Physics Department Strategic Planning Document

Investment of Choice: Intellectual Mission and Scholarly Recognition

Destination of Choice: Doctoral and Undergraduate Education

Overview of the Department and the Planning Process

The Physics Department presently has 28 faculty FTE's, and 2 lecturers. Research groups in the department are organized around two themes: (i) the physics of macroscopic and microscopic systems, and (ii) the physics of sub-atomic particles, gravity and cosmology. In the former category, the department has research programs in condensed matter experiment and theory, both hard and soft condensed matter, and biophysics; these programs are based in Hasbrouck Lab. In the latter category the department has experimental groups in high energy, nuclear, gravity, neutrino, and astrophysics, and fundamental interaction theory; these programs are based in LGRT.

For the research self-assessment, faculty were asked to respond to these prompts:

- *At present, how would you describe your department's place in your discipline?*
- *What is its special character or niche?*
- *What are you known for by colleagues elsewhere?*
- *Understanding that departments cannot do everything, what subfields or foci have attained a critical mass?*

To move the process along as quickly as possible, groups in Hasbrouck met separately from groups in LGRT. In Hasbrouck there were meetings of separate research groups, followed by meetings where the entire faculty in Hasbrouck came together. In LGRT the approach was akin to a series of 'town meetings', where the faculty in LGRT came together for an open discussion of the global program and aspirations for the future.

For several years the Department has run a series of lunch meetings dedicated to undergraduate and graduate education, and teaching innovation. These meetings have flourished and prospered under the mentorship and guidance of a few faculty members with a real passion for teaching. The self-study of the undergraduate program and the self-assessment of the graduate program took place during several meetings of the group, led by Heath Hatch, Jennifier Ross, and Mark Tuominen. The physics department currently has over 200 undergraduate majors, and 82 graduate students enrolled.

Sections I and II contain self-assessments written by the groups in Hasbrouck (condensed matter experiment/theory and biophysics), and the groups in LGRT (sub-atomic physics, gravity, cosmology), respectively. Section III contains summary comments written by the Department Head on the opportunities and challenges for the research sub-fields in the department. These comments are meant to address the Provosts question, *"Understanding that departments cannot do everything, what subfields or foci have attained a critical mass? "* Section IV provides the self-assessment of the graduate program. Appended to this document is the department's statement on undergraduate education that was sent to the CNS Undergraduate Curriculum Committee.

I. Self-assessment of the Research Groups in Hasbrouck

Introduction: The research carried out by the Biological Physics (BIO), Condensed Matter Experiment (CME) and Condensed Matter Theory (CMT) groups seeks to explore Nature from the macroscopic to the microscopic, with the exception of the astrophysical and subatomic realms. In the international context many members of these groups are well-documented leaders, highly recognized for their expertise and contributions. This is in some sense remarkable because in the national context of peer institutions these groups are unusually small and in most cases have limited access to appropriate facilities. Selected highlights of faculty members appear in the boxes in each subsection. Targeted investment will enhance our strengths through improved synergy and opportunities for additional major external funding.

I.A <u>Condensed Matter Theory</u> (CMT)

Faculty	*Rank*	*Hired*	*Major Honor*	*Area*
C. Santangelo	Assoc	2007	NSF CAREER	A,C
B. Davidovitch	Assoc	2007	NSF CAREER	A,C
J. Machta	Full	1982	APS Fellow	A,C,D
B. Svistunov	Full	2003	APS Fellow	B,C,D
N. Prokofiev	Full	1999	APS Fellow	B,C,D

A - soft condensed matter, **B** - hard condensed matter, **C** - statistical physics, **D** – computational physics

Numerical snapshot of group:
- **1455** citations in 2013
- $ **5.2M** in active funding ($ **1.05M** in 2013 **)** ; CMT share
- **11** national or international honors/awards
- **177** invited external talks (last five years)
- **10** PhDs defended (last ten years)

The group consists of five faculty members, who supervise, on average, 8 graduate and 2 undergraduate students, and 4 postdocs. The group has the critical mass, is recognized nationally and internationally, and, if allowed to grow, will rise in stature to the level of the best state schools.

Santangelo (CS) and Davidovitch (BD) are known for their ground-breaking research in "extreme mechanics," which seeks to understand the principles underlying the interplay of geometry and mechanics in objects that are very thin (*e.g.* sheets, shells, rods), liquid crystals (CD), and nonequilibrium pattern formation (BD). Prokofiev (NP) and Svistunov (BS) are leaders in first-principles approaches to strongly correlated quantum systems (they invented two state-of-the-art numeric technologies, Worm Algorithm and Diagrammatic Monte Carlo), critical/superfluid phenomena, and dissipative dynamics. Machta (JM) is a leading expert in properties of disordered materials (spin glasses and random field models), efficient computational methods, and applications of computational complexity theory to statistical physics.

The group's work is published in the best physics journals (**24** articles per year with **5-6** of them in Physical Review Letters, Science, Nature Physics, and PNAS) and is well funded (**11** active grants). Apart from regular grants from NSF (everyone), PRF, and BSF, substantial funding comes from prestigious and highly-selective initiatives: NSF INSPIRE grant (JM), **$2M** NSF initiative on origami-based design (CS), **$1M** Keck Foundation grant (CS & BD with NM of the CM Exp. group), **$12.5M** (UMass share **$800k**) AFSOR Multi-University Research Initiative "Advanced Quantum Materials – A New Frontier for Ultracold Atoms" (BS & NP), and **$20M** (UMass share **$1.67M**) Simons Collaboration on the Many Electron Problem (BS &NP).

<u>National and international visibility</u> of the research program is reflected (apart from the many invited talks, the grants, and the awards), in the number of organized conferences, workshops, and schools **- 23** (in the last 10 years), including programs at the Aspen center for Physics, the KITP at Santa-Barbara and Beijing, the Lorentz Institute at Leiden, and ICTP Trieste. JM and NP were/are serving as Divisional Associate Editors for the leading physics journal, Physical Review Letters.

<u>Ties with other groups:</u> In the physics department, CS and BD are collaborating with Menon's and Dinsmore's CME groups. NP, BS, and JM have strong research overlap with Hallock's CME group. On campus, CS and BD are collaborating with Russell's and Grason's groups in the PS&E department; CS is also collaborating with Hayward's and Crosby's groups. In the ME department, CS and BD have been working with A. Ramasubramaniam. JM has established record of joint work with Ellis (M&S).

Group members have an extensive network of active collaborations worldwide, with groups at Oxford, ENS (Paris), ESPCI (Paris), MIT, Harvard, Berkeley, Columbia, ETH (Zurich), LMU (Munich), U. of

Michigan (Ann Arbor), Cornell, King's College (London), RIKEN (Tokyo), Hebrew Univ. (Jerusalem), USACH (Santiago), Western New England Univ., Univ. of Leiden, UC (Davis), Texas A&M, CSI CUNY, and USTC (Hefei). Many of these are funded by specific grants and world-wide research initiatives mentioned above.

Weak points The CMT group size of 5 is small compared to peer and aspirant institutions such as U. Michigan Ann Arbor (11), Rutgers (11), or U. Minnesota (10), U. Maryland (13), or UC Davis (11). We lack the faculty numbers to provide theoretical support for experimental efforts in materials, nano and energy research.

I.B Condensed Matter Experiment (CME)

The group consists of six faculty members and works with 16 graduate students, 4 postdocs and over 10 undergraduate students. The breadth of research has led to the successful placement of grad students (33 PhDs in the last ten years) both in academia and industry. Group expertise is centered in three broad areas: (A) quantum fluids and solids and low temperature physics, where Hallock (RH) is known for his pioneering experiments in liquid and solid helium, and Candela (DC) for his work with NMR; (B) soft matter physics, where Menon (NM) is highly regarded for his innovative research on non-equilibrium systems, Dinsmore is known for his work on colloids, gels and interfacial physics, and (C) electronic, optical, magnetic, i.e., nano materials, where Tuominen (MT) is an expert on charge transport and magnetism in nanosystems and Yan (JY) pioneered scattering studies of graphene. Quantum fluids and solids (A) is a long-term strength of this campus; soft-matter physics (B) has become well connected with a high profile in the past several years, and nano (C) is a core component of CME, in which our group has achieved notable leadership despite very limited size. (MT) is the Director of the National Nanomanufacturing Network and Co-Director of the NSF NSEC Center for Hierarchical Manufacturing. Our visibility is demonstrated by the number of invited talks at academic institutions and conferences including prestigious plenary talks, national and major international responsibilities in either ad hoc or permanent roles and by national or international awards. CME also offers a soft matter summer school with CMT colleagues that has brought more than 200 off-campus grad students to UMass in 6 years.

Faculty	*Rank*	*Hired*	*Major Honor*	*Area*
Hallock	Dist.	1970	Guggenheim, Sloan, APS Fellow	A
Candela	Full	1986		A,B
Tuominen	Full	1993	APS Fellow	A,B,C
Menon	Full	1998	APS Fellow	B
Dinsmore	Full	2001	Cottrell	B,C
Yan	Asst	2012		C

A: Quantum fluids, **B**: Soft Matter; **C**: Nanophysics

Numerical snapshot of group:

- ~**1500** citations in 2013
- **$12.9M** in active funding **(2.74M** in 2013); CME share
- **12** national or international awards
- over **80** national or international committees in the last 5 years.
- over **120** invited talks in last 5 years
- **33** PhDs in the last ten years

The group has a large (**$2.74M** in 2013; $**12.9** M total current funding), stable, and varied funding portfolio that draws from several directorates of NSF (including CMP and Engineering), NASA, DOE, NIST, as well as industry funding (e.g. P&G, Xerox, Seagate, BP, and PMUSA), as well as the only two Keck Foundation grants awarded to UMass. This will continue to be a strength as condensed matter and materials have the broadest opportunities for funding among all of the subfields of physics.

Ties with other campus groups CM Expt has been a leader in on-campus materials efforts such the CHM and MassNanotech (Tuominen) and a major contributor to others including the MRSEC, EFRC, and several REUs and RET. We collaborate with fifteen faculty members in Chemistry, Microbiology, MIE, PSE, Chemical Engineering and Food Sciences, several others in the Five College Community and more than a dozen nationally and internationally.

Weak points*:* Our group of 6 is small and has a top-heavy age structure. At most major public or private research universities, condensed matter experiment is a large segment of the Physics Department.

By comparison, we are numerically weak (e.g., Penn State has 14, Michigan State 13, UMinn 10, Ohio State 10, Stony Brook 14, Rutgers 16, UC Riverside 10, a list that excludes public universities with bigger and elite CME groups such as Illinois (26 for CMT plus CME), UC Santa Barbara, Berkeley). This numerical weakness limits the ability to compete for large grants centered in the Physics Department, has led to difficulty in faculty retention, and results in a narrower range of instrumentation and experimental techniques than is desirable. This affects not just scientific choices but also graduate training; our graduate offerings are sparse, and do not feature even a single course focused on experiment.

Lack of quality space has led to lost hiring opportunities and to research groups being scattered over the buildings. The planned Physical Sciences Building will alleviate some of these issues but it will not accommodate all of our faculty; attention and resources must also be focused on renovating the space vacated in Hasbrouck and locating additional space.

I.C <u>Biological Physics</u> (BIO)

Faculty	*Rank*	*Hired*	*Major Honor*	*Area*
Ross	Assoc	2007	DAYHOFF (BPS), NSF INSPIRE, Cottrell	A,C
Goldner	Full	2008		A,C
Parsegian	Full,	2009	DCRT/NIH	A,B,C
Kilfoil	Asst	2010		B,C

A – molecular, **B** – membranes, **C** - cellular

Numerical snapshot of group:

- **910** citations in 2013
- **$4.5M** in active funding, **($1.16M** in 2013); BIO share
- **16+** National or International awards
- **39+** National or International committees
- **21+** events organized in last 10 years.
- **114+** invited talks in last 5 years.

The group consists of four faculty members, three of whom are women, who supervise on average 10 graduate and 12 undergraduate students, and 2 postdocs. This highly interdisciplinary group is the newest in the Physics Department and is recognized for strengths in molecular biophysics (esp. single-molecule, molecular motors, intermolecular forces, biopolymers), membrane biophysics (esp. transport), and cellular biophysics (esp. cytoskeleton physics and active matter). We are strengthened by our synergy with soft matter physics.

For a new group, biophysics has excellent visibility. Our senior member, who holds the Gluckstern Chair, Parsegian (AP) is acclaimed for his fundamental work on molecular interactions (h-index = 68) esp. through his textbook, <u>Van der Waals Forces A Handbook for Biologists, Chemists, Engineers, and Physicists</u>. Goldner (LG) is known for pioneering new techniques in single molecule detection. Kilfoil (MK) is known for applying rigorous analytical techniques to examine biomaterial properties. Ross (JR) is an expert in microtubule cytoskeleton biophysics.

<u>National and International Visibility:</u> In the last five years, group members have given more than **114** invited talks at seminars, colloquia, or national or international meetings and published a total of **48** peer-reviewed papers. We currently hold a total of $4.5M in active funding from NSF (several divisions including Physics, Engineering, BIO, and Materials), NIH, DOE, and the Mathers Foundation. **27** former students or postdocs hold positions as University faculty, or staff at National Labs. In the last 10 years, the conferences and workshops organized include a new GRC on single molecule biophysics (LG), several recurring local meetings and workshops (JR, MK), and summer workshops in biological physics joint with NIH (AP).

<u>Ties with Other groups:</u> On campus we are sought out for our quantitative approaches, state-of-the-art measurement and imaging capabilities, and expertise in analysis, theory, and modeling. Not coincidentally, our interests overlap with faculty all over campus: we participate in MCB and IALS and have grants or collaborations with PSE, Biology, Veterinary and Animal Sciences, Biochemistry and Molecular Biology, Mechanical Engineering, Chemical Engineering, Microbiology, Kinesiology, and Chemistry. In a first success at larger interdisciplinary group funding, we lead the Biological and Soft Matter Research Traineeships (B-SMaRT) Research Experience for Undergraduates, funded by NSF (JR), which is joint with the soft matter physics group (including MK, AP, LG, Candela, Davidovitch, Dinsmore, Grason, Menon, Santangelo) and Springfield Technical Community College.

Weak points: Our group size is small compared to aspirant institutions such as the University of Illinois Urbana Champaign (11), UC San Diego (8) and Cornell (8), or some peer institutions such as Georgia Tech (7) and comparable to other good institutions with modest biological physics programs such as Ohio State (4) and Rutgers (3). Our small size makes us less competitive for grants and limits the research and course options for graduate students. Although there have been substantial successes among individuals in the group, the group has not yet achieved the cohesion or the level of productivity at UMass that the department anticipated would be the case by this point in the evolution of the group.

Common weaknesses: As is clear from the individual assessments, a crucial weakness of the groups is the fact that they are much too small; in some cases they are sub-critical. This lack of adequate size greatly limits our ability to compete for major collaborative and Center funding. Indeed the stability of these groups to faculty erosion is threatened by their subcritical size. This also limits our ability to offer a quality curriculum to our graduate students. In addition, the experimental groups are space-bound. As noted, the new PSB will help, but even with renovations the space available will be inadequate for the faculty expansion that is really needed.

Summary: Our small research groups are, for the most part, very strong for their size. Individual group members have made substantial impact and achieved wide recognition. But we are vulnerable to erosion and limited in our ability to create enhanced impact. We have noted our strengths, but also have been serious about making clear our weaknesses. The strengths need to be built on and the weaknesses need to be addressed if we are to have a future that will allow us to attract and then keep high quality colleagues and thereby enhance our international visibility and impact.

II. Self-assessment of the Research Groups in LGRT

Introduction: Research in fundamental interaction groups seeks to explain the fundamental laws of nature that underlie all observed phenomena, from the subatomic scale to the cosmic scale. We continue to test and elucidate the known laws of nature: gravity as described by General Relativity, together with the strong and electroweak interactions as encompassed in the Standard Model of elementary particle physics. At the same time, we seek to discover new laws of nature that would account for as yet unexplained phenomena such as the abundance of non-luminous dark matter and the excess of visible matter over antimatter.

Experimentally, the study of fundamental interactions takes place at three frontiers: the Energy frontier, where the present focus is at the CERN Large Hadron Collider; the Intensity Frontier, comprised of a wide array of high-sensitivity/high precision low-energy measurements; and the Cosmic frontier, including studies of cosmological and astrophysical phenomena. Theoretically, fundamental interaction studies include delineation of phenomena that arise within the framework of the Standard Model and General Relativity as well as the construction and phenomenology of scenarios that go beyond them.

UMass researchers are world leaders in experiments and theory in all three frontiers as well as at their intersection, with a growing level of international stature and visibility. The establishment of the Amherst Center for Fundamental Interactions (ACFI) in September 2013 has significantly enhanced the UMass international visibility in this area, providing a unique-in-the-world home for physics at the interface of the three frontiers. In addition to generating a new level of coherence and synergy within UMass-led research, the ACFI is also quickly becoming a focal point for the international community. Through a program of targeted workshops and research presentations, the ACFI has brought over 100 researchers from around the world to the department to develop new research directions and form new collaborations.

II.A Fundamental Interactions Theory (FIT)

The FIT group currently consists of 7 research-active faculty, 4 post-doctoral researchers, and 7 students. The research-active faculty includes two current members who share 1.5 faculty FTE and two emeritus faculty.

Faculty	*Rank*	*Hired*	*Major Honor*
Golowich	Emer.	1967	APS Fellow
Holstein	Emer.	1971	APS Fellow
Donoghue	Dist.	1980	APS Fellow
Traschen	Full	1989	APS Fellow
Kastor	Sen. Lect.	1989	APS Fellow
Sorbo	Assoc	2005	
Ramsey-Musolf	Full	2013	APS Fellow, NSF YI, DNP Thesis

Numerical snapshot of group:
- **47** invited talks last year
- **23** PhD students defended (last 10 years)
- **7** PhD students, 2 visitors (currentl)
- **4** postdocs/research scientists (current)
- **35** publications last year
- **11** conferences/workshops organized (past year)
- **$0.5M/year** total grant funding

In recent years, the UMass theory group has been particular visible in the area of gravitational physics and cosmology. Donoghue and Holstein are known for their pioneering applications of effective field theory to weak, strong, and gravitational interactions. Traschen and Kastor are well-known for the early calculations on reheating the universe (Traschen) and investigations of classical and quantum gravity with ties to string theory, black hole thermodynamics, and coalescing black holes. Sorbo is known for studies of particle creation after inflation and gravitational waves.

The arrival of Ramsey-Musolf in September 2013 has brought a growing emphasis on theoretical physics of the Intensity and Energy frontiers, their interface with the Cosmic frontier, and the interplay with the experimental program in these areas. Ramsey-Musolf is a leader in the study of the cosmic matter-antimatter asymmetry, tests of fundamental symmetries in nuclear and particle physics, physics beyond the Standard Model, and the electroweak phase transition. Golowich, Donoghue, and Holstein are well known for their contributions to flavor and chiral physics. They have recently published an updated version of a highly regarded research text, "Dynamics of the Standard Model", that has become a standard for researchers in particle physics.

Since September 2013, the members of the group have published over 30 articles. The average "h-index" for the group is 39. Collectively, FIT theory is funded at the level of $500k/year through a combination of Department of Energy and National Science Foundation grants, including the largest single-PI award in nuclear theory from the Department of Energy (RM).

International visibility and leadership: Since September 2013, members of the group ten workshops and conferences, including a Kavli Institute for Theoretical Physics program on the origin of the matter-antimatter asymmetry and six ACFI workshops. FIT faculty members have given over 25 external invited presentations during that period. Holstein is editor of Annual Reviews of Nuclear and Particle Science and an associate editor for Journal of Physics G. Donoghue recently chaired the selection committee for the prestigious J. J. Sakurai prize in high energy physics. Traschen has been on several prestigious awards selection committees. Ramsey-Musolf, ACFI Director, is a member of the scientific and program advisory boards for several major international facilities, including the Paul Scherrer Institute, the Sanford Underground Science and Engineering Laboratory, the Fundamental Neutron Physics Beamline at the Spallation Neutron Source, the Facility for Rare Isotope Beams (FRIB), and the Munich Institute for Astro-Particle Physics. He is also an editor for Physics Reports, a member of the DOE/NSF Nuclear Science Advisory Committee Long Range Plan working group, and convener of the East China Particle Physics Working Group.

External Collaborations: Group members have extensive national and international collaborations, including collaborators at Caltech, Harvard, U.C. Berkeley, U.C. Davis, U.C. Santa Cruz, U.C. Santa Barbara, Los Alamos National Laboratory, SLAC National Accelerator Laboratory, Wayne State U., Technical University Munich, Niels Bohr Institute, University of Minnesota, U of Hawaii, Texas A & M, Perimeter Institute, U. of Sao Paulo, U. Astral de Chile, U. of Sussex, U. of Durham, Imperial College, CEA Saclay, U. de Paris-Sud, U. of Paris 7, U. of Zurich, National Center for Theoretical Sciences Taiwan, Shanghai Jiao Tong University, Nanjing University, Hong Kong University of Science and Technology, and the Center for High Energy Physics Beijing.

Growing Edges: Through the recent P5 (Particle Physics Project Prioritization Panel, a subpanel of the High Energy Physics Advisory Panel) process, the high energy physics community has identified experiments at the LHC, a future neutrino physics program based at Fermilab, and searches for dark matter as priorities. In its 2007 NSAC Long Range Plan, the nuclear physics community identified hadron structure and interactions at Jefferson Laboratory, nuclear structure and astrophysics at FRIB, tests of fundamental symmetries and neutrino property measurements, and "hot" QCD at Brookhaven National Laboratory and the LHC as its highest priorities. The area of fundamental symmetries and neutrinos is in particular a growing area of nuclear physics. Together with the Fermilab-based neutrino and muon programs, this component of nuclear physics comprises the bulk of the Intensity Frontier.

The recent retirements of Golowich and Holstein have weakened the ties of the theory effort to these long-term priorities for high energy and nuclear physics. Through the presence of Sorbo and the emphasis of Donoghue, Kastor and Traschen on gravity, the direct connection with the Cosmic Frontier has been stronger. The coupling between theory and experiment at UMass has also not been as pronounced as at other institutions. Fortunately, the arrival of the Ramsey-Musolf group (four post-docs and four students) has brought a substantial new thrust coupled to the long-term priorities at the Intensity and Energy Frontiers as well as close interaction between theory and experiment. Nevertheless, the group lags behind other top-ranked groups in high energy phenomenology and nuclear theory. This situation will be exacerbated by the impending Donoghue retirement. UMass has not developed a group in string theory, though the work of Kastor has some overlap with this research direction. The Department has also not developed an effort in lattice Quantum Chromodynamics, nuclear structure theory or nuclear astrophysics, areas that constitute cutting-edge directions in nuclear theory.

II.B Fundamental Interactions Experiment

The experimental staff includes 8 faculty, 1 research scientist, 9 post-docs, and 18 Ph.D. students. Two faculty members, Cadonati and Kumar, are officially on leave and will be moving to new positions at Georgia Tech and Stony Brook University. In order to provide a picture of the full experimental scope prior to these departures, we include their research activity in what follows.

Experimental research in fundamental interactions at UMass is providing international leadership at all three frontiers. At the Energy Frontier, Brau, Dallapiccola, and Willocq are members of the ATLAS collaboration, which was one of the two LHC experiments responsible for the discovery of the Higgs boson (2013 Nobel Prize). Willocq just completed two years as co-convener of the Exotics Physics group, a position of considerable visibility within the ~3000 member ATLAS collaboration. He also led the muon reconstruction for ATLAS experiment at the Large Hadron Collider, which was instrumental in the discovery of the Higgs boson in 2012. Brau and Dallapiccola are known for expertise in heavy flavor physics, in particular B-Bbar mixing, rare B decays and CP violation in the B sector. At the LHC the UMass group is known for new interactions in the dileptonfinal state, TeV-scale gravity, measurements of W/Z+jets and searches for displaced vertex signatures and other Beyond-Standard-Model phenomena.

At the Intensity Frontier, Kumar (on leave), is a leader in parity-violating electron scattering, having shepherded the precise measurement of the Moller asymmetry at SLAC and leading the planned Moller experiment (a $20-25M project) with the Jefferson Lab 12 GeV beam. Miskimen is known for precision tests of low-energy QCD, precision tests of chiral symmetry with measurements of the neutral pion lifetime and the electromagnetic polarizabilities of the nucleon and pion. Kawall's research focuses on the up-coming Fermilab measurement of the muon anomalous magnetic moment, precise measurements of muonium hyperfine levels, and nucleon spin structure at Brookhaven National Laboratory. Pocar is an expert on low-background detectors, with Intensity Frontier work as a member of the EXO-200 and nEXO collaborations that search for the neutrinoless double beta decay of Xenon-136.

Faculty	*Rank*	*Hired*	*Major Honor*	*Area*
Miskimen	Full	1986	APS Fellow	N
Willocq	Full	1998		HE
Kumar	Full	1999	APS Fellow	N,n
Dallapiccola	Full	2000		HE
Kawall	Assoc.	2005	RIKEN Fellow	N
Cadonati	Assoc.	2007	NSF CAREER	G
Brau	Assoc.	2008		HE
Pocar	Assist.	2009		n,A

HE – high energy; **N** – nuclear; **n** – neutrino; **A** – astroparticle; **G** – gravitational

Numerical snapshot of group:
- **31** invited talks last year
- **17** PhD students defended (last 10 years)
- **15** PhD students, **2** masters (currentl)
- **8** postdocs/research scientists (current)
- **43** publications last year
- **6** conferences/workshops organized (past year)
- **$1.7M/year** total grant funding

For the Cosmic frontier, the Cadonati group focuses on searches for gravitational wave transients in data from ground-based detectors LIGO and Virgo. Pocar and Cadonati have played a major role in the solar neutrino detector Borexino and is developing a dark matter direct detection experiment known as DarkSide.

Since September 2013, the FI experimentalists have published over 40 papers. They are funded at the level of $700k/year (high energy experiment), $797k/year (nuclear experiment), $342k/year (astro-particle experiment).

International visibility and leadership: Visibility and leadership in experimental fundamental interactions physics is reflected through being a PI or analysis leader of a major experiment. In that regard, UMass has established a remarkably high level of visibility for a department of this size. Willocq has been convener of the ATLAS Exotics Physics group. Brau is convener of the ATLAS Unconventional Signatures and Exotic Higgs Decays subgroup of the ATLAS Exotics Physics Analysis Group. Dallapiccola chairs the US ATLAS Speakers Committee.

Kumar is PI of the Jefferson Lab Moller experiment, NSAC Long Range Plan Working Group member, and member of the advisory committee for the Electron Ion Collider, a potential next generation nuclear physics/QCD facility that would be based in the United States. Pocar is nEXO R&D L2 manager and member of the EXO-200/nEXO Institutional Board, the Borexino Steering Committee and Institutional Board and the DarkSide Institutional Board. Kawall serves on the PHENIX Institutional Board, the Muon g-2 Steering Committe and Institutional Board, and is L3 scientific/technical leader for the g-2 magnetic field measurement. Miskimen has served as spokesman for the JLab PRIMEX experiment, precision measurement of neutral pion lifetime, and the charged pion polarizability experiment, as well as serving on the Mainz A2 collaboration steering committee. Cadonati is vice-chair for the APS Topical Group on Gravity. Within LIGO, she chairs the data analysis council, is on the Executive Committee for the LIGO Scientific Collaboration and Virgo, and was chair of the transient search group in 2010-13.

Since September 2013, the experimental faculty members have given 31 invited conference or workshop talks, colloquia, and seminars. They have organized three workshops.

External Collaborations: International collaborations include the ATLAS experiment, EXO-200/nEXO, Borexino, LIGO, RHIC Spin, Fermilab E989 (muon g-2), Dark Side, Storage Ring EDM, J-PARC (Japan) muonium hyperfine measurement, JLab GlueX, and Mainz A2.

Growing Edges: The moves of Kumar to Stony Brook and Cadonati to Georgia Tech constitute substantial losses to the overall fundamental interactions experimental program, in general, and to the Intensity (Kumar) and Cosmic (Cadonati) frontiers, in particular. The ATLAS effort remains vital, with particular emphasis on analysis rather than hardware. The UMass leadership at the Intensity Frontier retains visibility through participation in the EXO-200/nEXO experiment, Jefferson Lab chiral symmetry test experiments, and Fermilab E989, though the loss of Moller leadership means UMass will no longer have a PI of a project of this scale on our faculty. It is also not represented in the Fermilab neutrino program.

The impending loss of Cadonati leaves UMass particularly vulnerable at the Cosmic frontier, with only Pocar's Borexino/DarkSide program remaining.

The UMass unique "claim to fame" as providing both leadership in, and an international focal point for, physics at the interface of the three frontiers relies on high visibility experimental efforts and leadership in all three frontiers as well as theoretical leadership at their intersection. Even without the Cadonati loss, the experimental effort in the Cosmic Frontier had not yet achieved a faculty count comparable to that at the Energy and Intensity Frontiers. This loss, along with the loss of Kumar, constitutes a significant setback.

Diversity: Of the 15 research-active faculty in theory and experiment, two are female and one gay for a total or 20% gender and sexual minority representation. We are still collecting data on student and post-doctoral membership in under represented groups.

III. Summary Comments on Opportunities and Challenges for the Physics Department

- **Condensed matter theory:** Investment in this group presents a key opportunity for the Physics Department. This is a relatively young group with notable strengths, although it is undersized compared to peer institutions. Egor Babaev recently left UMass, and the search in CM theory that's currently underway will only bring this group back to its level from fall 2013. In spite of the loss of Babaev, CM theory is thriving, providing an opportunity for the department to hire superb faculty. Investments in this area are warranted and urgently needed.

- **Condensed matter experiment:** Active groups in this sub-field of physics are critical to the health of physics departments, and the senior leaders in our department have been quite successful. The challenges this group faces are its small size, which limits the ability to compete for large grants centered on physics, and being top-heavy in age structure. A faculty search currently underway will help alleviate this situation. The challenges the department faces in growing this group into the next tier of physics departments are (i) large start-up costs required to be competitive with other top-40 ranked physics departments, and (ii) lack of lab space and aging facilities in Hasbrouck, and high costs for renovation. Not all of the new CM faculty will be able to go into the new PSB building.

- **Biophysics:** This is a young group with a very senior, named professor, group member. Three of the five women in the department are in this group. Prominent successes have been achieved, but not uniformly across the group. Given other critical needs of the department, further investments in this group should come later.

- **Fundamental interactions theory:** Investment in the Amherst Center for Fundamental Interactions (ACFI) provides an opportunity for the department to attain national and international prominence in an increasingly important sub-field of nuclear/particle physics. The challenges here are (i) replace the retired and retiring faculty in the theory group who originally built up the group's strong reputation, and (ii) grow this group into emerging forefront areas. A theory search is currently underway. To achieve the department's goal of making ACFI a nationally funded theory center, further investments are essential.

- **Fundamental interactions experiment:** The experimental program had been well positioned for future opportunities, but was recently hit by the loss of two members with national and international prominence, Cadonati and Kumar. This loss presents a challenge and opportunity to the experimental group: come forward with a plan that builds on their present strength and connection to the theory effort in ACFI, to move the group into emerging high-priority areas of nuclear/particle/astrophysics research. A key step forward will be in defining and starting faculty searches for spring 2015. The present planning process provides an excellent opportunity for deciding on these future directions.

IV. Investment of Choice: Doctoral Education

Mission: Our mission is to maintain and expand high quality learning for our graduate students, through a culture of exciting research engagement, timely coursework and professional development. We work to foster a mindset of *professional physicist* for each student from moment they arrive on campus – cultivating the attitudes of mastery, autonomy and proactive curiosity that builds leaders. Through the activities enabling this mission, we work to attract the best students, enabling our graduate program to strengthen continuously.

Established Excellence:

1. Providing TA or RA support for all of our graduate students
2. Providing strong research engagement over a breadth of research areas
3. Intensive mentoring through frequent interactions with faculty
4. Engaging and informative seminars and colloquium
5. Interdisciplinary research opportunities
6. Forefront engagement with a broader research community:
    - Amherst Center for Fundamental Interactions (ACFI)
    - NSF NSEC Center for Hierarchical Manufacturing
    - Annual soft matter physics summer school
7. Graduate student research seminar – for self-directed engagement
8. A graduate student orientation
9. Pathway for a reasonable time to PhD compared to national trends

Enhancements: To enhance UMass Physics as a destination of choice the Department plans to strive for the following enhancements:

1. Provide a more complete and coherent graduate curriculum (as compared to peer institutions)
2. More frequent offering of advanced, research-focused courses (i.e., those beyond the required core courses)
3. Maintain the momentum of enthusiasm of entering grad students experience through early research engagement
4. Develop and maintain a strategy on diversity in our graduate program through recruiting and on-campus support
5. Work to eliminate the long tail in the time-to-PhD distribution through early research engagement and a program of professional development. (That is, to address the small handful of students who take an unusually long time to complete their PhD, thereby skewing the distribution and the average.)
6. Update the qualifying examination structure to best meet our graduate mission.
7. Program of early experimental training to cultivate curiosity, strengthen engagement, and facilitate research thinking:
    - Early interactions with research groups
    - Strengthen professional development an integral part of the TA training
    - Research course or bootcamp-style courses
    - Professional development in communication and inquiry skills
    - Co-instruction: Senior grad student instructors working alongside faculty instructors in bootcamp-style courses (cultivating professionalism and forming near-peer aspiration for junior grad students)

8. Use a three-day orientation to firmly establish a culture where students view themselves as professional physicists. Use the research and professional development program to reinforce this culture.
9. Publicize and enhance the exchange program
10. Reinstitute the biophysics workshops and Gluckstern lectures
11. Survey current students and alumni on UMass grad experience for continuous improvements
12. Maintain a competitive level of TA stipend
13. Provide an effective program of publicity for recruiting the very best graduate students. Satisfied customers (i.e., successful, well-trained grad students moving on to excellent positions) is the key metric of graduate program quality.

Resources: The greatest factor for recruiting the best graduate students is high quality faculty with high quality research programs. To accomplish the enhancement objectives described above, we urgently need to enhance the faculty count and the number of TA positions and provide quality suitable research space to accommodate these people.

V. Destination of Choice: Undergraduate Education. Established Excellence and Planned Enhancements

Overarching Statement: The Department of Physics has two distinct, yet simultaneous, teaching missions focused on two audiences: (1) our physics majors who focus on physics mastery and (2) all other students of the university who require the quantitative reasoning skills provided by a physics education. In this document, we separately treat these two educational programs, designated, "Physics Majors" and "Service and GenEd Courses."

I. Physics Majors: Our mission is to attract and educate students in the conceptual knowledge, innovation and problem solving skills, and hands-on experience of Physics to make them motivated and successful leaders in their chosen field.

Established Excellence: The University of Massachusetts Department of Physics has an excellent track record educating physics majors in the following:

1. Our lecture-based courses, the core course offerings of the major, and the recommended trajectory the students take through the curriculum provides a thorough training of the professional physicist.
2. The required coursework in laboratory physics is more comprehensive than in most physics departments.
3. Our majors' courses are relatively small (12 at smallest – 100 at largest) allowing the faculty to have meaningful individual interactions with our students.
4. Many of our undergraduates have research experiences on campus or in summer programs (current count of 34 undergraduate researchers among 13 research groups).
5. The number of physics majors is growing (now about double what is reported in large well-known Midwestern universities). This is not a national trend, since many peer and aspirant universities have not reported similar increases in majors. It demonstrates that UMass Physics is becoming a destination of choice for college students with an interest in Physics.
6. Our first-year curriculum for majors is now being taught in the TBL format.

Enhancements: There are a number of possible enhancements we envision to make UMass Physics a destination of choice and to encourage more STEM students to major in Physics once arriving on campus including the following:

1. An **EPIC Goal** for our majors is to have every graduating physics major have a research experience before graduating. Such experiences include research experiences on campus in both theory and experimental research groups, independent study on advanced topics in theoretical fields or experimental work, Research Experiences for Undergraduates (REU, both on or off campus), student-led faculty-coached team research projects, internships in either research or innovative teaching.
2. In order to ensure that all students achieve a research experience and establish an excellent career trajectory, we plan to enhance student advising and professional development for our majors. Some proposed changes to benefit the students included:
    a. A 1-credit junior-level professional development course, to complement our freshman seminar; this will focus on the skills needed by professionals in technical fields.
    b. Another option would be to piggy-back 1-credit honors sections on professional development onto the courses that already work toward professional skills including sophomore level computational course (P281), junior-level writing (P381), and junior/senior level integrated experiences and advanced laboratory course, (I-Lab, P440).
    c. Enhanced advising will continue to shift the focus of advising sessions from simply what they should do in the major to what they want to do in life and how their courses can help them to

achieve it. Discussions will include getting into research on campus, REUs, and internships. We will also be better able to identify students who are at risk of leaving the major or not following the preferred track.

d. We currently do not have a continuation policy to help ensure student success in the Physics Major. (1) The Physics Major is very demanding, and many students who do not excel in the first year leave the physics major, and then continue in another STEM major, which we believe is a success for CNS as a whole. (2) We will consider the adoption of a policy that requires a threshold competence in mathematics courses to continue the major into the junior year. If adopted, this should enhance student success in upper division Physics or ensure the transfer of students to more suitable major where they can achieve better success.
e. We can train undergraduates in professionalism and teaching through including them as paid undergraduate teaching assistants. We currently do this in a limited fashion, but we seek to increase the number of undergraduate TA students.

3. We seek to increase the contact between Physics Majors and faculty.
    a. Better advising, more research opportunities, and contact through working with undergraduate teaching assistants will enable more contact between Physics Majors and research faculty.
    b. Such contact can be formal, such as advising or research mentoring, or informal, such as mentoring groups and the Society for Physics Students (an undergraduate student organization).
4. We have been working over the past few years to further enhance the teaching laboratory experience for Physics Majors. We currently offer twice as many labs (7 offerings) as peer and aspirant institutions for Physics Majors, but we seek to create more cohesive curriculum for training in hands-on problem solving, measurement, and analytics.
5. We seek to offer more, broader advanced courses for undergraduate students to give them more exposure to different specialized fields in Physics. We currently require that our majors take 1 advanced topic course for the BS tracks. We would like to offer more advanced courses, especially those with laboratories.
6. Another **EPIC Goal** of the Physics Department Teaching includes creating a new 5th year Master's Program for undergraduates interesting in focusing on a specific topic in physics that would work for all tracks including the Applied Physics BS, Professional Physics BS, and the BA track. Having more advanced course offering in more specialized fields of physics will enable more students to take a 5th year master's curriculum in a particular field.

At the undergraduate/graduate teaching interface: Items 5 and 6 above impact both our undergraduate and graduate programs. Currently several of our graduate students (from Physics and other departments) enroll in the 500-level advanced undergraduate courses, especially when they did not acquire such learning in their own undergraduate experience. One new advanced course the department plans to offer is focused on the skills of acquiring and analyzing data, with a course title of "*Data: The Art of Measurement and Analytics*." This course would complement a graduate level course on data analysis we already offer. Another **Epic Goal:** To meet the rapidly expanding career opportunities, we encourage a consortium of departments (Physics, Computer Science, Statistics) in CNS to offer a Masters degree in Data Science. Physics has a particular strength in emphasizing the importance of both *measurement* and *analysis* in the data science enterprise.

II. Service and GenEd Courses: The Physics department teaches upwards of 2000 students each semester between the service courses required by other majors and the Gen Ed courses we offer. We strive to deliver the best physics education experience that can be found anywhere in the country. For many students, these courses are foundational for developing critical thinking, quantitative analysis, and visualization skills.

<u>Established Excellence:</u> The University Of Massachusetts Department Of Physics has an exceptional track record educating the rest of the university:

1. Diversity of general education and service course topics routinely offered.
    a. Required by other majors
        - P131, P132, P151, P152, P100, P114
    b. General education courses
        - P115, P116, P117, P118, P120, P125, A105
2. Despite teaching a large number of students we strive to maintain a reasonable faculty-to-student ratio to preserve a quality learning experience
3. Our department has been and continues to be a leader with instructional innovation. We were the first or among the first for the following innovations;
    a. Active hands on learning through labs and demos
    b. Online HW – Owl
    c. Clickers – Class talk → PRS
    d. Tablet computers
    e. Lecture capture
    f. Blended learning
    g. flipped/inverted classrooms
    h. Team based Learning (TBL)
4. The department has a culture of teamwork and teaching excellence:
    a. Multiyear departmental support for weekly teaching workshop
    b. Transfer of materials and institutional knowledge from instructor to instructor
    c. Best practice transfer
    d. Service courses committee to stream line and improve service courses

<u>Enhancements:</u> We have developed a culture of continuous teaching innovation and excellence. Therefore, we envision even more we can do to improve our service/teaching role to the rest of the UMass community.

1. Using the department's unique position in the university to more clearly and effectively support and deliver the general education goals through delivering courses that:
    a. Are current and interesting to the wider community
    b. Demonstrate the application of math thus cultivating in learners the visualization of math
    c. Use dimensional analysis
    d. General problem solving skills
2. Expand *learning by doing* activities:
    a. Shrink the class sizes of the *large* service courses
    b. More TBL
    c. Using more current real world, quantitative and current literature
    d. More at-home, out-of-the-classroom experiments
3. Standardize to achieve efficiency without loss of quality
    a. Team based teaching and curriculum and procedures (efficiencies in teaching)
    b. Learning objectives (clearly identifying learning objectives for each course and design commensurately)
    c. Enhanced assessments emphasizing the processes of thinking
        i. Long answer (show work)
        ii. Show steps to solve vs the answers

Resources: To accomplish our enhancements, indeed to better deliver to our students what we are now stretched too thin to deliver in an optimal way, will require additional resources. These will be needed to (1) enhance the faculty count to allow additional courses to be taught by faculty members (an enhancement of the faculty count will also allow additional research opportunities for our majors), (2) enhance the number of teaching assistants to allow additional laboratory sections to be offered, and (3) increase the equipment infrastructure to allow modernization of the teaching laboratories and the lecture demonstration equipment. In addition, due to enrollment pressures and the desire for enhanced quality of laboratory offerings, it is essential that we have an expansion of the space that is used for the undergraduate laboratories at both the service course and the advanced levels.