Theme Group 2 Theory

Particle Theory [EP]

Gravitational Theory [GRT]

Theory of Quarks Hadrons & Nuclei
(Nuclear Theory) [TQHN]

Overview

- Maryland has a long and distinguished history in all three subfields.
- Since the previous review there have been many changes:
  - Faculty:

Buonanno (GRT)	Brill (GRT)
Tiglio (GRT)	
McKinney (GRT)	
Chacko (EP)	Becker (EP)
Agashe (EP)	Luty(EP)
Sundrum (EP)	Pati (EP)
Abazajian (EP/cosmo)	Abazajian (EP/cosmo)
Bedaque (TQHN)	Wallace (TQHN)
	Griffin (TQHN)

– Institutionally

- Formation of the Maryland Center for Fundamental Physics.
  - State supported center to promote theoretical research in particle nuclear, and gravitational physics.
  - Support at a level of $300 K/yr

- Formation of the Joint Space Institute with Astronomy and NASA Goddard.

Ongoing MCFP support critical !!!

- **Competing on par with other top institutions;**
- **Augmenting NSF support for students and post-docs**
  - **MCFP support has been essential in developing a critical mass of young researchers.**
- Vigorous visitor, seminar and lecture programs;
- Hosting meetings, workshops,
  - e.g. Joint seminars with Hopkins;
  - "SEARCH" Intern'l LHC workshop 100 participants, UMD, 2012
- Theory computing cluster for particle physics computation
- Outreach efforts

Outreach etc.

- Theorists in TG2 have played an extraordinary role doing scientific outreach and contributions to public policy on STEM
  - Jim Gates is a member of PCAS and the Maryland state school board.
  - Member of the group have given talks to public schools from kindergarten through high school.
  - Numerous members of the the group have supervised high school students research.
  - Members of the group have played leadership and organizational roles in particle, nuclear and gravitational physics

GRT

Gravitation Theory Group Profile

Professors:
Alessandra Buonanno (2005- Prof.) Gravitational wave theory and phenomenology
Bei-Lok Hu (1980- Prof.) Stochastic, Analog, and Emergent/Quantum Gravity, Quantum decoherence and entanglement, Relativistic Q Info.
Ted Jacobson (1988- Prof.) Quantum gravity, black hole thermodynamics, modified gravity
Jonathan McKinney (2012- Asst. Prof.) Black hole MHD astrophysics of disks and jets
Manuel Tiglio (2008- Asst. Prof., *likely departing*) Numerical relativity

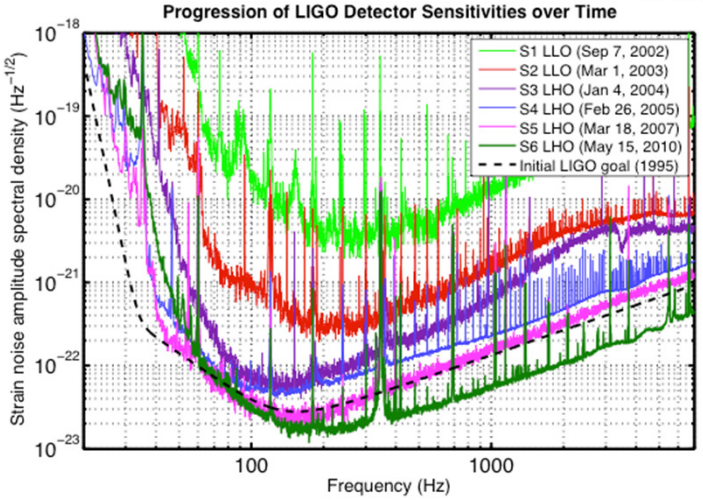
Emeritus Professors:
Dieter Brill & Charles Misner

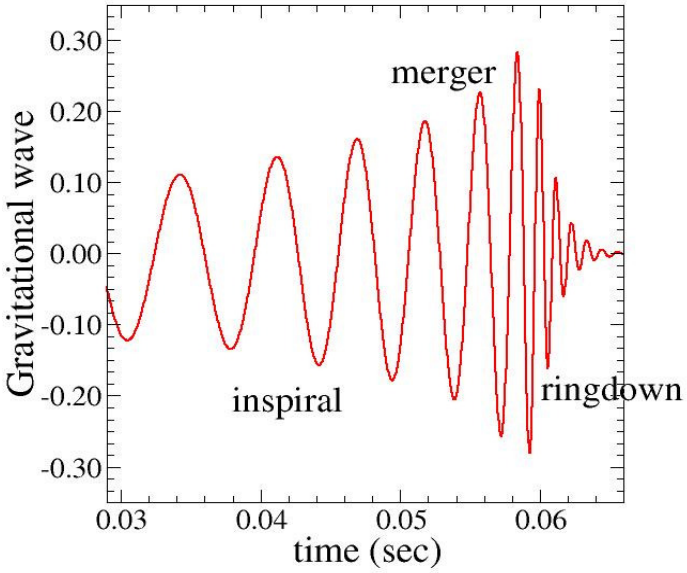
Currently 7 postdocs, 5 graduate students, a few undergrads

Strong overlaps with MCFP, JSI, JQI in the UMD Phys. Dept.
Local links to UMD Astro. Dept., NASA GFSC.

The GRT group continues to maintain a leadership position in the country as evidenced by the impact of its research measured by NSF and NASA grants, participation on national and international committees, invited talks, and citations.

Gravitational-Wave Theory [Buonanno's group]





- Interfacing analytical and numerical relativity techniques to solve the two-body problem in general relativity

- Modeling the dynamics and gravitational-wave emission from compact binaries composed of black holes and/or neutron stars

- Provide advanced LIGO detectors with accurate templates to search for gravitational waves from compact binaries

Bei- Lok Hu: *Current Research Directions*

I. Gravitation Theory

A. ***Stochastic Gravity*** : (90s) ← Activities at MCFP

[Quantum field theory in CST (70s), Semiclassical Gravity (80s)]

Effects of fluctuations in the quantum field and induced metric fluctuations (``spacetime foam') on the structure and dynamics of **spacetime**

Applications to structure formation, nonGaussianity problems in the early universe and backreaction and end state problems in black hole evolution.

B. ***Analog Gravity*** in atomic and condensed matter systems

C. ***Emergent/Quantum Gravity:*** *induce/infer* micro structures of spacetime *from observed Macro phenomena of spacetime described by GR.*

II. Quantum Foundation Issues aided by ← Activities at JQI

nonequilibrium statistical physics ideas and methods:

A. ***Decoherence*** and *quantum to classical transition*

B. ***Entanglement*** as *resource of quantum information Processing.*

III. Relativistic Quantum Information (Int'l Soc. RQI inaugurated 2009)

from frame dependence of quantum measurement, quantum `nonlocality' (EPR) (special relativity) to black hole information (general relativity) issues.

← Combining I and II.

Ted Jacobson's research areas

Black hole thermodynamics

Nature of horizon entropy, Hawking radiation, condensed matter analogs, information paradox, inclusion of higher curvature effects, …

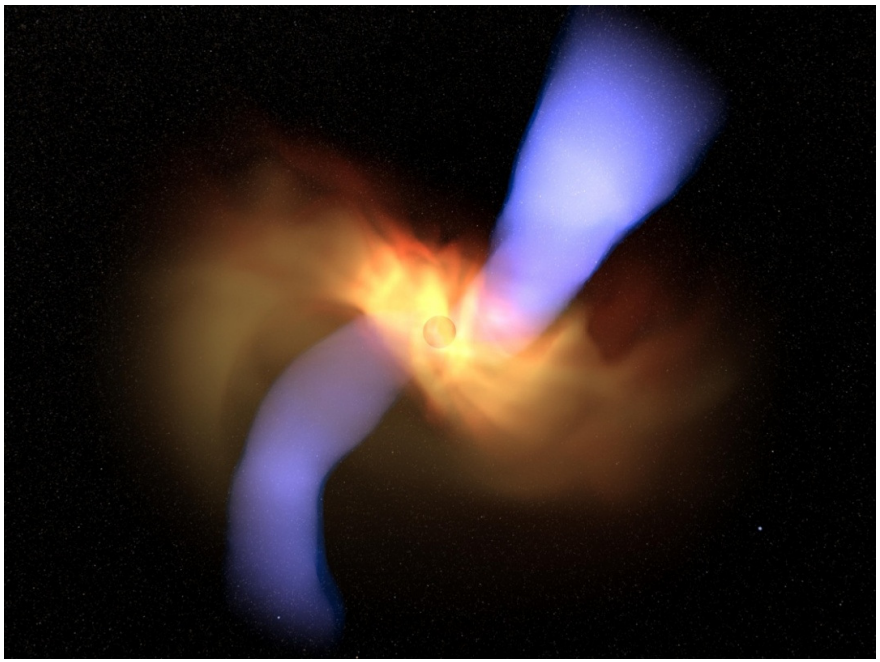
Testing relativity

Theory and phenomenology of Lorentz violation in particle physics and gravity theories

Phenomena around spinning black holes

Relativistic strings, testing cosmic censorship, particle acceleration, force-free plasmas

Magnetized Accretion Disks and Relativistic Jets around Spinning Black Holes (BHs) [McKinney's group]



General Relativistic Simulations of Brightest Events in the Universe by Jonathan C. McKinney

McKinney, Tchekhovskoy, Blandford (Science Mag. Express Nov 15, 2012, published Science Mag. Jan 4, 2013)

Physical Problem:

- How Plasma inflows and Jet outflows behave around Spinning BHs

Discovered New Mechanism:

- Magnetic Torques align Disk and Jet with BH Spin near the BH

Broader Scientific Impacts on:

- SgrA* & M87 for VLBI and EHT
- Electromagnetic counterparts to gravitational waves for LIGO
- Blazar zone emission for FERMI

Future Work (Two NSF grants pending):

- Mutli-Scale (plasma to global) Multi-Physics (radiation, sub-grid physics) Multi-Institution study

Numerical Relativity [Tiglio's group]

Current focus:

Developing "Reduced Basis" method sampling of gravitational waveforms for template matching, in both inspiral and ringdown phases.

Previous major results:

• Analyzed which formulations of the evolution equations are well-posed

• Formulated boundary conditions that preserve initial value constraints, are well-posed, and numerically stable.

• Developed computational methods ensuring numerical stability, including high order methods, spectral methods, and domain decomposition.

• Developed improved analytical first and second order black hole perturbation methods using advanced computer algebra tools for tensor manipulations, improved accuracy of black hole ringdown spectrum.

Opportunities & Challenges

- Opportunity: The direct detection of gravitational waves is expected in the near term (Advanced LIGO) which should usher in an age of gravitational astronomy.

- Challenge: Alessandra Buonanno who is a very major player in the field of gravitational waves is being recruited by other institutions.

  It is also very likely that Manuel Tiglio will leave after next year.

EP

Particle Theory at UMD

Faculty: K. Agashe, Z. Chacko,
S. J. Gates, O. W. Greenberg,
R. Mohapatra and R. Sundrum
+ 5 post-docs, 10 grad students

Ongoing faculty search at junior/senior level

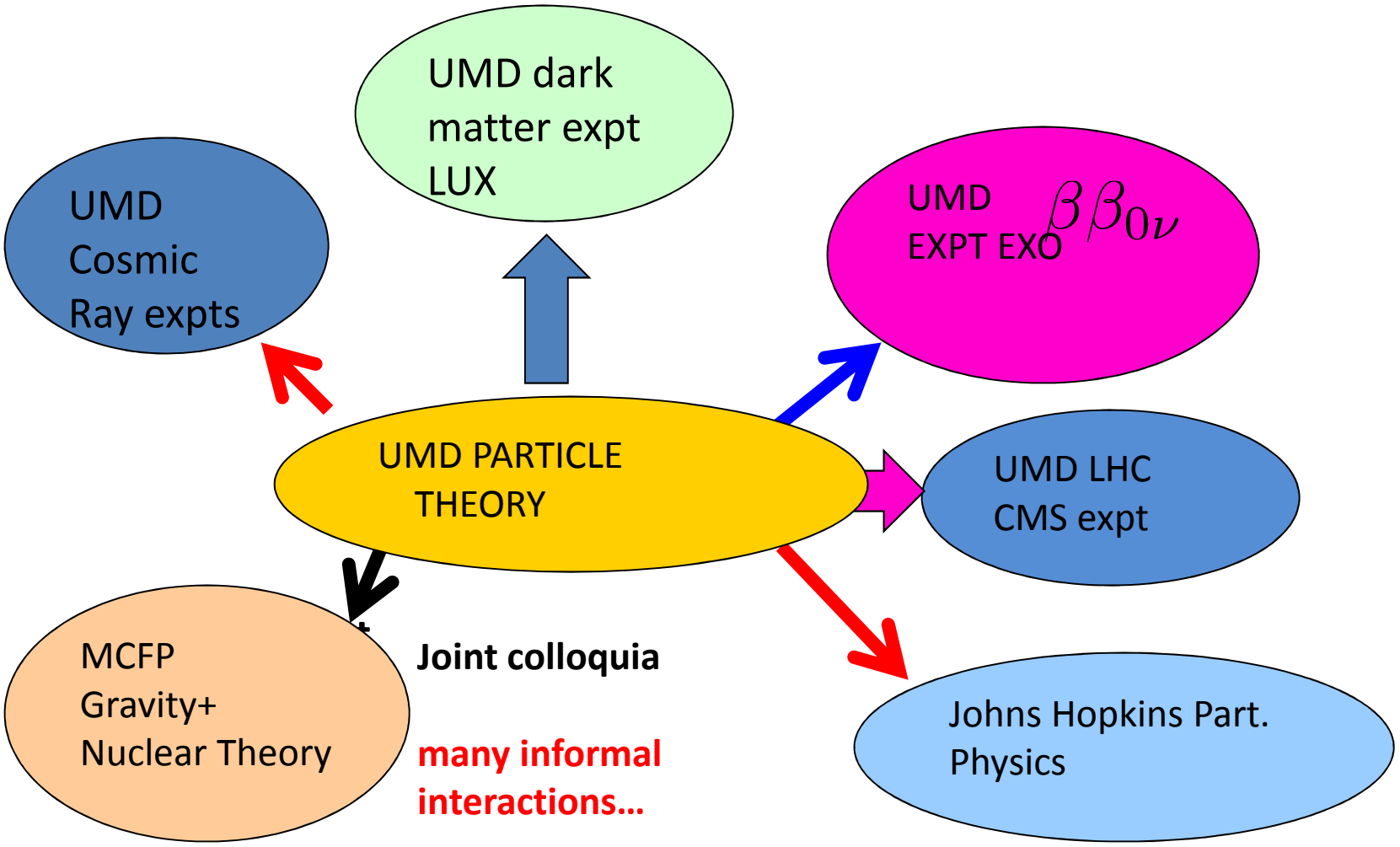
Group is a leader in particle theory. It is exceptionally strong in BSM model building. Its work is highly cited, its members give numerous invited talks and its members play prominent roles in national committees.

Research Emphasis

- Develop new Quantum field theory MECHANISMS → Build New Physics MODELS → Study particle Astro, cosmo PHENOMENOLOGY

UMD faculty pioneered several dominant paradigms within
Quark Color –Greenberg;
New forces, new W's,Z's–Mohapatra;
Supergravity- Gates
Supersymmetry breaking: Chacko, Sundrum
Neutrino Mass- Mohapatra;
Extended Higgs Structure/Portals: Chacko, Agashe;
Warped Compactification: Agashe, Sundrum

LOCAL CONNECTIONS



Opportunities

- New theoretical paradigms are in place
- Experiment is providing critical new data and one expects a fruitful interaction between theory & experiment:
  - Discovering the full mechanism behind the unification of two major forces of Nature, electromagnetism and the weak interactions. The LHC has a major experimental program in this area, with considerable input from UMD theorists. A discovery in this arena would further lay the groundwork for understanding grander unifications with other forces.
  - Dark matter: the dominant but most enigmatic form of matter in our Universe. In conjunction with the LHC, there is a large suite of direct and indirect dark matter detection experiments, with considerable interplay with theory.
  - Neutrino, baryon violation, and flavor experiments on a very broad front continue to provide clues to the Flavor Puzzle
  - The interface of cosmology and particle physics contains several mysteries, where experiments may shed light in the next decade e.g. cosmic Inflation, the origin of the Matter-Anitmatter asymmetry, the nature of Dark Energy.

TQHN

Faculty members:

Thomas Cohen (1988)
Xiangdong Ji (1996)
Paulo Bedaque (2006)

Steve Wallace (2009)
Jim Griffin (2009)
Manoj Banerjee (2001)

3 Postdocs
6 students

The TQHN group despite some recent retirements remains in a leadership position in the country. Its members participate on national and international committees, are invited to give talks at international meetings are highly cited. Its postdocs do exceptionally well in the academic job market.

Recent D0E funded averaging about $740k/year + MCFP

Broad range of research topics both within nuclear physics and overlapping with particle physics and astrophysics:

- Perturbative QCD & generalized parton distribution functons (Ji)
- ν physics (Ji)
- Hadron structure (Bedaque, Cohen, Ji, Wallace)
- Heavy quarks (Cohen)
- Lattice QCD and other non-perturbative methods (Bedaque, Cohen, Ji, Wallace)
- Neutron stars (Bedaque)
- High density nuclear and quark matter (Bedaque, Cohen)
- Dark matter (Ji)
- Nuclear forces and few-body structure (Bedaque,Cohen)
- Jet physics
- RHIC dynamics
- Fundamental symmetries
- Nuclear structure (ν-less double β decay, ...)
- Supernovae and the origin of elements

Opportunities:

A Golden Age for Hadronic & Nuclear Physics

- 40+ years quest for realistic lattice QCD calculations pays off
- Tractable *ab initio* approaches to the nuclear few and many-body problems have finally been developed.

- **FRIB** and CARIBU explore the origin of the elements
- **JLab upgrade** probe the structure of the proton (including the proton spin "puzzle") and exotic hadrons
- **RHIC+ LHC heavy ions**, nature of quark-gluon plasma, viscosity bounds and the QCD-string theory connection,
- **nEDM, CUORE, EXO, Majorana, Katrin, muon g-2**, ...: probe beyond the standard model physics
- **Advanced LIGO**: neutron dense matter from neutrons star
- **FAIR** (Germany): nuclear dense matter, rare isotopes **ARIEL** (Canada), **TRIAC** (Japan), **SPIRAL 2** (France): rare isotopes

—Challenges

- Loss of faculty may make it difficult to maintain national leadership; compounded by fact that Ji is spending ½ time in China and is spending much of his time as an experimentalist (spokesperson for Panda X, a dark matter experiment).
- Competition (U. of Washington, MIT, Berkeley, Michigan State, Stony Brook, ...), aging members and lack of substantial experimental program poses challenge.
- Broad DOE review of whole nuclear program could change funding outlook in the near future given diminished group size.

Priorities

- **GRT—Top priority is for the department to do what is needed retain Alessandra Buonanno. If this fails, a fresh evaluation of opportunities and priorities should be carried out, in particular with regard to the area of gravitational waves.**
- **EP—Top priority is to hire a truly top-flight theorist in the current search. Ideally this would compliment our strength in model building.**
- **TQHN—Top priority is to hire a young faculty member to help group maintain leadership in field; should complement current strengths and should be synergistic with the MCFP: eg. ν physics, symmetries, jets, nuclear/particle astro...**

- **Longer term possibilities: Exploit our strengths and seek complementary directions. Seek synergistic hires bridging MCFP subfields. Exploit connections with JSI & NASA GSFC (eg. graviational waves, cosmology, particle/nuclear astro). Consider expanding in formal fundamental theory such as strings.**