A brief overview of research areas in the OSU Physics Department
Physics Research Areas

- Astrophysics & Cosmology
- Atomic, Molecular, and Optical Physics
- Biophysics
- Cold Atom Physics (theory)
- Condensed Matter Physics
- High Energy Physics
- Nuclear Physics
- Physics Education Research (A Scientific Approach to Physics Education)
Biophysics faculty

Ralf Bundschuh - Theory

Michael Poirier - Experiment

Dongping Zhong - Experiment

C. Jayaprakash - Theory (Biophysics since 2001)

Comert Kural - Experiment
Biophysics Research

Main theme:
Molecular Mechanisms Behind Important Biological Functions

Research areas:
• chromosome structure and function
• DNA repair
• processing of genetic information
• genetic regulatory networks
• ultrafast protein dynamics
• interaction of water with proteins
• RNA structure and function
Experimental Condensed Matter Physics

Rolando Valdes Aguilar  
THz spectroscopy of quantum materials

Roland Kawakami  
Spin-Based Electronics and Nanoscale Magnetism

Fengyuan Yang  
Magnetism and magnetotransport in complex oxide epitaxial films; metallic multilayers; spin dynamics/ transport in semiconductor nanowires

Ezekiel Johnston-Halperin  
Nanoscience, magnetism, spintronics, molecular/organic electronics, complex oxides. Studies of matter at nanoscopic length scales

Jay Gupta  
LT UHV STM combined with optical probes; studies of interactions of atoms and molecules on surfaces structures built with atomic precision

Thomas Gramila  
Electronic materials at low temperatures and high magnetic fields; 2DEGs and Quantum Hall effects; electron interactions and correlation effects

P. Chris Hammel  
Nanomagnetism and spin-electronics, high spatial resolution and high sensitivity scanned probe magnetic resonance imaging

Leonard Brillson  
Semiconductor surfaces and interfaces, complex oxides, next generation electronics, high permittivity dielectrics, solar cells, biological sensors

Jon Pelz  
Spatial and energy-resolved studies of contacts, deep-level defects, films and buried interfaces in oxides and semiconductors; spin injection into semiconductors.

Thomas Lemberger  
Magnetic and electronic properties of high temperature superconductors and other oxides; thin film growth by coevaporation and sputtering; single crystal growth.

R. Sooryakumar  
Light scattering in solids and biological tissues, magnetic tweezers and photonic devices, biomagnetism
Single Molecule Spin Transport

Atomic scale understanding electronic and structural properties of contact to molecule on charge/spin transport

- Chemical bonding
- Charge transfer
- Electron/spin/vibrational coupling

Constructing atomically-precise contacts: Co on Cu$_2$N

M[TCNE] complex:
Co[TCNE]$_2$ $T_c$ (bulk) = 44 K

TCNE
Co[TCNE]
Co[TCNE]$_2$
Ultrasensitive Scanned Probe Magnetic Resonance Imaging

Chris Hammel

\[ F = (m \cdot \nabla B) \]

\[ B_1 = B_1^0 \cos(\omega t) \]

\[ \omega(r) = \gamma B(r) \]

\[ \Delta z = \frac{\Delta H_{\text{linewidth}}}{\partial B/\partial z} \]
**Mobile Magnetic Tweezers**

- *Programmable directed forces for on-chip platforms*
  - Remote (joystick or voice activated), multiplex (~$10^6$ cells)
  - Probe, sort, assemble biomolecules
  - Nanoscale engines, pumps, ........

Harnessing nano-scale magnetism and engineering for biology

*No Game: Scientists Move Cells With Joystick*

Fox News.com

Monday, September 21, 2009
Center for Emergent Materials:
An NSF Materials Research Science and Engineering Center (MRSEC)

ENCOMM: Electronic & Magnetic Nanoscale Composite Multifunctional Materials
Spin-Based Electronics and Nanoscale Magnetism (Su 2013)

Roland Kawakami

Nanoscale devices
- Spin transport in graphene, 2D materials
- Spin-based logic, post Si-CMOS electronics

Atomically controlled materials by molecular beam epitaxy
- Complex oxide heterostructures
- Ferromagnet/Si,Ge hybrid structures

Ultrafast optics
- Spin dynamics in semiconductors
- Valleytronics in 2D materials
- Dynamics in many-body systems

Surface science approach to nanoscale devices
- Spin-polarized STM
- NanoARPES

We employ a powerful combination of materials synthesis and advanced measurements to explore novel condensed matter systems and provide exceptional student training.
Condensed Matter Theory

1. Ho : cold atom physics
2. Gruzberg : quantum condensed matter; scaling and critical phenomena & transport
3. Randeria : ultracold Fermi gases & optical lattices, high Tc Superconductivity, photoemission, metallic magnetism in oxides
4. Stroud : (Emeritus) spintronics, graphene, nano materials, Josephson Junction array and Josephson qubits, Molecular dynamics of surfaces
5. Trivedi : cold atoms in optical lattices, complex oxides, disorder-driven superconductor-insulator transition
6. Wilkins : defects and dynamics in metal/semiconductors using QMC, DFT and MD.
7. Putikka : high Tc superconductor, spintronics

graphene
APRES high Tc
Band structure, optical lattice
High Tc superconductor
Disordered superconductor
Complex oxides
Metallic magnetism in oxides
High Tc superconductor
Disordered superconductor
Complex oxides
Metallic magnetism in oxides
Spintronic materials
JJ array and qubits
Graphene
Nano materials
MD of surfaces
Mesoscopic physics
1D superconductor
Ultra-cold atoms

Quantum Hall states
large spin bosons & fermions
Low D quantum gases
Optical Lattice Emulator

Quantum information
Strongly Interacting gases

Material Science
Electronic structure
Defects, Dynamics in metal & Semiconductors

Nuclear, High energy String Theory
Ilya Gruzberg - Condensed matter theory

• Quantum condensed matter physics:
  disordered electronic systems, localization, quantum Hall effects, interplay of interactions and disorder, topological states of matter, quantum hydrodynamics.

• Classical condensed matter physics:
  non-equilibrium (stochastic) growth phenomena, diffusion-limited aggregation (DLA), Hele-Shaw flows, turbulence, spin glasses.

• Statistical and mathematical physics:
  Schramm-Loewner evolutions (SLE), conformal field theory (CFT), statistical mechanics, critical phenomena, random matrix theory, supersymmetry, algebraic, analytic, probabilistic and field-theoretical methods in condensed matter physics.
Theoretical Astrophysics/Cosmology Group

Core Faculty

John Beacom
Neutrinos

Chris Hirata
Cosmology

Annika Peter
Dark matter

Terry Walker
Particle Astro

Affiliated Faculty

Gary Steigman
Cosmology
Experimental
Astrophysics/Cosmology Group

Core Faculty

Jim Beatty
Cosmic rays

Amy Connolly
Neutrinos

Klaus Honscheid
Dark energy

Affiliated Faculty

Richard Hughes
Gamma rays

Brian Winer
Gamma rays
Examples of CCAPP Science

What is Dark Energy?
SDSS, SDSS-III, Dark Energy Survey, LBT, LSST, theory

What is Dark Matter?
SDSS, SDSS-III, Dark Energy Survey, LBT, theory

What drives supernova and GRB explosions?
SDSS, SDSS-III, Dark Energy Survey, LBT, GLAST, theory

What are the sources of the cosmic rays?
Auger, Auger North and extensions, theory

What powers GeV and TeV gamma-ray sources?
FERMI, theory

Are there high-energy neutrino sources?
ANITA, ICE CUBE, theory

ccapp.osu.edu
Example: High-Energy Astronomy

Auger

Fermi
NASA's Fermi telescope reveals best-ever view of the gamma-ray sky

IceCube

Ultra High Energy Neutrino Astronomy: ANITA (Amy Connolly, Jim Beatty)

- ANITA is a balloon-borne experiment that takes ~40 day flights over Antarctic ice
- Searching for a radio Cherenkov signal from neutrino-induced showers
- 3rd flight in 2012-2013
- Closing in on neutrino flux from UHECR interactions with CMB
Example: Experimental Cosmology

Dark Energy Survey (DES, 2011 - 2016)

- CTIO Observatory
- Survey 5000 sq degrees of the sky in 5 filter bands
- Constrain the dark energy equation of state using 4 complementary methods (SN 1, Gravitational Lensing, Cluster counts, Large Scale Structure)
- Project Leadership
  - DAQ hardware and software
  - Weak lensing reconstruction software
- Systematic study of weak lensing cluster mass estimates using the LBT
- Image processing
- Development of the Cluster
- Step program
- Advanced shear estimators
- Full size prototype of the Dark Energy camera

Sloan Digital Sky Survey (BOSS, 2010 - 2014)

- Map spatial distribution of galaxies and quasars to detect the characteristic scale imprinted by baryon acoustic oscillations in the early universe
- Front end electronics
- DAQ hardware and software
- Observation control software
- Measurement of baryon acoustic oscillations with QSOs and the Ly-α forest
- BOSS First Light

Large Synoptic Survey Telescope (LSST, 2116 - ?)

- Fast and deep survey of 20000 sq degrees
- Image the entire sky every 3 nights
- Development of optical data links
- Continuation of the DES science program
- LSST Design
**Annika Peter: Dark matter (and galaxies)**

**Standard Model particles: ~4%**
Everything we interact with on a daily basis is like sprinkles on a cupcake.

**Dark matter: ~24%**
The dominant gravitationally attractive component of the Universe. We don’t know what it is! My theory-based research program is centered on figuring out what it is. I also am interested in how galaxies evolve. Dark matter is the glue that holds galaxies together, much like frosting keeps sprinkles on the cupcake. By understanding how dark matter works, we can shed light on galaxy evolution, and vice versa!

**Dark energy: ~72%**
Most of the universe is gravitationally repulsive. We don’t know why!!! But it eats most of the mass-energy budget of the Universe, just like the cake part of a cupcake.
Atomic, Molecular and Optical Physics

Diverse group beyond traditional AMO

– Intense Laser-Matter interactions
  • Relativistic laser produced plasmas (Freeman, Van Woerkom, Schumacher)
  • Laser fusion schemes (Freeman, Van Woerkom, Schumacher)
  • Attosecond science (DiMauro, Agostini)
  • Strong field atomic physics (DiMauro, Agostini)
  • Ultrafast x-ray physics (DiMauro, Agostini)

– Submillimeter & Terahertz physics (De Lucia)
  • Millimeter & sub-Millimeter spectroscopy
  • Laboratory Astrophysics & Atmospheric chemistry
  • Remote & Point sensing
  • Chemical Physics

– Ultrafast nonlinear optics (DiMauro, Agostini)
• novel sensors
  ✓ complex gas mixtures with absolute specificity
  ✓ compact & inexpensive devices

• astrophysics simulation
  ✓ chemistry of interstellar medium collapsing to form stars and planets
DiMauro, Agostini

- fundamental study of isolated laser-atom interaction in the Keldysh limit of tunnel ionization

Freeman, Schumacher, Van Woerkom

- experimental probing & modeling of the production of energetic protons & neutrons
Nuclear Physics Faculty:

Theory

Dick Furnstahl
Professor
Fellow APS, AAAS
Funding: NSF/DOE
h-index: 31

Uli Heinz
Professor
Fellow APS, AAAS
Funding: DOE
h-index: 55

Sabine Jeschonnek
Assoc. Prof., OSU Lima
Funding: NSF
h-index: 11

Yuri Kovchegov
Assoc. Professor
Funding: DOE (OJI)
h-index: 28

Robert Perry
Professor
Fellow APS, AAAS
Funding: NSF
h-index: 21

Experiment

Tom Humanic
Professor
Funding: NSF
h-index: 58

Mike Lisa
Professor
Fellow APS
Funding: NSF
h-index: 58

CERN LHC ALICE
(RHI and pp)

STAR/BNL-RHIC & CERN LHC ALICE
(RHI and pp)
Why heavy ion collisions?

• Study **bulk** properties of nuclear matter

• **Extreme** conditions 
  (high density/temperature) expect a transition to **new phase of matter**…

• Quark-Gluon Plasma (QGP)
  • partons are relevant degrees of freedom over large length scales (deconfined state)
  • believed to define universe until $\sim \mu$s

• Study of QGP crucial to understanding QCD
  • low-q (nonperturbative) behaviour
  • confinement (defining property of QCD)
  • nature of phase transition

• Heavy ion collisions ("little bang")
  • the only way to experimentally probe deconfined state
One Dedicated HI experiment with pp: ALICE
One pp experiment with a HI program: CMS
One pp experiment considering HI: ATLAS
The Nuclear Theory Group addresses fundamental problems in:

- hadronic structure and few-body problems (Jeschonnek) (JLab program)
- the nature and structure of the nuclear force and how it binds nuclei and nuclear matter (Furnstahl, Perry) (FRIB program)
- the properties and dynamical evolution of QCD matter at extreme densities and temperatures (Heinz, Kovchegov) (RHIC/LHC/EIC program)

Typical distances increase to the right.
Elementary Particle Theory

4 faculty + 3 postdocs + 2 students

Braaten
Heavyquarks; Ultra-cold atoms

Mathur
String theory
Black holes

Shigemitsu
QCD; Lattice gauge theory

Carpenter
Supersymmetry Phenomenology

Raby
Beyond the Standard Model; Supersymmetry
35 years ago, Stephen Hawking found the 'Black Hole Information paradox': Black holes make Quantum Mechanics inconsistent.

Using String Theory, Mathur and his students/postdocs have found a resolution of this paradox: Quantum gravity effects are not over planck length, but $N$ times planck length, where $N$ is the number of particles in a bound state. This makes the black hole interior a quantum fuzzball, rather than 'empty space with a central singularity.'
Research of Stuart Raby

Beyond the Standard Model

- The study of supersymmetry and supersymmetry breaking mechanisms

- The construction of models of fermion masses (including supersymmetric grand unified theories)

- The analysis of the consequences of new physics for high energy accelerator experiments (such as the LHC), neutrino masses and mixing, proton decay and cosmology.

- Derive one of these models from a more fundamental theory, such as string theory.
Lattice Gauge Theory
(Junko Shigemitsu)

The theoretical framework of the Standard Model is
Quantum Field Theory
(Quantum Mechanics + Relativity)

Replace continuous space-time by a 4 dimensional lattice
and use super computers ⇒ particle masses etc.
Most strongly-interacting particles can be classified as mesons \((Q\bar{Q})\) or baryons \((QQQ)\).

Since 2003, more than a dozen new particles containing charm quarks or bottom quarks have been discovered.

Some are definitely not ordinary mesons or baryons.

What are these mysterious particles?
The Large Hadron Collider (at CERN)

Higgs Search at Fermilab

CDF Candidate

\[ ZH \rightarrow \mu^+ \mu^- b\bar{b} \]
Ohio State led the design and construction of Endcap Muon electronics.

OSU CMS

4 faculty + 2 postdocs + 3 grad students + 1 engineer
endcap yoke disks–CSC’s from OSU

Three disks for one endcap

One disk loaded with CSCs
3 faculty + 3 postdocs + 4 grad students + 2 engineers
Critical role in the design, construction, & operation of the pixel detector & Beam Condition Monitors

Inner most charged particle tracking
Measures (x,y,z) to ~30 µm
Pixel detector is based on silicon
Pixel size 50µm by 400 µm ~10^8 pixels
Radiation hardness is an issue
must last 10 years
Search for Beyond the Standard Model Physics (Chris Hill)

• For a number of theoretical and experimental reasons the **Standard Model of particle physics is known to be incomplete**

• We analyze CMS data from the **world’s highest energy collider** in order to find **new particles** that would be **evidence for one of the many theories** which have been proposed to address these shortcomings. In particular we are interested in:

  – **Long-lived particles** - many ideas (e.g. GUTs, Split Susy) have particles with lifetimes $>>$ CMS experimental timescales. We have developed novel techniques to search for these unusual signatures.

  – **Particles that couple to top quarks** - the top is the heaviest and (one of the) least well-understood fundamental particles; it is quite possible it plays a special role in the new physics.
Physics Education Research

- **Education Measurement (Lei Bao)**
  - Research in experimental methods and quantitative models to measure and analyze the dynamic process of learning.
  - Develop technologies, instruments, and analysis tools for large scale quantitative assessment of learning.

- **Fundamental Learning Processes (Andrew Heckler)**
  - Learning and reasoning biases causing misconceptions
  - Differences in learning abstract vs. concrete
  - Memory decay and interference in learning from related topics

- **Revision of curriculum (Gordon Aubrecht (emeritus) – Marion campus)**
Example – from Lei Bao’s research [Bao et al., Science 2009]
Does STEM content knowledge affect scientific reasoning?
Does STEM content knowledge affect scientific reasoning?
[Bao et al., Science 2009]
Does STEM content knowledge affect scientific reasoning?  
[Bao et al., Science 2009]

Research Results of Scientific Reasoning

Results suggest:

Improved Stem Content $\star$ Improved Scientific Reasoning (traditional)

Improved Scientific Reasoning $\Rightarrow$ Improved Stem Content

Scientific Reasoning can be trained (inquiry-based courses show promise)