the gas giants Jupiter, Saturn, Uranus, and Neptune. The model can also be applied to terrestial class atmospheres including Venus, Earth, Mars, and Titan (a large moon of Saturn with a substantial atmosphere). Current topics of research include Jupiter's Great Red Spot, thunderstorms on Jupiter and Saturn, jet-stream stability, Venus and Titan spinup and superrotation, and the dynamics of vortices and clouds on Uranus and Neptune. (Dowling)

Active research in atmospheric turbulence also takes place in the department. The stable atmospheric boundary-layer exhibits significant complexity due to the interactions between several phenomena over multiple scales. Using the National Taiwan University-Purdue University Nonhydrostatic model with higher-order turbulence closure schemes, simulations are probing the role of internal gravity waves as an excitation mechanism for isolated layers of turbulent mixing. These gravity waves may be generated from shear layers inside or outside the boundary-layer or from topography. The goal is to shed light on the poorly-understood energetics surrounding the formation of turbulent structures in stable environments. (MacCall)

Faculty

Timothy Dowling, Ph. D. (California Institute of Technology)
Jian Du-Caines, Ph.D. (University of New Brunswick)

Representative Publications

1 Buras R, Dowling T, Emde C, 2011, New secondary-scattering correction in DISORT with increased efficiency for forward scattering, *J. Quant. Spectr. Ra.,* doi:10.1016/j.jqsrt.2011.03.019
2 Dowling TE, Bradley ME, Colón E, Kramer J, LeBeau RP, Lee GCH, Mattox TI, Morales-Juberías R, Palotai CsJ, Parimi VK, Showman AP, 2006, The EPIC atmospheric model with an isentropic/terrain-following hybrid vertical coordinate, *Icarus* 182, 259–273.
3 Du, J., W. E. Ward, J. Oberheide, T. Nakamura, and T. Tsuda (2007), Semidiurnal tides from the Extended Canadian Middle Atmosphere Model (CMAM) and comparisons with TIMED Doppler Interferometer (TIDI) and meteor radar observations, *J. Atmos. Sol. Terr. Phys.*, 69, 2159– 2202, doi:10.1016/j.jastp.2007.07.014.
4 Read PL, Dowling TE, Schubert G, 2009, Rotation period of Saturn from its atmospheric planetary-wave configuration, *Nature* 460, 608–610, doi:10.1038/nature08194.
5 Zeng, Z., W. Randel, S. Sokolovskiy, C. Deser, Y.-H. Kuo, M. Hagan, J. Du, and W. Ward (2008), Detection of migrating diurnal tide in the tropical upper troposphere and lower stratosphere using the

Challenging Minisatellite Payload radio occultation data, *J. Geophys. Res.,* 113, D03102, doi:10.1029/2007JD008725.

Atomic and Molecular and Optical Physics

Atomic, Molecular and Optical Physics research in the department includes theoretical work on small molecules focusing on those of astrophysical interest, laboratory astrophysics investigating radiative processes in stellar atmospheres, and applied optical physics, providing advanced technology and analysis to infrared imaging. Note that other research areas in the department, notably condensed matter physics and astrophysics, are deeply connected with atomic, molecular and optical physics.

In the theoretical effort, mathematical techniques are being developed which make it possible for the first time to obtain a very accurate representation of the excited states of diatomic molecules. These methods enable us to study very precisely the energy of small molecules as a function of interatomic distance and to study dynamical processes such as photoionization and molecular dissociation (Morrison). The theory of radiative collisions is being applied to the atmospheres of cool dense stars (Kielkopf).

Laboratory experimental work is directed toward precision measurements that test the accuracy of theoretical calculations of interatomic potentials, radiative transition rates, and spectral line shapes under well defined conditions. The laboratory facility includes extremely high resolution optical and vacuum ultraviolet spectrometers, as well as laser-plasma sources. The laboratory supports an intensive collaborative program with research groups in Electrical and Computer Engineering to develop near-infrared imaging devices with on-pixel processing. These devices have applications in adaptive optics for astronomy, remote sensing and surveillance (Kielkopf).

Faculty

John F. Kielkopf , Ph.D. (The John Hopkins University)
John C. Morrison, Ph.D. (The John Hopkins University)

Representative Publications

1. *Phase continuity in molecular orbitals: Enumeration of zeros in the dipolematrix element*, J.M. Peek, T. Kereselidze, I. Nozelidze, and J. Kielkopf, Journal of Physics B, 40, 565-575 (2007).
2. *Spline collocation calculation for* H_2^+, J. Morrison, C. Baunach, L. Larson, B. Bialecki and G. Fairweather, J. Phys. B29, 2375 (1996)

Condensed Matter Physics

The Condensed Matter Physics program at the University of Louisville focuses on cutting-edge research in nanoscience and photonics with its researchers engaged in theoretical (Wu), computational (Jayanthi, Liu, and Yu) and experimental studies (Sumanasekera) of nanomaterials and biomolecular films (Mendes). Quantum mechanics based computer simulations and synthesis techniques are used to discover novel nanomaterials for efficient energy storage and energy production and for their potential use as components of nanoscale electronic devices and chemical sensors. The photonics group (Mendes) uses experimental tools based on integrated optics and surface waves to investigate the interface of biomolecular films.

Seminal contributions by the condensed matter theory (CMT) group include the developments of real-space electronic structure methods based on Green's function techniques; algorithms for large-scale simulations; novel semi-empirical Hamiltonians (SCED-LCAO) for quantum-mechanics based simulations of complex materials, *etc*. The salient features of the SCED-LCAO method are: (i) it is developed in the framework of linear combination of atomic orbitals (LCAO), (ii) it includes electron-ion and electron-electron interactions that are modeled via phenomenological environment-dependent (ED) functions, and (iii) its framework allows a self-consistent (SC) calculation of the charge redistribution. The molecular dynamics scheme based on the SCED-LCAO Hamiltonian has been applied successfully to study a variety of problems that include: (i) the electromechanical responses in single-wall carbon nanotubes, (ii) the structure and stability of the entire family of carbon clusters (fullerenes, bucky-diamond structures, cage structures, etc.), (iii) structural and electronic properties of SiC nanostructures including nanowires, nanotubes, clusters, and graphitic-like sheets (CMT RESEARCH).

The research interests of the theory group also include modeling the growth mechanisms of thin films and nanostructures based on Kinetic Monte Carlo techniques and the rate equation theory (Liu) .

The research of the experimental condensed matter physics group led by Dr. Sumanasekera focuses around the following topics: synthesis and characterizations of novel nanostructures; electronic properties of hydrogenated and fluorinated graphene; efficient energy conversions of waste heat using high figure of merit thermoelectric materials; thermionics based on doped nano-diamonds; phonon confinements in semiconducting nanowires; chemical sensors based on carbon-based nanostructures and oxide nanowires; novel electrode materials for Li-ion batteries, and conducting transparent electrodes for solar applications (Sumanasekera).

The research activities of Dr. Mendes' group focuses on novel analytical tools based on integrated optics and surface waves for research in biomolecular films and interface phenomena, the spectroscopic investigation of the physical/chemical properties of biomolecular films, and on the integration of nano-structured photonic devices with molecular assemblies for selective and sensitive transduction in chemical and biological materials. (Mendes).

Faculty

Chakram S. Jayanthi, Ph.D. (Indian Institute of Technology, Delhi)
Humberto Gutierrez, Ph.D. (University of Campinas, Brazil)
Shudun Liu, Ph.D. (Rutgers University)
Sergio B. Mendes, Ph.D. (University of Arizona)
Gamini U. Sumanasekera, Ph.D. (Indiana University)
Shi-Yu Wu, Ph.D. (Cornell University)
Ming Yu, Ph.D. (Hokkaido Institute of Technology, Japan

Emeritus Faculty

Wei-Feng Huang , Ph.D. (University of Virginia)
P.J. Ouseph, Ph.D. (Fordham University)

Representative Publications

1. *Coherent Treatments of the Self-Consistency and the Environment-Dependency in a Semi-Empirical Hamiltonian: Applications to Bulk Silicon, Silicon Surfaces, and Silicon Clusters*, Phys. Rev. B 74, 155408 (2006).
2. *Geometric and Electronic Structures of Graphitic-like and Tubular Silicon Carbides: Ab-initioStudies,* M. Yu, C.S. Jayanthi, and S.Y. Wu, 'Phys. Rev. B82, 124027 (2010).

3. *Energetics, Relative Stabilities and Size-Dependent Properties of Nanosized Carbon Clusters of Different Families: Fullerenes, Bucky-Diamonds, Icosahedral, and Bulk-Truncated Structures*, M. Yu, I. Chaudhuri, C. Leahy, S.Y. Wu, and C.S. Jayanthi, Journal of Chemical Physics 130, 184708 (2009).
4. *Stability and Mechanical Properties of Silicon Nanowires, Shudun Liu, C.S. Jayanthi, Zhenyu Zhang, and S.Y. Wu, Journal of Computational and Theoretical Nanoscience, Special Issue on Nanomorphology*, Vol. 4, 275 (2007).
5. *Preferential growth of single-walled carbon nanotubes with metallic conductivity*, Avetik R. Harutyunyan1 , Gugang Chen, Tereza M. Paronyan, Elena M. Pigos, Oleg A. Kuznetsov, Kapila Hewaparakrama, Seung Min Kim, Dmitri Zakharov, Eric A. Stach, and Gamini U. Sumanasekera, Science, 326 (5949), 116-120 (2009).
6. *Electrostatic deposition of graphene in a gaseous environment: a deterministic route for synthesizing rolled graphenes?,* A. Sidorov D. Mudd, G. U. Sumanasekera, P. J. Ouseph, C. S. Jayanthi, Shi-Yu Wu, Nanotechnology, 20 (5), 55611 (2009).
7. *Large area synthesis of conical carbon nanotube arrays on graphite and tungsten foil substrates*, S. Dumpala, J. B. Jasinski, G. U. Sumanasekera, M. K. Sunkara, CARBON, 49, 2725 (2011).
8. *Hypergolic fuel detection using individual single walled carbon nanotube networks*, S. C. Desai, A. H. Willitsford, G. U. Sumanasekera, M. Yu, W. Q. Tian, C. S. Jayanthi, S. Y. Wu, JOURNAL OF APPLIED PHYSICS, 107 (11), 114509 (2010).
9. *Low-Loss Optical Waveguides for the Near Ultra-Violet and Visible Spectral Regions with Al_2O_3 Thin Films from Atomic Layer Deposition*, Mustafa M. Aslan, Nathan A. Webster, Courtney L. Byard, Marcelo B. Pereira, Colin M. Hayes, Rodrigo S. Wiederkehr, and Sergio B. Mendes, Thin Solid Films (2010), 518, 4935-4940.
10. *Solid Immersion Lens at the Aplanatic Condition for Enhancing the Spectral Bandwidth of a Waveguide Grating Coupler*, Marcelo B. Pereira, Jill S. Craven, and Sergio B. Mendes, Optical Eng (2010), 49, 124601.
11. *Broadband Spectroelectrochemical Interrogation of Molecular Thin Films by Single-Mode Electro-Active Integrated Optical Waveguides*, Sergio B. Mendes, S. Scott. Saavedra, and Neal R. Armstrong, invited book chapter in "Optical Guided-Wave Chemical and Biosensors," Editors: Zourob, M. and Lakhtakia, A.; Springer-Verlag book series on Chemical Sensors and Biosensors (2010), ISBN 978-3-540-88241-1, 101-129.
12. *Investigations of the Q and CT Bands of Cytochrome c Adsorbed onto Alumina Surfaces Using Broadband Spectroscopy with Single-Mode Integrated Optical Waveguides*, Rodrigo S. Wiederkehr, Geoffrey C. Hoops, Mustafa M. Aslan, Courtney L. Byard andSergio B. Mendes, J. Phys. Chem. C (2009), 113, 8306-8312.
13. *An Electroactive Fiber Optic Chip for Spectroelectrochemical Characterization of Ultra-Thin Redox Active Films*, Brooke M. Beam, Neal R, Armstrong, and Sergio B. Mendes, Analyst (2009) 134, 454-459.

High Energy Physics

The High Energy Physics group at the University of Louisville is concerned with fundamental questions about the basic structure of matter and its interactions. We ask why the visible universe seems to be dominated by ordinary matter (where has the anti-matter gone?), why are the masses of the particles in nature what they are, and how do the interactions among these particles help shape the universe? In particular, we study the production of the relatively heavy proton and neutron and related heavy particles known collectively as baryons. We hope to understand the surprising 'abundance' of these particles in matter.

We are members of the BaBar Collaboration and the ATLAS Collaboration. The BaBar detector collected data from 1999 to 2008 in electron-positron collisions at the SLAC National Accelerator Lab in California. ATLAS began taking data in late 2009 with proton-proton collisions at the Large Hadron Collider (LHC) of the European Organization for Nuclear Research (CERN - which stands for the French "Conseil Europeen de Recherche Nucleaire"). BaBar has produced copious high-quality data that we will continue to analyse for many years. ATLAS is just beginning to produce high-quality data for analysis and discovery over the coming decades.

Babar is a large, general-purpose electron-positron collider detector operating at center of mass energies near 10 GeV. The experiment ran in the PEP-II storage rings at SLAC in "B-Factory" mode, meaning that it was tuned for optimal production of the B meson, a particle whose decays provide an excellent glimpse at matter-antimatter asymmetry. Currently, the University of Louisville group is investigating probes of QCD in quark and gluon jets, studying inclusive hadron production, and searching for rare CP-violating decays of the B-meson to final states with baryons. This work involves extensive software development. The group has been steadily involved in software development and administration on BaBar since 1996. (Brown, Davis).

On ATLAS, we are assisting with simulations of radiation backgrounds that affect the detector. In data, we will be searching for as-yet unseen triply heavy baryon states. This will help us fill in our knowledge of the possible baryonic particle states, but will also aid in understanding the production mechanisms of baryons. (Brown)

Faculty

David N. Brown, Ph.D. (Purdue University)
Christopher L. Davis, Ph.D. (Oxford University)

Representative Publications

1. *Searches for B Meson Decays to $\varphi\varphi$, $\varphi\rho$, $\varphi f_0(980)$, and $f_0(980) f_0(980)$ Final States,* B. Aubert, D. N. Brown, C. L. Davis et al. (BABAR Collaboration), Phys. Rev. Lett. 101, 201801 (2008)
2. *Measurement of the Branching Fractions of $B^{-} \rightarrow D^{**} \ell^{-} \bar{\nu}_{\ell}$ Decays in Events Tagged by a Fully Reconstructed B Meson*, B. Aubert, D. N. Brown, C. L. Davis et al. (BABAR Collaboration), Phys. Rev. Lett. 101, 261802 (2008)
3. *Measurements of $B(\bar{B}^{0} \rightarrow \Lambda_c^{+} \bar{p})$ and $B(B^{-} \rightarrow \Lambda_c^{+} \bar{p} \pi^{-})$ and studies of $\Lambda_c^{+} \pi^{-}$ resonances*, B. Aubert, D. N. Brown, C. L. Davis et al. (BABAR Collaboration), Phys. Rev. D 78, 112003 (2008)