SELF-STUDY AND LONG-RANGE PLAN

Department of Physics and Astronomy, University of New Mexico

Long-Range Planning Committee (LRPC)

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December 23, 2009

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List of abbreviations

AAAS	American Association for the Advancement of Science
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AMO	Atomic, Molecular, and Optical
APR	Academic Program Review
APS	American Physical Society
AFRL	Air Force Research Laboratory
AIP	American Institute of Physics
A&S	College of Arts and Sciences
CAPS	Center for Academic Program Support
CARC	Center for Advanced Research Computing
CAS	Center for Advanced Studies
CERN	European Center for Nuclear Research
CHTM	UNM Center for High Technology Materials
CM/CS	Condensed-Matter Physics and Complex Systems
CNM	Central New Mexico Community College
CS	Department of Computer Science
CQuIC	Center for Quantum Information and Controls
DoD	Department of Defense
DTRA	Defense Threat Reduction Agency
ECE	Department of Electrical and Computer Engineering
F&A	Facilities & Administration
GQI	Topical Group on Quantum Information
HAWC	High Altitude Water Cherenkov
HSC	Health Sciences Center
HVAC	Heating, ventilation, and cooling
IARPA	Intelligence Advanced Research Projects Agency
I&G	Instruction & General
IGERT	Integrative Graduate Education and Research Traineeship
IPG	Information Physics Group
J-PARC	Japan Proton Accelerator Research Complex
JPL	Jet Propulsion Laboratory
JQI	Joint Quantum Institute
LAC	Lodestar Astronomy Center
LANL	Los Alamos National Laboratory
LHC	Large Hadron Collider
LRP04	P&A's 2004 Self-Study and Long-Range Plan
LRPC	Long-Range Planning Committee
LWA	Long Wavelength Array
MAP	Measurement Astrophysics
MURI	Multidisciplinary University Research Initiative
NAIC	National Astronomy and Ionosphere Center
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health

NIST	National Institute for Standards and Technology
NRAO	National Radio Astronomy Observatory
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSMS	Nanoscience and Microsystems
OS	Optical Science
OSE	Optical Science and Engineering
OVPR	Office of Vice President for Research
P&A	Department of Physics and Astronomy
PIBBS	Program in Interdisciplinary Biology and Biomedical Science
PIF	Physics at the Information Frontier
QIS	Quantum Information Science
RA	Research Assistant
REU	Research Experience for Undergraduates (NSF)
SFI	Santa Fe Institute
SI	Supplemental Instruction
SKA	Square Kilometer Array
SM	Standard Model
SNL	Sandia National Laboratories
SoE	School of Engineering
SoM	School of Medicine
STMC	Center for the Spatiotemporal Modeling of Cell Signaling Networks
TA	Teaching Assistant
UNM	University of New Mexico
USSKAC	US Square Kilometer Array Consortium

I Executive summary of departmental goals and objectives.

This document presents the 2009 self-study and long-range plan for the Department of Physics and Astronomy (P&A). It serves as the self-study required for the Department's Academic Program Review (APR), which is taking place during the 2009–10 academic year, and it formulates a comprehensive statement of the Department's goals and plans for the next seven years.

It should be noted at the outset that the Optical Science and Engineering degree programs, which are administered jointly by P&A and the Department of Electrical and Computer Engineering (ECE), will have their own Academic Program Review during the spring of 2010 (OSE APR Self-Study). Because of the OSE programs' importance to P&A generally and critical importance to faculty in our Optical Science (OS) and Biological Physics research groups (our biophysicists use many optical techniques in their research), many issues connected with the OSE degree programs are discussed in this document as well.

This self-study/plan is built on the foundation of a previous comprehensive Self-Study and Long-Range Plan, referred to herein as LRP04, which was completed on May 15, 2004; the current document should be read as an update of that previous plan, which provides essential context and establishes a baseline for the current planning process. This document draws on a process of self-evaluation and planning, spearheaded by the LRPC, which has occurred over a period of about a year beginning in the fall semester of 2008.

LRP04 was invaluable in organizing and focusing the Department faculty's thinking and planning for its own future. It has been successful in guiding changes in the Department's service courses and degree programs and in navigating the potentially contentious process of faculty hiring. It is to be hoped that the current update will play just as important a role in the Department's internal deliberations, but we are also confident that this plan, as part of the APR, will serve to inform and instruct the administration above us, from Dean to Provost to President, about the Department's role in and contributions to the University, and to engage the administration in a genuinely collaborative effort to enhance our educational and research contributions. In particular, the Department looks forward to receiving comments and recommendations from UNM's administration and from the APR Review Team and to including such comments and recommendations in our further planning and during the implementation of our long-range plan.

There is no better way to begin this document than by repeating the Department's summary Statement of Purpose and Mission Statement from LRP04. These two statements encapsulate the Department's role within the University and form the basis for all our planning. Although formulated before the issuance of President's Schmidly's Strategic Framework, our Statement of Purpose and Mission Statement directly support the Framework's Cornerstone Missions of Teaching and Research, and they demonstrate clearly the Department's commitment to the Framework's Priorities of Student Success and Systemic Excellence.

Statement of Purpose

The Department of Physics and Astronomy is a science department that (i) teaches a substantial load of introductory undergraduate courses, these mainly serving other constituencies within the University, (ii) offers small, high-quality degree programs for undergraduate majors in physics and astronomy, and (iii) maintains high-visibility research and graduate programs.

Mission Statement

The Department's mission is to perform these three educational and research functions not just well, but in a fashion that is recognized as superior on a national scale, and thus to become and to be recognized as an excellent, highly visible medium-sized physics and astronomy department.

The difficulties, challenges, and importance of planning at the departmental level are nicely summarized by parts of Sec. III.5 of LRP04.

> *A department, though the smallest unit at a university, is nonetheless a complex system of faculty, staff, and students, interacting with one another and with other units of the university. The Department of Physics and Astronomy at UNM is no exception. Carrying out the primary functions of the Department requires a complex organization that must be continually reviewed, maintained, and renewed to ensure its effectiveness. The Department's limited resources, both human and material, mean that this process of review and renewal can be likened to a juggler whose act is condemned never to end. The Department must continually reëxamine and decide on the fly which aspects of its operations deserve or require attention, which are working well enough that they can be safely left alone, and which have outlived their usefulness and should be allowed to fall to the floor. …*
>
> *The jobs of a university department are to conserve the body of knowledge in its discipline, to transmit this knowledge to new generations, and to expand the body of knowledge through research at the edges of what is known. Given the timeless character of these tasks, a department should not change direction with every breeze that blows in the front door, whether the breeze originates in the university's higher administration or in the world outside the university. Of course, there is little risk that a university department will become a weather vane, shifting direction with every change in the wind. A department is buffered against change by the inertia that comes with the fundamental four-decade time scale of a professor's career. Although this is as it should be, it means that the greater risk is ossification, as a department fails to keep up with the long-term changes in its own discipline and to grasp interdisciplinary opportunities available to it.*
>
> *Physics and astronomy are increasingly dynamic disciplines, richer and more diverse and thus less focused than they were 50, or even 25, years ago. If the Department is to remain vital, it must keep track of long-term changes in the practice of physics and astronomy. … The Department must try to anticipate and respond to changes in practice and interest by hiring new faculty in exciting new research areas and by adjusting its course offerings to expose students, both graduate and undergraduate, to developments in these new areas.*

Within this context, LRP04 identified eight major objectives for the Department, listed immediately below, for the period 2004–09. These objectives were categorized as *Urgent*, *Critical*, *Continuing*, or *Long term*;

these categories were not meant to rank the various objectives in relative importance, but instead indicated the time frame on which each objective needed to be addressed.

LRP04 goals and objectives

Urgent

- Open and inclusive governance by the faculty and effective administration by the Chair
- Fast, reliable, secure, convenient computer network
- Effective and productive administrative staff with high morale

Critical

- Recruitment of high-quality graduate students
- Attractive web-based presence for departmental programs, courses, research, and business

Continuing

- Monitoring, upkeep, and enhancement of the Department's undergraduate programs, both the service courses and the degree programs
- Implementation of the faculty-hiring plan

Long term

- New building that meets the Department's long-term needs

From the perspective of today, this list evokes the immediate response that the Department is in much better shape than it was five years ago. Under the leadership of the current Chair, Bernd Bassalleck, the three Urgent objectives are no longer major sources of concern. The Department's computer network is in good shape, and there is a strong sense that the Department runs much more smoothly now than it did five years ago, in terms of governance by the Chair and the faculty and of administration through the support staff. This sense is strong enough that governance and administration are not a focus of departmental assessment and planning in this document. We do understand, however, that as the Department's number of faculty and research presence increase, we must be vigilant to ensure that the number of administrative staff and their skill levels remain sufficient to provide the required staff support.

Given the successes of the past five years, the Department can afford to identify a smaller, more focused set of objectives for the next seven years. The Department's main physical facility, the Physics and Astronomy building on the northeast corner of Lomas and Yale, has only gotten more decrepit in the intervening five years; a new building for the Department is now urgently needed. There are critical needs for new faculty, to replace retiring faculty members, to support our undergraduate and graduate teaching missions, and to maintain our national and international research presence. The Department still faces serious challenges in recruiting a sufficient number of high-quality graduate students to staff our research programs. The undergraduate service courses and our undergraduate degree programs require constant monitoring to ensure that they are serving the needs of our students and other units in the University. The Department's web page, which serves as our chief face to the world and as a critical tool for organizing departmental affairs, is in need of a major overhaul.

Out of this litany of challenges, we have distilled six goals and objectives for the next seven years. One overarching goal, a new physical facility for P&A, stands by itself in terms of importance to the Department and required resources of time and money. The remaining five objectives are categorized, just as in LRP04, not in terms of relative importance or resources required to make them happen, but in terms of the time frame on which they need to be addressed. A *Critical* objective requires immediate attention and action, generally to be followed by continuing implementation activity throughout the life of the plan. A *Continuing* objective requires continuing activity and effort over the duration of the plan.

I.1 Overarching goal.

New building that meets the Department's long-term needs (Sec. VI)

The Department's main physical facility, located on the northeast corner of Lomas and Yale, is now nearly 45 years old, with some parts nearing 60. It is difficult to maintain, makes a poor impression on prospective faculty, staff, and students, is a major impediment to high-quality experimental research programs, and has a chronic negative impact on departmental morale. A new facility for P&A has been shepherded forward in the University's planning for the last five years, but it is now critical that it be pushed forward to completion. *In the absence of the completion of a modern new facility to house the Department during the life of this plan, the University will be sending an unmistakable message that it does not intend to have a high-visibility, world-class, research-intensive physics and astronomy department.*

Planning and constructing a new building will require the attention of all of the Department's faculty, but especially that of the Chair or proxies assigned to the task by the Chair, and it will also require a major commitment from the entire academic administration, from the Dean of Arts & Sciences (A&S) to the Provost/Vice President for Academic Affairs and the President.

I.2 Critical objectives.

New full-time-faculty hires in areas of critical need (Sec. II and Sec. VII)

Two of the Department's three Lecturers—the two who were full-time instructors in the Department's service courses—left in 2008, with only one having been replaced. The Department is committed to hiring a third Lecturer as a full-time instructor, to teach mainly in the Department's introductory service courses. This hire will enrich the undergraduate experience in our introductory courses; we will prefer the new Lecturer to have demonstrated experience in physics/astronomy education research.

The Department's hiring plan for tenure-track faculty is aimed at maintaining our high-visibility research programs, but with three special emphases: building our successful, but undersized research groups, which have attracted a disproportionate number of high-quality graduate students to the Department over the last decade; working toward an appropriate balance of experimental/observational and theoretical expertise within each group, an effort initiated by LRP04; and building clusters of researchers to work across research-group boundaries, another initiative from LRP04. The first five hires in our hiring plan are critical to this endeavor: an astro-particle theorist, an astrophysics theorist, an optics theorist, a quantum information theorist, and a quantum optics experimentalist.

Recruitment of high-quality graduate students and retention of students in our graduate programs (Sec. IV)

Recruiting and retaining a sufficient number of high-quality graduate students to staff the Department's research programs remains a major challenge. Although applications for graduate study are up by nearly a factor of two in the last six years, it is still true that to assemble an incoming class of just under 20 each year, the Department must admit essentially every student who, in our judgment, has any chance of succeeding in our program. Some research groups, notably astronomy and subatomic physics, have particular difficulty in attracting a sufficient number of high-quality students. Once students are in our program, we must ensure that each receives the timely and individualized advice needed to tackle our graduate curriculum and that the curriculum prepares students for success in our research programs and as professional physicists.

The Department must pursue multiple initiatives to attract and recruit additional high-quality students. Other of our priorities—a new building, hires aimed at attracting graduate students, and a more effective web presence—will have a major impact on our ability to attract graduate students. The Department has just addressed perhaps the most pressing need by voting to reduce the number TA slots in favor of increasing TA stipends to make our financial-aid offers competitive with peer institutions. In addition, the Department should work to make available prize fellowships with a competitive stipend to attract the most highly qualified graduate students. In this regard, UNM's successful use of incentives to attract National Hispanic/Merit Scholars as undergraduates might serve as model for a similar program of incentives, including a set of full graduate fellowships, to attract the best PhD students to UNM.

I.3 Continuing objectives.

Monitoring, upkeep, and enhancement of the Department's undergraduate programs (Sec. II and Sec. III)

The Department's undergraduate educational programs include introductory service courses, which mainly serve the needs of other units and constituencies in the University, and our undergraduate degree programs in physics and astronomy. All these programs are in relatively good shape, in terms of meeting academic goals, enrollment in the service courses, and graduation rates for our degree programs, but to be able to make that statement requires constant attention from the Department's faculty and a sympathetic ear from the University's administration when new resources are requested. Of particular concern for the service courses are the addition of a third Lecturer, which is a critical need already identified in Sec. I.2; transfer of administration and funding for the program of Supplementary Instruction (SI) to the Department from the Center for Academic Program Support (CAPS), thus allowing us to optimize the choice and deployment of SI leaders; and revitalization of our Regener-Hall/Service-Courses Committee to deal with service-course issues. The chief concern in our undergraduate degree programs is the recruitment and retention of majors, especially women and minorities; additional issues include the role of our BA degree and the function and utility of the math courses required for our undergraduate degrees.

Implementation of the faculty-hiring plan to support the Department's educational and research missions (Sec. VII)

The Department's tenured and tenure-track faculty are the lifeblood of the Department. We seek to hire faculty who (i) have high potential or demonstrated ability to teach effectively, especially in the Department's introductory service courses, (ii) have a record, appropriate to the number of years since the PhD and to the individual's life and work experience, of high-quality research that is recognized as such by the relevant community of researchers, (iii) have high potential or demonstrated ability to create a research program that is attractive to graduate students and that can also secure external funding for support of graduate students and perhaps for postdocs and research staff/faculty, and (iv) show evidence of willingness and aptitude to be good departmental citizens. In doing so, the Department is committed to identifying and recruiting outstanding women and minority candidates for all positions in our hiring plan.

We organize our proposed hires around a set of six challenges distilled from three National Academy of Sciences reports, which spell out the primary scientific challenges for physics, astronomy, and optical science in the early decades of the 21st Century. From the lists of challenges in the Academy reports, we formulate in Sec. VII.4.1 a set of six research challenges for our department in the light of our strengths and the special opportunities we have within New Mexico.

The Department's hiring plan, detailed in Sec. VII, will increase the number of FTE tenured and tenure-track faculty from the current 28 (counting Kevin Malloy, who as of November 2009 has joined the Department from ECE) to 31. As noted above, the plan aims to maintain our high-visibility research programs, with the additional objectives of building our successful, but undersized research groups, working toward an appropriate balance of experimental/observational and theoretical expertise within each group, and creating clusters of researchers who can work across the boundaries of our present research groups. The hiring plan lists twelve positions, prioritized in three groups. The first five of these hires, included in Sec. I.2, are truly critical to maintaining the Department's research success. The remaining seven positions, prioritized in a first group of four, followed by a group of three, are essential for maintaining the Department's viability in view of retirements anticipated over the next six to seven years, but the precise nature of these hires will need to be reëxamined in light of experience and changing needs as the plan progresses.

Aside from making a serious commitment to a new P&A building, the most important action that could be taken by the College of Arts and Sciences and UNM's central administration in support of the Department would be to endorse the objectives of our hiring plan, to work with us to make it happen, by hook or by crook, and to move to a hiring model that plans for the large start-up packages required to attract experimental physicists and that anticipates and plans proactively for retirements.

Overhaul, enhancement, and maintenance of the Department's web presence (Sec. V)

The Department's web page is our face to the world. For graduate students we want to recruit, for example, it is often, perhaps typically, the only face they see. It should be the go-to source for faculty, staff, students, and external constituencies seeking information about any aspect of departmental life, including our research programs, and it should be a major tool for organizing departmental administration. We intend to make it so by undertaking a major overhaul and then maintaining that enhanced presence through the life of this plan.

The foundation for an outstanding departmental web presence has already been laid as a consequence of initiatives outlined in LRP04. The P&A web page contains much valued, valuable, and useful information, which is generally maintained efficiently. These positives are offset, however, by the visual impact of our web pages, which do not grab the attention of a casual user, and by the difficulty in navigating the web pages to find much of the useful information. Our planned overhaul will address these deficiencies and will be implemented by departmental and University personnel, assisted by outside consultants if necessary.

II Undergraduate education. Service courses.

The Department of Physics and Astronomy teaches two kinds of introductory service courses: a variety of *general-interest courses*, which have no prerequisites and which introduce topics in physics or astronomy to a general audience; two introductory *general-physics sequences*, one algebra-based and one calculus-based, both of which provide a technical introduction to all of physics. These service courses continue to constitute the bulk of student credit hours taught by the Department. They serve an essential function as an institutional contribution to several other departments, especially the science departments in the College of Arts and Sciences, departments in the School of Engineering (SoE) and the College of Fine Arts, the Department of Speech and Hearing Sciences, and all students aiming toward some sort of medically related career that requires postgraduate training in a professional school.

Enrollments in the service courses have generally been steady over the past few years. The Department has implemented several improvements in these courses and has further plans for the next several years, as we now discuss in detail by first reviewing LRP04 (Sec. II.1), then assessing the last five years (Sec. II.2), and finally spelling out our plans and goals for the next seven years (Sec. II.3).

The Department has a well established administrative structure for handling our service courses and our undergraduate degree programs: the Associate Chair for Undergraduate Affairs has direct responsibility for undergraduate education, including oversight of the Regener-Hall/Service-Courses Committee, which deals with the Department's service courses, and of the Undergraduate Committee, which handles matters related to the Department's undergraduate degree programs. The two committees' responsibilities overlap in the calculus-based general-physics sequence, since the three courses in this sequence are required for majors in our undergraduate degree programs.

II.1 Review of LRP04.

The Department's service courses and their role within the University were discussed in some detail in Secs. III.1 and V.3 of LRP04. At that time, there were several recent or imminent initiatives for improvement of the service courses. For the general-interest courses, the main initiatives were the first use in the University of immediate student-response devices, known colloquially as "clickers"; an experimental third section of Phys 102; the introduction of an evening section of Astro 101 at the LodeStar Astronomy Center (LAC); and the creation of the Regener-Hall/Service-Courses Committee. For the general-physics sequences, an important goal was to continue to monitor their effectiveness in meeting the needs of majors in other departments who depend on them, especially the engineering departments. This raised perennial questions of introducing tutorial sections and of requiring the associated laboratory courses. Finally, a revamping of the service-course labs had recently been completed.

II.2 Assessment of last five years.

Enrollment in the service courses has remained steady. The total number of credit hours generated per year remains at about 13,000. The table below gives the semester averages for all service lecture and lab courses for the past five years. A history of overall student credit hours generated by the Department's service and upper-division courses over the last decade is available as Attachment A.

There are generally four sections of Astro 101 each academic semester, three taught on campus and one taught in the evening at the LAC as noted above (at least once there were five such regular sections); in addition, there is typically a section at Kirtland Air Force Base and occasionally one at UNM West. One section of Astro 101 is offered during the summer semester. There are many distinct sections of the Astro 101L laboratory, including one which is offered online, although there are nowhere near enough sections to enroll every student in the lecture in a laboratory section, which is acceptable since it is not required that both be taken. Astro 109 is a follow-on course after Astro 101, for special topics, and is only offered in some semesters. It and Phys 105 do not have labs associated with them. At most of the time during this period there have been two sections of Phys 102 every semester. Physics 151 and Phys 152 have one daytime section every semester, plus additional sections of Phys 151 (152) in the evening in the fall (spring) and on Saturday in the spring (fall). Physics 160 and 161 each have one daytime section in the fall and one in the spring. In addition, there is one evening section of Phys 160 (161) in the fall (spring), and one section of Phys 161 is taught in the summer.

	Average number of students per semester in service courses for last five years				
	Lecture course			*Associated lab course*	
General-interest courses	Astro 101	Introduction to Astronomy	896	Astro 101L	354
	Phys 102	Introduction to Physics	238	Phys 102L	109
	Astro 109	Selected Topics in Astronomy	23		
	Phys 105	Physics and Society	26		
	Phys 106	Light and Color	18	Phys 106L	18
	Phys 108	Introduction to Musical Acoustics	46	Phys 108L	16
General-physics sequences	Phys 151	General Physics (algebra-based)	253	Phys 151L	119
	Phys 152	General Physics (algebra-based)	145	Phys 152L	81
	Phys 160	General Physics (calculus-based)	187	Phys 160L	67
	Phys 161	General Physics (calculus-based)	122	Phys 161L	51
	Phys 262	General Physics (calculus-based)	54	Phys 262L	22

Phys 106, although still in the catalog, was dropped as a regularly-offered course since enrollment underwent a steady decrease, at least in part because it was no longer required by any degree program. The third section of Phys 102 was also deemed a low priority and was dropped; this had been an experimental offering, as noted above, and the very small increase in total enrollment did not justify the additional section. The only other significant drop in enrollment has been in Phys 262 (about 35%) and Phys 262L (about 25%; now only one section), as the number of programs in Engineering requiring it has decreased to only one (Nuclear Engineering). On the other hand, Phys 108 has experienced an increase in enrollment of about 25% over the last five years.

The Department has implemented several improvements to its service courses in the past five years. A new "catchment" class, Introduction to Applied Physics (Phys 110), was introduced to help students who struggle with the level of math required in Phys 151 or in Phys 160. Taking place in the second eight weeks of the semester, so as to "catch" students who would otherwise be failing in those other courses, Phys 110 reviews the basic algebraic foundations of physics, such as vectors, trigonometry, and even fractions, and emphasizes the relation of these concepts to aspects of everyday life. In fall 2008, enrollment in Phys 110 was 46, but in fall 2009, enrollment fell to 25. We have received good informal feedback on the utility of this class, but we need to determine whether all students who require intensive help are being identified and advised to enroll in this catchment course.

A second issue was the rather large jump as our majors transitioned between the sophomore- and junior-level classes. One aspect of this issue was how well Phys 262 prepares students for Phys 330 (Introduction to Modern Physics). These two classes have overlapping subject matter, with Phys 330, generally taken in the second semester of the sophomore year, being the first course explicitly for our majors. The syllabi of these classes were reformed to make them into a more coherent sequence and to improve the transition between the two. Work to aid in the jump from the sophomore level is continued in the junior-level courses by one-credit-hour, credit/no-credit problem sessions now associated with all of these courses, at which students work directly on the physics concepts and mathematical techniques of the course, with assistance from the instructor.

Supplemental Instruction (SI) was introduced into many of the courses in the general-physics sequences, the goal being to improve students' problem-solving skills at this level. SI is meant to provide help to students outside of the lecture setting in a friendlier, small-group setting, which is also more directly focused on the specific topics being covered in a particular class than is the standard tutoring available from the Center for Academic Program Support (CAPS). CAPS is a University-wide program created more than a decade ago to provide support for individual and online tutoring, study groups, and other learning-support functions. Its services are offered through an office in the central library.

SI leaders are advanced undergraduates or early graduate students, who are individually selected by the Department for their interest and aptitude in working closely with students in the introductory courses. Unlike standard tutoring, the SI leader sits in on all the lectures and coördinates her or his work directly with the instructor; the SI leader thus is able to guide students through specific difficulties that arise in applying the lectures to individual problems. Typically, an SI leader has three different lecture periods each week at which she or he solicits input from students and then gives mini-lectures addressing difficulties raised by the students or perceived by the leader during the regular lecture. In addition, the SI leader has two to three open office hours per week, which are available to all students.

The Department has now found for several years a strong correlation between final course grades and the number of SI sessions attended by the student. After the Department's demonstrated success with SI, a program was formalized within CAPS and extended to several other departments, where it has indeed become quite popular.

The Department uses SI leaders in the two algebra-based general-physics courses, Phys 151 and 152, and in the first two of the three calculus-based courses, Phys 160 and 161. SI was introduced into the third course in the calculus-based sequence, Phys 262, but was dropped when the aforementioned correlation with outcomes was not found in that setting. In addition, we make use of SI leaders in Phys 110, the "catchment" class aimed at students who are struggling to acquire sufficient mathematics background to be able to succeed in either of the general-physics sequences. All this requires about 6.5 FTE SI leaders per semester. Because of the Department's successful introduction and use of SI, A&S provided additional TA slots to P&A to support 2.5 FTE SI leaders, chosen from P&A graduate students. About a semester or so later, the CAPS program was begun, with funding to provide SI leaders for various departments on campus, including P&A. In the beginning, CAPS provided 3 FTE SI leaders for P&A—these are slots funded and filled by CAPS—and we funded at least 1 more from our regular TA funds, bringing us up to the required 6.5 or so FTE. A problem arose when, as has been true for the last couple of years, CAPS was unable to find sufficiently many qualified students to assist with our needs, so that CAPS support dwindled to a low of 1 FTE (in the fall 2009 semester, the number from CAPS was at 1.5 FTE).   To make up the difference, the Department has been putting more of its own TA funds into the program, since we continue to find SI quite important to our educational mission.

As part of the assessment effort forming part of UNM's re-accreditation process, learning goals, student learning outcomes, and scoring rubrics were developed for all 100-level courses. Meetings of relevant instructors have been started to discuss implementation of changes to these courses as a result of this assessment. Formal assessment reports are now being written annually. Significant proposed changes will be brought to the whole departmental faculty. A spring 2009 assessment report for service courses, which contains the basis for an assessment plan, is available as Attachment B.

The use of web-based homework tools, particularly Mastering Physics and/or WebAssign, has greatly expanded. This allows a student to be involved with considerably more practice in applying the lecture material to problems, i.e., to have more assigned homework without imposing an additional burden on graders for the class. It also allows the instructor to be involved much more in details of assignments than with older forms of homework assignments. In an attempt to keep up with the sometimes quite rapid developments in these sorts of products, as well as the rapidly changing versions of textbooks, about five years ago the Department initiated biennial presentations by various publishers. When final decisions are made, it is usually the quality of the web-based homework tools that sways the decision on the use of a particular textbook.

The Astro 101L computer-based lab was revised in 2006, as it had not been reviewed since its inception several years previous. The questions were integrated into the labs to prevent students from "working backwards," i.e., opening up the questions section first and searching the rest of the lab for the answers. Other parts of the labs were cumbersome, outdated, irrelevant, or otherwise dull, and thus many improvements were made to make the labs more pedagogically sound and engaging. An online section of the Astro 101 lab was started as an experiment in distance learning, and it has now been running for three years. Additionally, sections of Astro 101, Astro 109, and Phys 102 have been taught at UNM West for the last three years, as well as sections of Astro 101 at the university's instructional site at Kirtland Air Force Base. All are having quite good enrollments. On the negative side, UNM's central administration has now taken away the option of our offering Astro 101 and Phys 102 at UNM West, reserving that role to Central New Mexico Community College (CNM).

Our rather large collection of demonstrations and audio-visual equipment in Regener Hall, which is very important to our teaching mission, has undergone several improvements in the past five years. There are much improved capabilities for real-time data collection from demonstrations during lectures. Video clips of many demonstrations have been created so that instructors can assess their utility. A dual-video projector system has been installed, with the second one in use for projecting demonstrations or material on a document camera and, quite often, for the projection of questions which will be answered by the students via their clickers, as well as serving as a backup. General improvements and additions are always being made to the demos and their associated web pages, along with preservation of demos unique to Regener Hall. Lab fees for students, which contribute to the funding of demos, were doubled since the last report, helping to make these improvements possible. Deterioration of demos is a constant concern, however, and water leaks in the building structure, in particular, are increasingly creating damage and safety issues.

Regarding personnel, it should be noted that a considerable challenge in delivering our service course mission was presented by the departure of two of our Lecturers, both of whom were full-time instructors in the service courses (the third Lecturer, Mickey Odom, is in charge of the introductory laboratory courses). John Caffo was a successful and popular teacher who made very significant contributions to the Department's educational mission before his retirement in 2008. Kathy Dimiduk, who was hired away by Cornell University in 2008, had a strong desire to improve instruction and initiated some of our successful reforms, including the introduction of SI (before CAPS became involved) and the first use of clickers at UNM. No doubt her success here was a major factor in Cornell's interest in hiring her. Both Caffo and Dimiduk played a major role in developing the tools for University-required outcomes assessment for the service courses. We have been able to replace one of these positions with the hiring of Jeff Saul, who arrived in the spring semester of 2009. Unfortunately, perhaps, these departures have also required us to make exceptions to our policy, mentioned in the LRP04, of using experienced instructors in the service courses. Some part-time instructors and, on rare occasions, graduate students have been employed, but the Department has instituted oversight procedures and prior interviews that assure us that the quality of instruction remains very high. The graduate students have been chosen carefully, based on demonstrated ability as teachers and a desire to enter a teaching-related career; the opportunity to teach in our service courses has thus contributed to their professional development.

The Regener-Hall/Service-Courses Committee was established as a consequence of the planning process for LRP04, with the mission of overseeing teaching issues in the service courses, lab improvements, demo improvements, enrollment issues, and the role of the service courses in the University. Initially very active, it has not been so active in more recent years, and the Department needs to re-activate this committee to oversee and address service-course issues.

II.3 Goals and plans.

The Department sees great value in the SI program, and there is a general desire among the faculty involved *for the SI program to be run fully by the Department, rather than through CAPS, allowing us full control over SI leader selection and training*. For the last few semesters, it has apparently been impossible for CAPS to locate students competent to perform this function for our courses, necessitating the Department to provide more of its regular TA funding to support this very important mission. This has increased the Department's desire to see *all funding for the program funneled directly to the Department*. This issue is a high priority for the Department and will be pursued with the University administration till it is addressed.

A perennial issue, currently under debate yet again, is whether to make problem sessions, carrying one hour of credit, a requirement in the 160 series. There is a strongly held opinion in the Department that students in the 160 series do not get sufficient practice at problem solving to prepare them adequately for more advanced courses; requiring small-group problem sessions is a possible way to address this deficiency. There are several issues associated with this possibility, however, including most prominently the effect on the course load of Engineering majors. One option, which avoids thorny and perhaps unresolvable issues with Engineering, would be to require the sessions for our majors only. Depending on how these issues are addressed, such a change could have a small or large impact on faculty and/or TA workloads.

The improvement of the Regener Hall demonstrations is a continual process. The Department's new Lecturer, Jeff Saul, is employed for one month in the summer to focus on this issue and has already started adding tools. Among the improvements he intends to work on are ready-to-use resources for interactive lecture demonstrations and comparing our demo list to the Physics Instructional Research Association list of essential demonstrations. Other ideas include a recommended list of videos as substitutes for demos we don't have and a Wiki of instructional resources. The possibility of a new lecture hall in the next several years has consequences for the demos: there must be adequate storage space and room for expansion; most of the demos could in principle be moved, although there are some, such as the heliostat, which cannot simply be transported to a new building, as they are unique to the design of Regener Hall itself.

Revitalization of the Regener-Hall/Service-Courses Committee, to take on such tasks as overseeing the Regener Hall demos, addressing (along with the Undergraduate Committee) the question of tutorial sessions in the 160 sequence, and dealing with University-mandated assessment, is necessary to make available the person-power to address effectively issues in the service courses and will demonstrate the Department's continuing commitment to its service-course mission.

The Department's service-course mission has been crucially supported by having three Lecturers, two of whom, Caffo and Dimiduk, taught a full-time load of introductory lecture courses; the third Lecturer, Mickey Odom, is in charge of the Department's introductory laboratory courses. With the departures of Caffo and Dimiduk, replaced by only one new Lecturer, Jeff Saul, the Department remains committed to hiring an additional Lecturer as a full-time instructor, mainly in the service courses. A pool of three Lecturers will provide stability for teaching and assessment of the introductory courses and expertise to address the tasks to be taken on by a revitalized Regener-Hall/Service-Courses Committee. The result will be better instruction than we can generally expect from the part-time instructors and graduate students we now sometimes use in the service courses. *It is a critical priority for the Department to hire a third Lecturer to enhance the undergraduate experience in our introductory courses* (see Sec. I.2), preferably one with demonstrated experience in physics/astronomy education research.

III Undergraduate education. Degree programs.

The Department offers three undergraduate degrees:

- BS in Physics
- BS in Astrophysics
- BA in Physics and Astronomy

Within the BS in Physics, a student may elect an Optics Concentration. Suggested course schedules for the several degree programs are available in Attachment C.

These degree programs play two broad roles: (i) educating the work force of practitioners and advanced researchers in physics and astronomy by providing the undergraduate education of students who take jobs in these physical sciences or go on to advanced degrees in physics, astronomy, or other closely related science and engineering disciplines; (ii) producing a scientifically educated work force by educating and training students who go directly to jobs or to advanced degrees in disciplines other than physics or astronomy, such as engineering, geophysics, atmospheric science, medicine, journalism, education, and patent law.

The goals of the two BS degrees are to prepare students for (i) advanced studies in physics, astrophysics, and related fields such as engineering, applied mathematics, biophysics, and medical physics and (ii) employment in industrial, government, or academic settings. The goal of the BA degree is different. It is not expected that the BA student will seek further education in physics or related technical fields. Rather, the goal is to prepare the student for careers in those aspects of various nonscientific areas where a scientific background is useful, examples being law, general education, science writing, business, finance, history, and philosophy. The Department also offers minors in physics and astrophysics for students who wish to focus primarily on another field.

The Department has formulated three broad educational goals for the undergraduate degree programs.

- *Physics knowledge.* To provide students with a basic foundation in physics and astronomy and in the scientific method generally, especially the interplay of theory and experiment, and to motivate scientific enthusiasm and curiosity and the joy of learning.
- *Problem-solving skills.* To provide students with the tools needed to analyze problems, apply mathematical formalism and experimentation, and synthesize ideas.
- *Employment and technical skills.* To provide students with technical skills necessary for successful careers in physics/astronomy and related fields (goal for BS degrees) or alternative careers for which a physics foundation can be very useful (goal of BA degree). These include mathematics, computers, electronics and devices, and communication skills (oral and written).

Our undergraduate degree programs continue to play the important roles summarized by these educational goals. Graduation rates in our degree programs have remained steady for the past five years. During this period, several initiatives to improve and expand the degree programs have been implemented. These and further improvements are discussed below. Section III.1 reviews the status of our undergraduate degree programs at the time of LRP04, Sec. III.2 assesses the last five years, and Sec. III.3 lays out our goals and plans for the next seven years.

As noted in Sec. II, the Department has a well established administrative structure for handling our undergraduate degree programs and our service courses: the Associate Chair for Undergraduate Affairs has direct responsibility for undergraduate education, including oversight of the Regener-Hall/Service-Courses Committee, which deals with the Department's service courses, and of the Undergraduate Committee, which handles matters related to the Department's undergraduate degree programs. The two committees' responsibilities overlap in the introductory, calculus-based general-physics sequence, since the three courses in this sequence are required for majors in our undergraduate degree programs.

III.1 Review of LRP04.

The Department's undergraduate degree programs were discussed in detail in Secs. III.2 and V.4 of LRP04. There the above educational goals for the degree programs were formulated. Statistics on the number of majors and degree recipients were presented. A substantial recovery in conferred degrees had been realized at the time of LRP04, from an average of 7.6 in the mid to late 1990s to 13 in the early 2000s. A new and successful advisement system had been created to allow us to pay close, personal attention to our majors' progress. Faculty advisors make sure majors are making good progress towards their degrees, uncover and diagnose problems, and provide mentoring advice on any topic of concern, including undergraduate research opportunities, potential careers, and graduate schools. The wide availability of undergraduate research opportunities in the Department was emphasized, as well as the Honors research program. Half of our majors continued to graduate school, with many others securing jobs at research facilities. The Departmental Open House was highlighted as a major recruitment tool.

The creation of a new BS degree in Optics was suggested as a possibility to be explored. Our majors' preparation in computational physics was being addressed by an experimental course in the use of MATLAB. The Undergraduate Committee was addressing the issue of the difficult transition between the sophomore and junior years. Recruitment at the high school level, particularly of women and Hispanics, was to get more attention.

III.2 Assessment of last five years.

The major initiatives planned for the previous five-year period have been realized, and additional actions not contemplated in 2004 have been taken to improve our undergraduate degree programs.

An Optics Concentration was created within the BS degree in Physics in 2006 (a full-fledged Optics degree program was considered premature), with the first graduates expected in 2009–10. Two students are officially enrolled in this concentration, while a few others have shown interest. It is too early, however, to judge the success of this endeavor.

The MATLAB class, now Computational Physics (Phys 290), was developed to the point that it was made into a required class for all undergraduate degrees and minors. During the last two years, it has added more and more of an introduction to the use of Maple as well. The MATLAB software is almost totally devoted to purely numerical computations, while Maple is more suited for algebraic ones; both are used in the course to go well beyond standard textbook involvement with problems that are sufficiently simple to allow analytical approaches.

Chemistry 121 and 122 were dropped from the Astrophysics BS requirements; while useful enough, they were not deemed essential to the preparation of our Astrophysics majors. This decision also prevented an increase in required credit hours when Phys 290 was added as a requirement.

The Phys 262/330 sequence was revised, as described in Sec. II.2, to help address the difficult sophomore/junior transition. Several of the other changes and improvements mentioned in Sec. II.2 obviously benefit our degree programs: the creation of Phys 110, the introduction of SI, the expansion of online homework, the assessment of 100-level courses, and the improvement of demos.

As part of the aforementioned re-accreditation assessment effort, two informal assessment tools employed by the Undergraduate Committee were formalized. These are instructor reports on student learning in 300–400-level classes and exit interviews. They have been revised and expanded so they can also be used for assessment of the goals of our major programs. The Undergraduate Committee now discusses assessment data annually and writes an annual report. Major changes, such as a significant restructuring of a course or series, or introduction of a new concentration, are brought to the entire faculty for approval. The assessment plan for undergraduate degree programs is available as Attachment D.

Alumni Questionnaires have also been resurrected as a longer-term assessment tool; our aim here is to understand our graduates' progress towards career goals five years after they leave the Department, including statistics such as the percentages of graduates who are pursuing graduate study or are in physics-related jobs.

Over the past five years, the Department has had three different persons as Academic Program Coördinator, the departmental staff member who is in charge of administrative aspects of our degree programs. This turnover has delayed progress in several critical areas, such as web-page development, student database, and alumni tracking. In 2008, the Department hired a consultant to create a comprehensive database for all our student records. A version zero is available and awaits data input, which has been delayed, as noted, by turnover in the Academic Program Coördinator position. The turnover in this position also delayed re-implementation of the Alumni Questionnaire.

In the last five years (2005–09), the average number of degrees conferred has been 13.4 (to be compared with 12.6 for the five years before that), with a peak of 21 degree recipients in 2007-08. A history over the last decade of the number of student credit hours in the upper-division courses and of declared majors and degree recipients, broken down by degree program, is available as Attachment A. Our average number of conferred degrees beats the national median of 10 in 2006 for PhD-granting departments, the most recent figure reported by the American Institute of Physics (AIP). Of our 2005–09 degree recipients, 22% were female, while nationally in 2006, 21% of Physics bachelors and 36% of Astrophysics bachelors were women, meaning that our numbers are about average. Also in 2005-09, 17% of our degree recipients were Hispanic. AIP reports that in 2006 New Mexico had the highest percentage of Hispanic Physics bachelors of any state, at 13%, and at UNM we have exceeded even that result. The Department was recently recognized by the AIP as one of the top departments for Hispanic Physics bachelor production in 1998–2007, with a total of thirteen Hispanic degree recipients. There is a feeling, however, that we could do even better by our Hispanic majors by early identification and intervention with students who are having trouble making the transition from the sophomore level to advanced undergraduate courses.

Apart from the tools in our assessment plan, we have also been examining retention of majors. We have found that for the four semesters from fall 2007 to spring 2009, we lost 50 students who declared a major in our department and who at least attempted Phys 160, the first required physics course in each program; this means that roughly 65% of declared majors who attempt Phys 160 leave our program before finishing a degree. Of the 50 students studied, twelve seemed to have left UNM, eight switched to Math, eight to Engineering, five to E&PS, and the remainder to various other majors. Twenty-three of the 50 attempted a 200-level physics course, and of these, six seemed to have left UNM, six switched to Math, three to E&PS and two to Engineering. At all levels then, we tend to lose some majors, mainly to science/math/engineering programs, but not exclusively. We feel that loss of majors at such a rate is to be expected in the challenging programs in our department. We certainly advise students of the possibility of switching majors if they seem to be struggling. That we end up graduating somewhat more majors than the national median hints that we are not doing badly on this score; nonetheless, retention is a matter that deserves our continued attention.

We continue to improve and expand the Honors Research program. Nine theses were completed in the past five years. Completed honors theses are now posted online on the Department’s web page (http://panda.unm.edu/AcadAdv/honorslist.html).

Our graduates continue to succeed in their subsequent endeavors, although we cannot provide detailed statistics until our Alumni Questionnaire effort is fully underway again. Nonetheless, comments on a few cases are in order. A 2008 graduate, Aaron Zimmermann, is now doing quite well in the graduate Physics program at Caltech. Edna Cardenas was our top female, Hispanic undergraduate degree recipient and is now developing new methods to detect delayed gamma rays in fissionable materials in the graduate program at Idaho State University; she has just received an MS with thesis and is embarking on research for her PhD dissertation. Paul Martin, who stayed a fifth year in our program to work on a very successful Honors

Thesis, is now in the physics PhD program at the University of Oregon and is also applying for nationally endowed fellowships. Nick Menicucci, whose Honors Thesis was the principal part of a publication in Physical Review Letters, was both an NSF Graduate Fellow and a National Defense Science and Engineering Graduate Fellow during his graduate study; he received a PhD in Physics from Princeton in 2008, for thesis work carried out in the quantum information group at the University of Queensland in Brisbane, and is now a postdoc at the Perimeter Institute for Theoretical Physics in Waterloo, Ontario.

The annual Open House is a recruitment and public-outreach event at which prospective physics and astronomy majors from area high schools and UNM visit the Department and learn about our research activities as well as the degree programs we offer. The event is held during an evening early in November. Students tour several labs during the evening and get a chance to view the deep sky at the Campus Observatory. The Open House is now advertised to an expanded and better targeted audience of teachers and schools. As a result, attendance has increased markedly in recent years, to a new high of 148 high-school students and UNM undergraduates at the most recent Open House in November 2009. The Open House is unquestionably a rousing success as outreach to physics teachers and prospective students; the Undergraduate Committee plans to study whether this evident success translates into an effective recruitment tool for our degree programs.

An informal subcommittee of two faculty members from the Undergraduate Committee attends several career fairs every year, some on campus and some in the community, and presents information on major programs, departmental research, and physics and astronomy careers in general, as well as occasional fun physics demonstrations

The Department continues to run, as a joint venture with Los Alamos National Laboratory (LANL), a ten-week summer program in physics for a select group of advanced undergraduate students. This Summer School includes lectures, tutorials, a unique high-performance computing experience, and a full-term research project mentored by senior scientific staffs at UNM and LANL. The school is supported in part as a Research Experience for Undergraduates (REU) site of the Physics Division of the National Science Foundation (NSF). Since 2005 the Department of Defense has contributed to the support of the school as well, through its ASSURE Program, as does the Institute for Advanced Studies, a coöperative enterprise between LANL the three New Mexico research universities. This joint venture effectively combines the unique strengths of UNM and LANL in a professional and educational activity of special character. On completion of this program, students receive three semester hours of UNM credit for Phys 452 (Research Methods) or 501 (Advanced Seminar).

III.3 Goals and plans.

Our undergraduate degree programs are in good condition, as the preceding discussion makes clear, but there are several areas in which improvements will be considered.

Two issues discussed in Sec. II.3 are also relevant to our degree programs: (i) how to gain more control over the SI program in order to have it better serve the needs of students in our introductory courses and (ii) how to improve students' problem solving abilities in the 160 series, with one possibility being to require the problem sessions for our majors.

Recruitment and retention of majors is a constant concern. It has been suggested by some faculty that the Department should make more effort to recruit students from the local private high schools, such as the Albuquerque Academy and Sandia Prep. Two ex-students from the Department now teach at the Academy, providing useful contacts to build on there. Retention and recruitment of women and minority majors, in particular, is an ongoing concern, despite the relatively healthy performance, mentioned in Sec. III.2, which we have achieved presently. One initiative just begun by a group of female graduate students is SWiPhT (Smart Women in Physics Together); these students have begun a mentoring program for female undergraduate majors, providing them with insight they have gained through their own undergraduate and graduate careers.

The Phys 262/330 transition has been improved, but the transition to the 300 level is still a steep one for many of our majors, and we will thus continue to address this issue. One obvious step is to create a problem session for Phys 330 to provide more practice at problem solving at this crucial transition (Phys 330 is the only required physics lecture course in the majors program that presently lacks a problem session); we have now initiated this change. Another idea would be to require the Phys 262 problem session, again possibly for our majors only. Early identification of students having trouble with this transition, either in Phys 330 or in the first junior-level courses, Analytical Mechanics I (Phys 303) and Thermodynamics and Statistical Mechanics (Phys 301), followed by intervention to provide special tutoring or direction to other resources, might be useful. These measures might particularly improve the retention rate of minority students.

Regarding retention in general, we plan to continue collecting and analyzing relevant statistics to help us identify possible ways to retain more majors. We will also account for majors who transfer in from elsewhere at various stages of their degree programs.

The Department continues to consider whether new degree programs or concentrations should be pursued as a way of better serving the career goals of our students. For instance, would a Biophysics concentration be useful for students wishing to go into that field? Our sense is that we are not yet in a position to create such a concentration, but this situation should be reëvaluated periodically over the next several years by the Undergraduate Committee, in consultation with our biophysics faculty.

It is also timely to revisit the role of the BA degree. As mentioned above, the BA degree was originally intended for students who would like to pursue physics-related careers such as patent law or science writing (thus expanding our major pool in a new direction), but there is a perception among some students that the BA is a “consolation prize” for those who have trouble with the BS degrees. This perception is reënforced by anecdotal evidence that most incoming majors are interested in a research career rather than these other directions and by the evident fact, hard to hide, that students who are having trouble in the required courses for BS majors often end up getting the BA degree. The Undergraduate Committee will evaluate the BA degree in terms of students’ initial career goals, advising strategies, and the aforementioned perception.

A continuing issue is the mathematics preparation of our majors and, in particular, how the required math courses can best serve our majors. There is a perception that physics students generally learn mathematical techniques best when they are presented within the context of physics concepts and applications. This perception argues for not expecting too much from math courses, but also for paying careful attention to what is taught in the required math courses and how it is taught. Among the questions that have arisen in this regard are whether students are exposed to integrals in Math 162 at an early enough point to be optimal for Phys 160 and whether Math 321 (or Math 314) provides the aspects of linear algebra relevant to the needs of students in our junior/senior-level courses, especially Phys 491/492 (Intermediate Quantum Mechanics). Discussions have been initiated between the Undergraduate Committee and relevant Mathematics faculty to address such specific issues and, more broadly, how to ensure that our majors get the mathematics preparation necessary for our upper-division physics courses.

IV Graduate education and research.

Graduate programs in the sciences are responsible for producing the next generation of experts in a particular field. Through a mix of classroom instruction and supervised apprentice-style research, graduate education in the United States provides students with a base of advanced scientific knowledge and skills and a focused research experience in a particular field of science. Scientific research is an integral part of the education and training of graduate students. In contrast to research in national and industrial laboratories, whose primary purpose is the advancement of science and technology in the service of national and commercial needs, scientific and technological research at academic institutions not only serves the purpose of expanding the knowledge base, but also supports education and training in the broadest sense. Research universities were created to provide the infrastructure and personnel to expose students to internationally competitive scholarly activities at the forefront of science and technology. *Research is thus a core component of the University's educational mission; it cannot be separated from graduate education.* The appropriate distinction, should one be necessary, is not between education and research, but between classroom teaching and apprentice teaching through supervised research, both of which serve the University's educational mission and both of which play an important role in graduate education.

The Department of Physics and Astronomy offers four graduate degrees:

- PhD in Physics
- PhD in Optical Science and Engineering (OSE)
- MS in Physics, with or without a thesis
- MS in Optical Science and Engineering (OSE), with or without a thesis

The OSE degree programs are jointly administered by P&A and ECE; they are available at reduced tuition to residents of thirteen other western states through the Western Regional Graduate Program of the Western Interstate Commission for Higher Education. The examination and course requirements for the PhD and MS in Physics are given in Attachment E.

In addition to these degree programs, graduate students can also choose one of the following concentrations within the physics degrees: MS in Physics with a concentration in Biomedical Physics and PhD in Physics with a concentration in Biomedical Physics. Students who pursue one of these concentrations must complete the same required course program and exam sequence as do other students in the Physics degree programs, but the concentration pre-defines the research area and a set of relevant elective courses. A student in a concentration receives a certificate certifying that concentration on graduation. The concentrations in biomedical physics were created in 2004 in response to the increasing importance of physics in the life sciences and the growing interest of both students and faculty in biomedical physics, but no students have taken advantage of these concentrations.

The Department also participates in the interdisciplinary Nanoscience and Microsystems (NSMS) MS and PhD degree programs, which were introduced in 2006 and are administered jointly by A&S, the SoE, and the Office of Graduate Studies. In spring 2009 two students from P&A were enrolled in this program.

The general goals of P&A's graduate degree programs are the following:

- To provide students in all programs with a solid foundation of advanced knowledge in broad areas of physics (and astrophysics, optics, or biomedical physics for students in these degree programs or concentrations).
- To prepare MS students for technical employment, as well as further graduate study.

- To prepare PhD students to conduct independent research programs in commercial, government, and academic settings.

To achieve these goals, the Department's curriculum and supervised research programs are designed so that students will, upon completion of a degree program, meet the following expectations:

- Each student will have a thorough grasp of undergraduate physics (and astrophysics for astrophysics students and aspects of biomedical physics for biomedical physics students).
- Each student will understand the general experimental basis, advanced concepts, and advanced problem solving methods of the core curriculum for the particular degree sought.
- Each student will be able to find and intelligently assess all of the important literature relevant to any particular research problem.
- Each student will be able to make professional oral and written presentations of research results.
- Most important (in PhD programs), each doctoral student will be an expert in some particular field of physics, astrophysics, optics, or biomedical physics and will have formulated and conducted an independent, professional quality research program in that field.

A plan to assess these general program goals was approved by the P&A faculty and the Office of the Vice Provost for Academic Affairs; it is available as Attachment F.

The Associate Chair for Graduate Affairs has direct responsibility for the Department's graduate programs and oversees the Graduate Committee, the P&A part of the Optical Science and Engineering degree programs, and the Graduate Examinations Committee. The Graduate Examinations Committee creates and administers the written preliminary exam and is responsible for policy and record keeping for the preliminary exam. The Graduate Committee assumes responsibility for recruitment, admissions, and retention of graduate students, for advisement of MS students and of PhD students until admission to candidacy, for the graduate curriculum, and for departmental policy on and implementation of the Candidacy (Comprehensive) Exam, which culminates in admission to PhD candidacy. The Optical Science and Engineering Graduate Committee administers the OSE degree programs under the direction of co-Chairs from P&A and ECE.

In Sec. IV.1, we review the status of our graduate programs at the time of LRP04. Section IV.2 assesses the last five years, and Sec. IV.3 details our goals and plans for the next seven years.

IV.1 Review of LRP04.

The Department's programs of graduate education and research were subjected to a thorough review in LRP04, particularly in Secs. III.3, V.5, and V.6.

At that time the Graduate Committee had just completed, in the fall of 2003, a review of the course requirements and of the comprehensive exam for students pursuing the graduate Physics degrees. At the recommendation of the Graduate Committee, the Department adopted changes in graduate course requirements and in the exam procedure.

On the core graduate curriculum, the Department decided that a 1996 reduction in core requirements had gone too far and re-instituted a mandatory second semester of graduate quantum mechanics, Phys 522 (students whose dissertation will be in astronomy or astrophysics are permitted to substitute a semester of Astro 537, Advanced Astrophysics II). The Graduate Committee was charged with continuing to monitor the graduate curriculum and recommending changes as necessary, particularly in new research areas such as biomedical physics and quantum information.

In addition, the Department adopted a radically revised graduate exam sequence for students in the Physics degree programs. The new sequence substituted a preliminary exam at the undergraduate level in place of the previous comprehensive exam, which involved a weighted average of core and elective course grades, a written comprehensive exam at the graduate level, and an oral exam. The new preliminary exam has four component exams in mechanics, electromagnetism, quantum mechanics, and thermodynamics and statistical physics. Once past the preliminary exam and the required graduate courses, a Physics PhD student proceeds to an oral Candidacy Examination (which also serves as the Department's Comprehensive Exam under University rules for PhD students) by the beginning of the fourth year. Admission to PhD candidacy completes the student's transition to research, with the Chair of the Candidacy Exam Committee becoming the student's PhD supervisor. LRP04 recommended that the new preliminary exam be closely monitored, with course corrections to be considered as experience with the new exam sequence accumulated.

LRP04 also noted with approval the Department's more intensive advisement scheme for graduate students, which was adopted in 2000 in response to a perception of declining quality of graduate students in the late 90s and a feeling that many PhD students were failing to fulfill departmental course requirements in a timely fashion. Under this scheme, each incoming graduate student is assigned an academic advisor from the Graduate Committee (or a P&A member of the OSE Graduate Committee for most OSE students), who advises the student periodically until the student advances to PhD candidacy (or receives an MS for Master's only students), at which time the torch is passed to the student's dissertation supervisor.

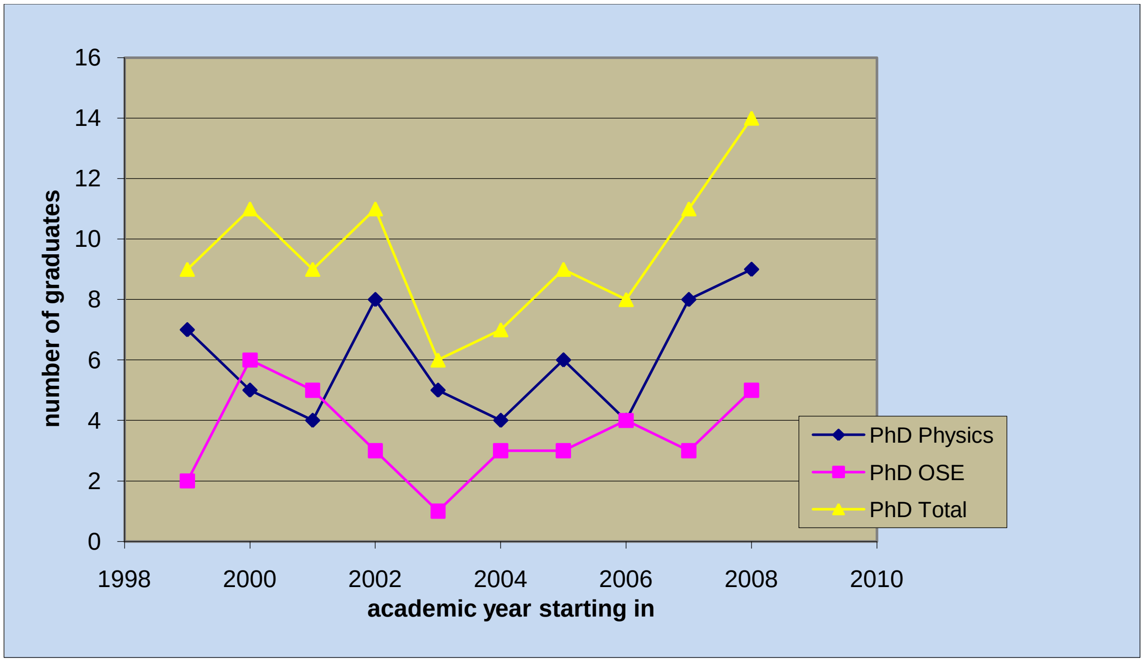
The highest priority identified by LRP04 was the need to attract and retain high-quality graduate students to staff the Department's research programs. LRP04 recommended a series of actions to address this need: an attractive, informative, and up-to-date web presence describing the Department's graduate and research programs; presentations describing our graduate and research programs to prospective students at other colleges and universities; aggressive use of personal contacts at other institutions; effective recruiting from abroad; competitive financial-aid packages; UNM graduate fellowships; visits to the Department by graduate applicants; exchange agreements with other institutions; and continuation and enhancement of P&A's good relations with local sources of students at the national laboratories and local industry.

IV.2 Assessment of last five years.

Just under 20 new graduate students join the Department every fall. The number of applications for the PhD and MS in P&A has almost doubled over the past six years. Before 2002, all OSE students were admitted through P&A, but since then, both ECE and P&A have admitted OSE students. The number of student credit hours at the 500 and 600 levels increased by about 40% between 2000–01 and 2008–09. The total number of students in our graduate degree programs has held steady since 1999–2000, at 100 or just above. Of the 122 students in our graduate programs (81 in Physics and 41 in OSE) in fall 2009, there are 27 women (21%), which is about average for physics departments.

The Department averaged 9.5 PhD graduates per year (6 in Physics and 3.5 in OSE) for the ten years ending in 2008–09. This should be compared to a national average in 2006 of 7.4 for PhD-granting physics departments, bearing in mind that our department, with 28 tenured and tenure-track faculty, is right at the midpoint of department size for PhD-granting physics departments. During the same ten-year period, there was an average of 8.9 MS recipients per year. The number of PhDs produced has held fairly steady over the past two decades. Students now take an average of 6.5 years to complete the PhD degree, which is near the national average for physics departments. The Department is concerned about the long time to the PhD, but this is heavily impacted by working with some ill-prepared students who need to take remedial courses before tackling our core graduate courses, as we discuss further below.

Attachment G gives the number of graduate degree recipients, number of graduate students enrolled near the beginning of the fall semester, and the number of credit hours in graduate courses over the last decade. The graph below summarizes PhD production since 1998–99.



Of the Physics PhD recipients since 1998–99, 63% proceeded immediately to postdoctoral positions, 11% went into jobs in industry, 19% took up teaching positions, and 4% became staff members at a national lab, with the remaining few recipients (3%) pursuing other alternatives. The comparable figures for OSE PhD recipients are postdocs, 55%; industry, 24%; teaching positions, 4%; and national labs, 17%.

The Biomedical Physics concentrations were introduced in 2003. The faculty member who spearheaded the formulation and adoption of these concentrations left shortly thereafter. Subsequently, the Department hired two new biophysics faculty, bringing the number of tenure-track faculty in this area to four. The biophysics faculty are supervising graduate students at the MS and PhD levels; moreover, several biophysics-related courses have been created and successfully taught in our department, with sufficient interdisciplinary content to attract students not just from P&A, but also from the Health Sciences Center (HSC), Biology, and Chemistry. Yet the Biomedical Physics concentrations have not attracted any students, and even our biophysics faculty question the usefulness of the program.

IV.2.1 Preliminary exam.

The current format of the preliminary exam for students in the Physics graduate degree programs, adopted in the fall of 2003, has worked reasonably well. There have been minor clarifications of the exam's level and content and somewhat more substantial changes in the timeline and rules for passing the exam. All four components are offered twice a year, during the weeks immediately preceding the fall and spring semesters (often called Duty Week at UNM). After fiddling with the timeline and rules, the Graduate Committee eventually extended the timeline so that to pass the exam at the PhD level, a student must pass all four component exams no later than the Duty Week at the beginning of the sixth semester and can take each component as many times as desired before that deadline. This timeline allows students with deficiencies in their physics background to take remedial courses to prepare for the exams before attempting the graduate core courses; we have had a number of successful Physics PhD students who would have failed had there been a stricter timeline. A downside is that a student can spend as long as 2.5 years in the Department before a final decision is made. Although there is a general concern that this is too long, this concern has been over-ridden by a desire to accommodate those students who evidently need such a long timeline to succeed. More importantly, the long timeline has caused financial problems for some students, since the

Department only guarantees TA support for four semesters. Several students have left the program before the deadline, prompted by unsatisfactory results on the preliminary exam. Students who fail the exam at the PhD level can receive an MS degree (without thesis) if they pass at the MS level (which requires passing three of the four components at a somewhat lower level); most students who are forced to leave the Department are able to take advantage of this option. Students who pursue an MS degree with thesis are not required to take the preliminary exam.

IV.2.2 Advisement.

The more intensive advisement scheme adopted in 2000 remains largely unchanged, which is a tribute to its success. An incoming student is assigned an academic advisor during Duty Week, when an initial advisement session formulates a plan for the student's academic program. After this initial session, the student meets with the academic advisor whenever the student desires or as problems arise, but particularly toward the end of each semester to assess progress, to plan the next semester's courses, and to discuss the student's transition to research. Instructors are urged to bring problems to the attention of a student's academic advisor. Although this scheme is a considerable burden for the advisors, making it necessary for the Graduate Committee to parcel out advising assignments carefully, it is strongly felt that such intensive advisement is essential to the success of many of our graduate students and is beneficial for all of them.

IV.2.3 Curriculum.

Two specific recommendations of LRP04 have been implemented: to increase students' exposure to contemporary physics research, the Department decided to offer the weekly colloquium as a one-credit hour course, to be taken by all graduate students at least for one semester, and most of the Department's seminar series are now offered for graduate course credit. In addition to these two changes, we also introduced a "Chair's Seminar," offered in the fall semester for entering graduate students. In this seminar, faculty members describe their field of research; these presentations have often initiated first contact between faculty and interested graduate students.

New courses in Quantum Computation (Phys 571) and Quantum Information Theory (Phys 572) have been approved and added to our regular teaching schedule to accommodate the increasing number of students who pursue research in these areas. A course entitled Advanced Topics in Physics and Astrophysics (Phys 581) was introduced to provide a venue for offering timely specialty courses on contemporary topics.

The Graduate Committee evaluated the effectiveness of our two-semester course sequence in Mathematical Methods of Physics (Phys 466/467). Although knowledge of the material in these courses was said to be a prerequisite for our graduate core courses, the courses themselves were not mandatory. The evaluation identified a number of problems: (i) it was difficult for advisors to determine if students had previously taken equivalent courses; (ii) both courses were waived for too many students whose self-assessment regarding knowledge of the material turned out to be too rosy, thus leading to difficulties in subsequent graduate courses and during dissertation research; (iii) experimentalists, both students and advisors, did not see the need for a two-semester sequence; (iv) theorists, both students and advisors, found the 467 curriculum too rigid. The combination of (iii) and (iv) meant that 467 usually had low enrollment and was sometimes cancelled. In response to these problems, the Department, at the recommendation of the Graduate Committee, made the following changes. Phys 466 was made mandatory for all incoming Physics graduate students, and the course content was modified to ensure coverage of essential topics; it will continue to be offered every year in the fall semester. Phys 467 is now optional and will be taught every other year in the spring semester; we anticipate that all theoretically inclined students will take 467, but the actual content will not be prescribed, to provide flexibility for the instructor and to allow for coverage of various modern aspects of mathematical physics.

The Department tries to offer four or five graduate electives each semester. Over the last five years, several electives had to be canceled for lack of student interest. This is perhaps a symptom of a mismatch between the student population and the research areas represented in the Department.

IV.2.4 Recruitment and retention.

Graduate-student recruitment remains a critical issue for us. The number of graduate students who apply to our PhD programs annually has almost doubled over the past six years; in 2008–09 we had about 120 applicants. This increase might be explained in part as a manifestation of a national trend toward slightly increasing numbers of graduate students in physics. We offer admission to about 60 students, roughly 50 of whom are offered full financial aid for two years, usually a TA, but sometimes an RA or a combination of the two. On average one-third of our offers are accepted, leading to an incoming class of just under 20. We have difficulty attracting students who rank highly on our application list, and based on our experience with the students we accept, we believe that dipping much below the mid-point of our pool would mean admitting students who would find it difficult to succeed in our program.

An increasing number of faculty members advertise our program at other universities and colleges during visits, and a few students have joined our program as a result of these activities. Our web page has been modified to advertise our program better and to streamline the application process, but the design and organization of our web page for this purpose and others need a major overhaul (see Sec. V).

We have continued our tradition of an Open House in March, to which we invite the 10–12 domestic students whom we most want to attract to our program for an intensive day in the Department on a Friday, followed by a full-day local outing on Saturday. About 30% of participating students decide to join our program. Some faculty, particularly those who participate in the OSE degree program, question the effectiveness of the Open House, thinking that our building contrasts so negatively with the physical facilities at major centers in the optical sciences that showing it to students drives them away. Most of the rest of the faculty feels that though the building is unquestionably a negative, the opportunity to sell their research program one-on-one is invaluable.

Major obstacles in attracting students have been our TA salaries, the substandard physics building (this negative was amplified by a major hospital construction project next to us for most of the past five years), and UNM's ranking in college surveys such as that of US News & World Report. The latter is particularly important in attracting qualified applicants from abroad.

Most incoming students receive a two-year TAship, which in 2009–10 pays between $13.8k and $15.2k for the academic year, depending on the student's background (BS or MS) and comes with a tuition waiver of up to twelve credits per semester and health insurance. A recent survey conducted by the Department found that our TA salaries for students with a BS degree are about 10% below those paid by peer institutions, this despite the 10% TA salary increase mandated by UNM in 2008, and below those paid by other science departments at UNM (~12% discrepancy). As of November 2009, the Department's faculty has approved a Graduate Committee recommendation to equalize the salaries of TAs with BS and MS degrees and thereby to raise stipends enough to be competitive with our peer institutions. This change, to become effective in academic year 2010–11, will come at the expense of a small reduction (~2 out of 33) in the total number of TAs. This will have two consequences: (i) some graduate and upper-division undergraduate courses will not have TAs assigned to them, and (ii) the number of incoming students to whom we can offer TA support (currently about 15) will decrease by 1.

Owing to the success of the Department's introduction of SI, A&S allocated 2.5 SI lines to P&A. We also received one additional TA position to support the introductory physics courses for students in the BA/MD program. This brings our total number of TAs to about 33. The fall 2009 semester provides a typical example of TAs and their assignments: of the 14 first-year students, 14 second-year students, and 5.5 students from third and higher years who have TAs, 14.5 were assigned to the undergraduate laboratories, 10 provided support in other undergraduate courses, 5 graded graduate courses, and 4 worked as SIs. A recent development is that fewer TAs are needed to grade introductory physics courses as more instructors use web-based homework assignments. The freed-up TA slots are generally re-assigned to additional SI or to teaching additional problem sessions.

Funding for RAships varies considerably depending on the research area and group. There is a reasonably good match of the number of qualified students seeking support and the availability of RA funds. In a few cases, however, a lack of research funding has meant that a student cannot pursue a PhD dissertation in the area he or she had originally intended. In the past the Department has been able to support some advanced PhD students with TAs when the student's dissertation supervisor is unable to provide RA support. Although this kind of TA support is and should be only a small part of the Department's overall TA budget, it provides crucial support in particular cases. The Associate Chair for Graduate Affairs and the Graduate Committee monitor the use of TA funds for this purpose.

Federal agencies and private foundations offer a number of fellowship programs for outstanding graduate students; some of our students have taken advantage of these opportunities. In addition, in the last decade, NSF and NIH have created graduate education and research programs targeted at increasing the number of domestic PhDs in technical and biomedical disciplines. These programs include fellowships at very attractive levels ($30k/yr in 2008–09). P&A has had one grant (Cross-disciplinary Optics Research and Education, 2002–07) from NSF's Integrative Graduate Education and Research Traineeship (IGERT) program, and has participated in three other such grants at UNM. Together, these have provided financial support to more than 20 OSE and Physics PhD students.

There is a noticeable discrepancy between the research interests of students and the numbers of faculty in the Department's research groups. While the Quantum Information Science (QIS) and Optical Science (OS) research groups attract a comparatively large number of students, astronomy and subatomic physics, with particle astrophysics being an exception, have problems attracting a sufficient number of high-quality students. This has an impact on teaching elective courses, as noted above, and leads to an uneven distribution of graduate students among the faculty. Some students change their research interest after they enter the Department, and this mitigates some of these problems. In the past we have admitted students on the basis mainly of their academic credentials and have paid little attention to expressed research interest. If the overall size and quality of the pool of applicants and the acceptance rate do not change substantially, we must continue with this policy, because as noted above, dipping further into our applicant pool to staff certain research areas is likely to lead to accepting students who cannot succeed in our program.

IV.2.5 Issues particular to the OSE degree programs.

Since the introduction of the graduate OSE degree program in 1985, P&A has traditionally provided the Chair of the program, and most of the administrative burden has rested on the shoulders of P&A faculty. In 2009, for the first time, the Chair position was assumed by an ECE faculty member. It is to be hoped that this signals that the burdens and benefits of the program will in the future be shared more equally between the two participating departments.

Meetings in late 2006 with the Deans of A&S and SoE (at the time, Vera Norwood and Joseph Cecchi) led to in-depth discussions of the urgent needs of the OSE program. A verbal agreement was made in December 2006 to support the program with a full-time Program Coördinator and an annual budget for administrative support. Only a 0.5 FTE slot was approved by both Deans at the time of hiring, however, with the promise of upgrading to a 1 FTE position in following years, and the allocation of a budget was made contingent on the formation of a reporting structure, such as an executive committee. With the subsequent departure of both Deans and the emergence of the current UNM budgetary crisis, these questions were set aside. The OSE co-Chairs are currently revisiting these and other issues with the Provost and the Dean of Graduate Studies. Among the topics of discussion are the important matter of the future direction of this program and its administrative structure, new student recruitment strategies, and ways to increase the program's visibility and impact, both in terms of graduate education and research at UNM and employment opportunities upon graduation.

The OSE degree programs will have their own Academic Program Review during the spring of 2010 (OSE APR Self-Study). Because of the OSE programs' importance to P&A generally and critical importance to faculty in our Optical Science (OS) and Biological Physics research groups, many issues connected with the OSE degree programs are discussed in this document as well.

IV.2.6 Administrative issues.

Over the past five years, the Department has had three different persons as Academic Program Coördinator, the departmental staff member who is in charge of administrative aspects of our degree programs. This turnover has delayed progress in several critical areas, such as web-page development, student database, and alumni tracking. In 2008, the Department hired a consultant to create a comprehensive database for all our student records. A version zero is available and awaits data input, which has been delayed, as noted, by turnover in the Academic Program Coördinator position. A half-time Program Coördinator for the OSE program was hired, which took some load off P&A's Academic Program Coördinator.

In 2008, the Department approved a plan to assess the graduate programs regularly relative to the broad program goals listed at the beginning of this section. The assessment plan (available as Attachment F) involves collecting various data on student performance (exams, defenses, etc.) and from exit interviews and requires the submission of annual reports to our upper administration. This formal procedure was mandated by UNM for all units. Our department has a good track record in identifying program weaknesses and making changes. It remains to be seen if this more formalized plan will become an efficient tool to improve our program rather than just being an additional bureaucratic burden.

IV.3 Goals and plans.

The recruitment of high-quality graduate students remains a top priority, as it was in LRP04. All measures laid out in the previous LRP should be reëxamined and reconsidered. In particular, we must continue to develop and use personal contacts and presentations at undergraduate institutions to attract applicants. The just-approved increase in TA salaries will need to be monitored to estimate whether it has a positive effect on recruitment of students and to assess the impact of fewer TAs on teaching in graduate and upper-division undergraduate courses.

The Department should motivate and encourage faculty to apply for grants from federally funded fellowship programs such as NSF-IGERT, GK–12 (NSF Graduate Teaching Fellows in K–12 Education), and NIH graduate training grants. These programs provide generous stipends and are used actively by other departments, including our peers, to recruit high-quality graduate students. In addition, the Graduate Committee should take charge of identifying students who could profitably apply for the major federal and other graduate fellowships and encourage them—indeed help them—to apply.

The Department should work to make available prize fellowships with a competitive stipend to attract the most highly qualified graduate students. One avenue for funding is the national laboratories; for example, Sandia National Laboratories, as part of new initiatives in quantum information science, currently funds a prize fellowship for an entering student who wants to do dissertation work on topics in quantum information science.

Another avenue is the University. President Schmidly's 2008 Environmental Assessment noted that we need mechanisms for attracting and graduating top students, but that we are "not currently competitive with peer institutions to attract top graduate students.'' Under President Schmidly, UNM has had notable success in enticing National Hispanic/Merit Scholars to enter the University as freshmen, by offering incentives to these much sought after high school graduates. Duplicating these successes in UNM's graduate programs should be a top priority for the University. Nothing could improve the University's graduate programs more than a similar program of incentives aimed at attracting the best PhD students to UNM. High on the list of incentives should be a set of College- or University-wide full graduate fellowships. The Department should help make this case to the College and the central administration.

The Department should discuss the possibility of an on-site NSF REU program, in addition to the LANL Summer School. Such a program would introduce the Department's research to a qualified and highly motivated group of undergraduate students, from which we could recruit into our graduate programs.

Over the last decade, about 30% of incoming Physics PhD students did not complete a PhD, with almost all losses occurring before admission to PhD candidacy. We estimate that 10% of entering students left the program for purely personal reasons, such as health issues or family concerns. Moreover, most of the students who failed to complete a PhD did receive a Master's degree: only about 5% of entering Physics PhD students left without receiving any degree in P&A. Students who did not complete a PhD tended to come from the bottom of our admissions pool. These considerations lead to several conclusions. First and foremost is that the situation would be most readily improved by attracting high-quality applicants and recruiting them into our graduate programs—thus our critical priority of recruiting high-quality graduate students. Second, lowering admissions standards to increase the number of incoming students would be misguided. Third, with the students who do enter our program, especially those near the bottom of our admissions pool, the Graduate Committee must continue to pay close attention to the effectiveness of our advisement process. In particular, advisors should identify students who need remedial course work and direct them into appropriate courses as soon as possible. In this regard, advisors should urge students strongly both to take the first sitting of the preliminary exam (on entry) and to take it seriously, so that the results can be used as a diagnostic tool to determine whether a student needs remedial course work.

The Graduate Committee and its advisors need to check student progress regularly and closely, at least once per semester. The Department has established program rules that are more stringent than the guidelines of the Office of Graduate Studies, specifically, the necessity of a grade of B– or better in core courses and the requirement that a certain number of core courses be passed by the end of each semester of residency. For these rules to achieve their purpose, they must be enforced.

The Graduate Committee, in consultation with our biophysics faculty, should evaluate the Biomedical Physics concentration and the Department's curriculum in biophysics. The Graduate Committee should bring to the faculty a proposal for changes in or dropping of the Biomedical Physics concentration and for a set of core elective courses in biophysics by the end of the 2010–11 academic year.

As has been done in the past, the Associate Chair for Graduate Affairs and the Graduate Committee will regularly assess the success of all aspects of our graduate program and recommend changes to the faculty as necessary. The Department's official graduate assessment plan will serve as a guide. A major tool in assessment will be the comprehensive department database, which is scheduled to be fully functional by the end of 2011 provided additional resources can be found for its development. The database will help to track graduate-student progress, to assess the overall strengths and weaknesses of our program, and to keep track of our alumni.

In view of the considerable demands on the Graduate Committee for recruitment, admissions, retention, advisement, curriculum, implementation of the Candidacy Exam, *and* new program assessment responsibilities, the current committee structure for graduate affairs should be reëxamined. The Graduate Examinations Committee will continue to have primary responsibility for preparing and administering the preliminary exam, but the Graduate Committee might be split in two, with a new Graduate Admissions Committee taking responsibility for recruitment and admissions, and the Graduate Committee retaining the other responsibilities of the current Graduate Committee. Another option would be to retain the current Graduate Committee, but with various tasks parceled out to subcommittees.

The OSE degree program needs greater visibility and support within UNM if it is to succeed. The steps now being discussed to increase the resources available to the program, such as a 1 FTE Program Coördinator and an annual budget for administrative support, need actually to be taken. It is now critically important for the OSE degree program to formulate a clear statement of its role within the University and a realistic plan for its future; in doing so, it will be important to keep in mind the strengths of existing OSE research at UNM, particularly at the Center for High Technology Materials (CHTM), the need to compete in a national environment that now includes several very large-scale and many smaller research centers in OSE, and the strength that comes from close association with both a physics department and an electrical engineering department.

There is much to be done to make the Department more attractive to graduate students, but much of this is tied closely to other departmental priorities. We need a new building that provides state-of-the-art facilities for our students, especially in experimental physics (Sec. VI); we need to make hires with an eye toward building research programs that have proven to be attractive to graduate students (Sec. VII); and we need a more attractive, more functional web site, with material on graduate affairs better organized so that essential graduate program information is easy to access and information about our research programs is presented in a way that is engaging and exciting (see Sec. V).

We realize that even with exciting research programs staffed by outstanding, productive faculty working in a new, state-of-the-art building, most prospective students will not get the message if it is not delivered effectively on our web page. As a successful recent applicant to our program put it, “A website can be dated by its appearance. An old-looking web page suggests the site is not being maintained and therefore stigmatizes the quality of the organization, posing a question of trust in the organization’s capabilities. I know for certain that some colleagues of mine (at UC Berkeley) did not consider UNM precisely because of the unappealing image presented by the Department’s web page.”

V Departmental web presence.

The Department's web page is the public face of the Department. It plays a crucial role in advertising our department to external constituencies, especially potential graduate and undergraduate students, as well as highlighting the research interests and accomplishments of the faculty. In addition, it plays an important role as an information source and administrative tool for faculty, staff, and students. The faculty recognizes that the current state of our web page is unsatisfactory and that revision to some degree is important. The primary deficiencies of the current web page are that (i) it is unattractive by modern standards, (ii) in comparison to peer departments, the research of groups and faculty are not presented in a prominent, clear, and consistent manner, and (iii) the webpage can be difficult to navigate.

V.1 Review of LRP04.

In LRP04, the Department's web page was identified as needing attention. The process to hire a webmaster, working at least part-time, was underway. It was intended that the Department's webmaster would organize the web page as a secure, central access point for departmental administration. It was also anticipated that the webmaster would be responsible for the maintenance of the Department's long-term databases concerning financial, student, and faculty information. Consistency of presentation for faculty and group's research interests was needed, and this was to be the responsibility of the webmaster. It was noted that although a high percentage of classes taught in the Department had class web pages, a goal of 100 percent had not yet been achieved.

V.2 Assessment of last five years.

Prior to LRP04, the Department's web page was redesigned by an outside design firm. Although many changes have been made to the web page since, the current web page maintains the overall look from that redesign. Shortly after LRP04, the Department's first part-time webmaster was hired. This webmaster implemented the back-end database, but remained with the Department for less than a year. After his departure, the current webmaster, who now works 3/4 time, was hired. The web page has undergone continuous upgrades, including adding the sidebar, adding the rotating research pictures, converting lab pages from Front Page, updating the Graduate Handbook, and redesigning the graduate recruitment/applications page. In addition, the databases have undergone continuous upgrades. The Department has clearly benefited from having the web page and databases maintained by a dedicated webmaster. As expected, over the last five years the Department's web page has become an indispensable tool for teaching and conducting departmental business. The major identified deficiencies of the current web page are not due to content or operation, but from style and presentation that are largely related to the outdated web-page design.

V.3 Goals and plans.

The Department's web page is in critical need of a major redesign. One promising approach for the redesign is basing the style around a set of templates maintained by the UNM Webmaster. UNM provides these templates and other guidance for designing UNM web pages to encourage a consistent look across units. The Department webmaster is currently revising the graduate-program portion of the website using these templates as a starting point. This set of pages is now being presented to the faculty for review and as a proposal for the complete website revision. Comparison with many other websites deemed effective by current graduate students, such as that of the University of Houston's Physics Department, shows that sites have converged to a common style and layout that is consistent with the UNM template. If the style provided by the UNM templates is acceptable to the faculty, the conversion of the entire departmental web page to this style can be implemented by the current webmaster without the need for an external design consultant. If it is found that the UNM templates cannot accommodate the needs of the departmental web page, an external design consultant could also be considered. Any such redesign will be greatly facilitated by the current databases that provide the majority of the web-page content.

The Chair has just appointed a new standing, faculty/staff IT Committee, which will take general charge of IT issues in the Department, including the Department's electronic record keeping. In particular, it will oversee the revision, as well as the maintenance of the web page. The IT Committee will be charged with periodically assessing the style, appearance, capabilities, and content of the Department web page and its ease of use. The Committee is chosen from those faculty and staff, including the Department's webmaster, who understand that web-page design is a nearly continual process; a design that looks good now will be dated and ineffective over a period as short as two years. The Committee will have the sole authority to approve changes or additions to the web page suggested by the webmaster, members of the Committee, or other individuals or committees, although in practice, this authority will usually be delegated to the webmaster. The IT Committee will also make recommendations to the Department Chair regarding IT staffing and hardware.

We note that nothing in this section is meant to reflect negatively on the Department's webmaster. It was not within the webmaster's purview to make the changes discussed here. Indeed, a primary reason for appointing a new IT Committee is to create a go-to body for guidance and approval of our web-page redesign.

VI Physical facilities and new building.

The Department of Physics and Astronomy has four on-campus physical facilities: (i) the main P&A building, which is on the north campus at the northeast corner of Lomas and Yale; (ii) Regener Hall, a major teaching and instructional-laboratory facility, mainly for the service courses, which is located in the southwest sector of the main campus about a ten-minute walk from the main building; (iii) the Campus Observatory, which is one block north of the main building on the west side of Yale; and (iv) a warehouse, located near the Physical Plant facility, with approximately 3,000 ft^2 of storage space. These physical facilities, with the exception of the warehouse, were the subject of Sec. V.11.1 of LRP04.

The main P&A building has office space for faculty, staff, and students, research labs, meeting and conference rooms, two classrooms for upper-division and graduate courses, and instructional labs for upper-division courses. The building was constructed in two initial phases, the older part being opened in 1951 and the newer in 1965. That newer phase was built with a large open space beneath about half of it, explicitly reserved to be available for future use; in 1987 that space was converted into the relatively high-quality research laboratory space that is there today. A small addition of just over 1,500 ft^2 was made in late 1998, and in early 2004, trailers attached to the east end of the building were demolished and replaced with a building of about 5,000 ft^2 on the northwest corner, unfortunately not any larger than the discarded trailer space, but clearly somewhat better as office space and conference rooms. Nonetheless, both of these two newest additions are not permanent construction, with the result that the heating and cooling and the flooring and foundation are inadequate even for office space and certainly nowhere near good enough for laboratories. Summing all these efforts at adding or remodeling space, the Department now has available in the main P&A building a total net assignable space of approximately 46,500 ft^2.

Regener Hall, the Department's large lecture and teaching laboratory facility, mainly for our service courses, was constructed in 1972. It contains a large (300-person) lecture hall, a smaller lecture hall with a 48-person capacity, a large area for storage and maintenance of classroom lecture demonstrations, and quite a few classrooms for laboratories, for a net total of 21,000 ft^2 of assignable space. Regener Hall is structurally in relatively good shape, but suffers from perennial water leaks and is grossly deficient from the perspective of the Americans for Disabilities Act. A more modern facility for service-course instruction is highly desirable, but would add perhaps $20M to the cost of a new P&A facility and thus is not part of our present focus on a new main building for P&A.

The Campus Observatory, built in 1956, includes a classroom, storage space, and several telescope domes. It has 2,500 ft^2 of space, of which the majority, about 1,900 ft^2, is actually outdoor walled courtyard area for exhibition and/or research. The Campus Observatory is used for instruction, mainly in undergraduate astronomy courses and increasingly as a research facility for our program in measurement astrophysics, and it hosts an Open House every Friday evening during the academic year. The Open House, run by P&A students and faculty from the Astronomy and Astrophysics group, is a two-hour viewing session for the general public. It is the Department's most visible public-outreach effort, with an average attendance of roughly 20.

The present Campus Observatory is now outdated and inadequate for its public-outreach, research, and teaching functions. The location is seriously compromised by nearby lights, especially from the new children's hospital, public access to the observing platform of the main telescope is via a single, narrow stairway, the platform itself is too small for convenient public viewing, the classroom is inadequately outfitted for the computer labs that take place there, and research space and infrastructure do not meet our needs, one instance being that several of the domes used for research are located in the much too cramped courtyard.

LRP04 characterized a new main building as a long-term goal for the Department:

The Department's main building is increasingly difficult to maintain and is inadequate for both teaching and research. It is a major negative in recruiting new faculty and graduate students. The Department needs a new building that meets its long-term needs for office space, instructional facilities, and research laboratories. .... High-level performance of our people and programs requires adequate physical resources, which surely includes buildings and furnishings as well as instrumentation, equipment, information technologies, classrooms, and libraries. It is a crucial long-term priority for the Department to push the planning and construction of a new building to ensure that construction begins within the next five years.

Needless to say, this long-term goal has not yet been achieved, although there has been progress in moving a new P&A building forward on the list of University priorities. Over the last five years things have not gotten better, and the need for a new main building has become acute. Our facilities and infrastructure have only deteriorated further, in some cases considerably. Significant inadequacies of our main building include the following:

- The building is unattractive and too small. There is inadequate space for current research programs, especially experimental ones, let alone for modest growth; this has a major negative impact on recruitment and retention of students and faculty. There is insufficient space for undergraduates to work collaboratively, with access to modern computing facilities, and for desks for graduate students, both TAs and RAs.
- The absence of any modern, well-equipped classroom in the main building has a major negative impact on instruction. The largest classroom in the building has a completely dysfunctional system for heating, ventilation, and cooling (HVAC), forcing instructors and students to be prepared on any given day for conditions ranging from tropical to polar and everything in between. An additional classroom is needed for teaching upper-division and graduate courses (the several meeting and conference rooms are not suitable as classrooms).
- None of the classrooms in the present structure can accommodate the audience of 75 to 100 that attends the Physics and Astronomy Colloquium, the chief department-wide activity, which is held weekly on Friday afternoons. The Colloquium has been held in Dane Smith Hall for over a decade, in order to have access to a room suitable for the purpose. This makes a negative impression on visiting colloquium speakers and is an inconvenience for faculty, students, and especially the staff that arranges the pre-Colloquium refreshments.
- The research labs are incompatible with state-of-the-art research in various subfields. Many of the labs have completely inadequate temperature and humidity control, too much dust and dirt, excessive electrical and magnetic noise, noisy electric power, and poor vibration isolation from major nearby sources. The chilled water used for cooling the building has insufficient capacity to serve our research labs.
- The layout of the building discourages intra-departmental collaborations by having faculty and students spread far and wide throughout a poorly connected structure.
- The building is one of the worst on campus from a maintenance perspective, with persistent problems related to the structure itself, electrical systems, HVAC systems, and plumbing. This is a chronic headache for researchers, departmental administration, and Physical Plant—and sometimes more than just a headache, since there is occasional major damage to valuable research equipment. Labs and offices have been flooded with a mysterious brown sludge whose provenance is here best left unspecified. Flooding of restrooms from backed-up sewer lines is such a common occurrence as scarcely to attract attention.
- The building has numerous health and safety issues, including the presence of asbestos in floor tiles, ceiling tiles, and insulation, mold growing on asbestos-insulated pipes, and electrical issues relating to, for example, high-voltage supplies and high-power lasers.

- The building is a major energy sink, inconsistent with President Schmidly's commitment to sustainability, with poor insulation, inefficient HVAC, and old windows.
- As of now, the main P&A building is the last remaining building on an old 4.16 kV power line, whereas other buildings in the neighborhood have been moved to UNM's new 12.47 kV electrical services. While this may have the advantage of fewer power outages related to tinkering with other buildings on the same power line, we have to deal with unexpected outages due to the old hardware in our line. Estimates for upgrading to the new services range to several hundred thousand dollars, and there is a reluctance to spend so much on an inadequate facility that needs to be replaced.
- The recent additions to the original building, the north and the northwest wings, useful though they are for office space, are temporary structures with barely functioning HVAC systems, buckling floors, and other problems.
- The building's IT infrastructure is inadequate. We need gigabit bandwidth throughout, strong wireless signal everywhere (some offices have no wireless signal at all), and a properly designed server room.

P&A has been and remains one of the largest and most research-intensive departments in UNM's largest College, yet our main building, with the oldest wing going back to 1951 and the main part dating from 1965, is simply not up to the task of supporting our teaching and research functions in the 21st Century. The P&A building is like a chronic illness, sapping the morale of faculty, students, and staff. It is certainly not up to President Schmidly's vision, promulgated in his 2008 Strategic Framework, of UNM's becoming "the first minority/majority university in the country to attain membership in the prestigious Association of American Universities."

Compared to 2004, when we made a new building a long-term goal for the Department, our building is even more difficult to maintain—in 2007 the P&A main building made Physical Plant's list of the five worst buildings on campus!—and is even less adequate for teaching and research. Therefore, a new building is now clearly our most important, most ambitious, and also by far most expensive goal; renovation of the current structure is not a cost-effective solution. It is our highest priority for the next seven years (or however long it takes). While we are desperate for a new building, we obviously must also pursue our faculty-hiring plan (Sec. VII), albeit from very different funding sources than the ones needed for a new construction project of this magnitude. On the other hand, *we are rapidly approaching the point where we won't be able to attract new faculty, especially experimentalists, given our decrepit building infrastructure.*

Let us be as plain and direct as we can. *The need for a new P&A building is now acute. In the absence of the completion of a modern new facility to house the Department during the life of this plan, the University will be sending an unmistakable message that it does not intend to have a high-visibility, world-class, research-intensive physics and astronomy department.*

No detailed architectural plans for a new P&A building exist as yet, making it impossible to give a reliable and precise cost estimate. During preliminary planning meetings in 2008, however, a ballpark number of $60M was mentioned, just for our main building and not including any replacement for Regener Hall. This is quite high relative to other recent UNM construction projects, apart from hospitals, but it does appear to be realistic based on comparisons with new structures for comparably sized physics and astronomy departments. A prominent reason for the high cost is that we are a particularly research-intensive department. The nature of much of our experimental research requires expensive laboratories with isolated floor slabs, well-regulated "clean" electric power, very good HVAC infrastructure, isolation from electrical and magnetic noise, availability of chilled water, and in some labs, wet-lab capabilities, fume hoods for ventilation of gases, and overhead cranes.

A needs assessment of our program and preliminary planning for a new building were performed in 2008, resulting in a draft of a so-called Integrated Plan. The Facility Plan section of the Integrated Plan, modified to include additional details about our four existing facilities, is available as Attachment H. The Facility Plan envisions a building with 15% to 20% more net assignable square footage than the present structure.

Planning and constructing a new building will require the attention of all of the Department's faculty, but especially that of the Chair and proxies assigned to the task by the Chair, and it will also require a major commitment from the entire academic administration, from the Dean of A&S to the Provost/Vice President for Academic Affairs and the President.

VII Departmental research programs and faculty hiring.

This section reviews and assesses departmental research programs and identifies directions for those programs and for faculty hiring over the next seven years. The discussion is almost entirely concerned with the "tenured and tenure-track faculty," who have research responsibilities, rather than with the broader class of "full-time faculty." The tenured and tenure-track faculty includes those faculty with appointments as Distinguished Professor (2 in P&A), Full Professor (15), Associate Professor (6), and Assistant Professor (5). The full-time faculty also includes Lecturers, of which there are currently two, Mickey Odom and Jeff Saul. The Department is committed to hiring a third Lecturer as an instructor, mainly in the introductory service courses, as is discussed in Sec. II; this Lecturer hire is included in the critical hiring needs of Sec. I.2.

Attachment I lists P&A faculty who are Fellows of scientific societies and the prizes, honors, and awards received by full-time faculty during the last five years. The list does not include departmental awards. Brief CVs for the tenured and tenure-track faculty are available as Attachment J**.**

Section VII.1 provides a summary of P&A's current tenured and tenure-track faculty and their overall contributions to research and compares our overall graduate education and research efforts with those of peer institutions; Sec. VII.2 draws attention to issues of research infrastructure and administrative support that are important to the Department; Sec. VII.3 provides a brief status report for each of the Department's six research groups; and Sec. VII.4 presents our plan for faculty hiring through 2016. The plan is summarized in a box on the final page of this document. Research programs and faculty hiring were the subject of Sec. VI of LRP04.

VII.1 Tenured and tenure-track faculty and comparison with peer institutions.

As of the autumn of 2009, the Department has 28 tenured and tenure-track faculty, including Kevin Malloy, who as of November 2009 has joined the Department from ECE.[1] That number is the baseline FTE count used in this section, but Malloy's contributions at UNM are not included in the historical and current statistics for funding, student supervision, and other measures, in this section or elsewhere in this document. The current 28 FTE is up by two from the number of tenured and tenure-track faculty at the end of the academic year in 2004, but is still well short of the goal of 31 set five years ago. In the last couple of years, the Department has seen the departures of McIver and Duncan, both of whom were in University administration at the time of their departure, and the death of Wódkiewicz, who spent every other year in P&A. In addition to these three losses, which have not been replaced, Murray Gell-Mann, a University Professor and UNM's only Nobel Laureate, who teaches two-thirds of a seminar course each year in P&A, is likely to retire soon. Counting each of these as 0.5 FTE owed to the Department gives a virtual tenured and tenure-track faculty of 30. The hiring plan presented in Sec. VII.4 is based on moving the Department to 31 real, as opposed to virtual, faculty within the next several years, as was contemplated in LRP04, and maintaining that size through 2016. The Department briefly achieved an FTE count of 31 in 1996–97. According to data from the AIP, the average number of faculty in American PhD-granting physics departments was 29 in 2006, up from 27 in 1996; with respect to faculty size, the Department thus lies squarely in the middle of such departments and will remain so under our plan.

Measures of overall research activity in the Department include the number of grants, total grant spending, and number of publications. During the last seven years, the total number of active research grants and contracts in the Department has fluctuated between 41 and 64, with the highest number being for the most recent year, FY09. Over the last five years, total grant spending in the Department, including centers and

[1] Assistant Professor JM Geremia has resigned effective January 1, 2010. His departure is not reflected in the text of this document.

institutes housed within P&A, has fluctuated between $6.6 million and $8.0 million per year. These dollar figures do not include the Long Wavelength Array (LWA), which has been run out of a project office in the OVPR. Annual F&A return to the Department over the last eight years has fluctuated between $140k and $190k. The most recent allocation was at the lower end of this range because the central administration recently cut the departmental share of generated overhead to 10.5% from 13.2%. The numbers of refereed publications reported by tenured and tenure-track faculty for calendar years 2004 to 2008 are 114 (2004), 166 (2005), 131 (2006), 163 (2007), and 163 (2008). These figures are dominated by publications from the Subatomic Physics research group, where the multi-investigator style of experimental research leads to publication of many papers, each with tens to hundreds of co-authors. Publication numbers by research group over the same period are given in Sec. VII.3.

The table below compares the Department's graduate and research programs to physics and astronomy departments at peer institutions. The official UNM peers in the table are those of our official peer institutions that have a combined physics and astronomy department. The other institutions are a selection of universities to which, we believe, UNM would generally be pleased to be favorably compared; all of these other institutions have a combined physics and astronomy department, except Arizona State. The data are from a publication of the American Institute of Physics. A close examination of this comparison with peers is quite revealing. UNM P&A looks very good compared to our official peers and stacks up quite well against the more select group of universities.

Comparison with Peer Physics and Astronomy Departments
Source: 2010 Graduate Programs, American Institute of Physics
Data for FY09

	# of faculty	# of grad students	research $ expended (in millions)	# of active grants	grad students/faculty	research $/faculty
UNM P&A*	27	110	8.9	75	4.1	0.33
Official UNM peers:						
Iowa	30	66	14.3	135	2.2	0.48
Kansas	24	45	2.9	?	1.9	0.12
Kentucky	31	55	2.3	?	1.8	0.07
Missouri	27	43	8.7	50	1.6	0.32
Nebraska	23	72	11.2	45	3.1	0.49
Oklahoma	30	59	3.9	70	2.0	0.13
South Carolina	25	45	3.0	20	1.8	0.12
Tennessee	32	100	9.6	94	3.1	0.30
					Average: 2.2	*0.25*
Others:						
Arizona State**	39	128	4.8	191	3.3	0.12
Johns Hopkins***	34	105	27.2	378	3.1	0.80
Pennsylvania	35	96	10.4	81	2.7	0.30
Pittsburgh	37	77	5.5	93	2.1	0.15
Rensselaer Poly	23	67	6.5	107	2.9	0.28
Rice	40	96	9.0	181	2.4	0.23
Rochester	27	142	7.4	67	5.3	0.27
Rutgers	67	93	11.0	?	1.4	0.16

Stony Brook	57	180	12.1	?	3.2	0.21
UC Irvine	42	108	17.4	267	2.6	0.41
					Average: 2.9	*0.29*

*UNM P&A research dollars include LWA funding.

**Arizona State does not have a combined physics and astronomy department. The data here are for the Physics Department. The total of 191 grants includes grants not run through the department and not included in the $4.8M of research funding. The 191 grants total $6.0M.

***228 of the 378 grants are in astronomy, reflecting the presence of the Space Telescope Science Institute and other large space-science projects at JHU.

VII.2 Research infrastructure and administrative support.

The Department's high-visibility research programs exist within an environment set by the Department, the College of Arts & Sciences (A&S), the Office of the Vice President for Research (OVPR), and the University at large. The ability of our research programs to thrive depends crucially on the support provided by these larger units. Two pieces of the current research environment deserve special comment here: (i) the inadequacy of the present P&A building as a site for modern physics research and, particularly, for high-quality laboratory work and (ii) the recent trend within Colleges/Schools and the University to reduce support for crucial research-administration functions and local research infrastructure.

The need for a new building, forcefully set out in Sec. VI, is particularly acute for the Department's research programs, especially for the experimental components. The current P&A building has insufficient laboratory space for our experimental programs, and what space it does provide is generally of low quality in a number of respects. Particular issues, as detailed in Sec. VI, include insufficient vibration isolation, inadequate temperature and humidity control, unstable electrical power, insufficient shielding from stray electromagnetic fields, and inadequate cooling water for high-power lasers.

Internal funding for research-related functions is clearly a vital issue for a research-intensive department such as ours. In that context it seems appropriate to make two points. The tendency at UNM has been to support research functions at all levels primarily out of the negotiated Facilities and Administration (F&A, often called indirect costs) component of funded research. The chief mechanism for this is F&A return, in which the OVPR returns a portion of F&A to Colleges/Schools, departments, and investigators. There appears to be a trend, perhaps exacerbated by the University's current financial condition, to try to identify the "research component" of, say, a staff position, and to switch that component of funding from state appropriations (I&G) to F&A return. Of particular current concern to P&A is the replacement of our very important electronics-shop engineer, who retired from a position that was funded from the Department's I&G budget. We have not been able to replace him, and it is presently unclear how the position should be and will be funded in the future. Another P&A example concerns our staff member who takes care of pre-award contract and grant questions for departmental researchers and thus takes care of functions that are handled by OVPR's Pre-Award Services Office/Sponsored Project Services for most other departments. This staff member's entire salary comes out of the Department's F&A return.

Point one is that the attempt to find a clean split between education and research is misguided. Education and research are the twin missions of the University, it is true, but they are not different currencies, but rather opposite faces of the same coin. Much, if not most of the research function supports the educational mission. As noted at the beginning of Sec. IV, this is particularly true for graduate research, which is always part of graduate education—indeed, the crucial part for PhD students. Undergraduate education is enriched considerably by research experiences, something that we in P&A make readily available to our majors. Given our research-support needs and the benefits of research experiences to our students, we recommend that the central administration reëxamine how research is funded at UNM in light of the fundamental understanding that research and education cannot be cleanly separated.

Point two concerns specifically the funding of research-office functions. Suppose we allow that for research-intensive departments such as P&A, some research-office tasks, say, pre-award functions of proposal-budget development and submitting and tracking research proposals or post-award functions such as grant accounting, are better performed in the departments. In that case such research-office functions should be explicitly funded out of University support for research administration. That could mean a research component in the College/School's I&G budget, or if research continues to be primarily funded from F&A, these research-office functions should be funded directly out of the OVPR's F&A, above and in addition to the regular F&A return to the departments. In fact, what has happened is just the opposite: F&A return to Colleges/Schools and to departments has recently been reduced. We understand that the OVPR is considering funding research-support positions in the units; we submit that our existing pre-award position represents an ideal candidate for such support.

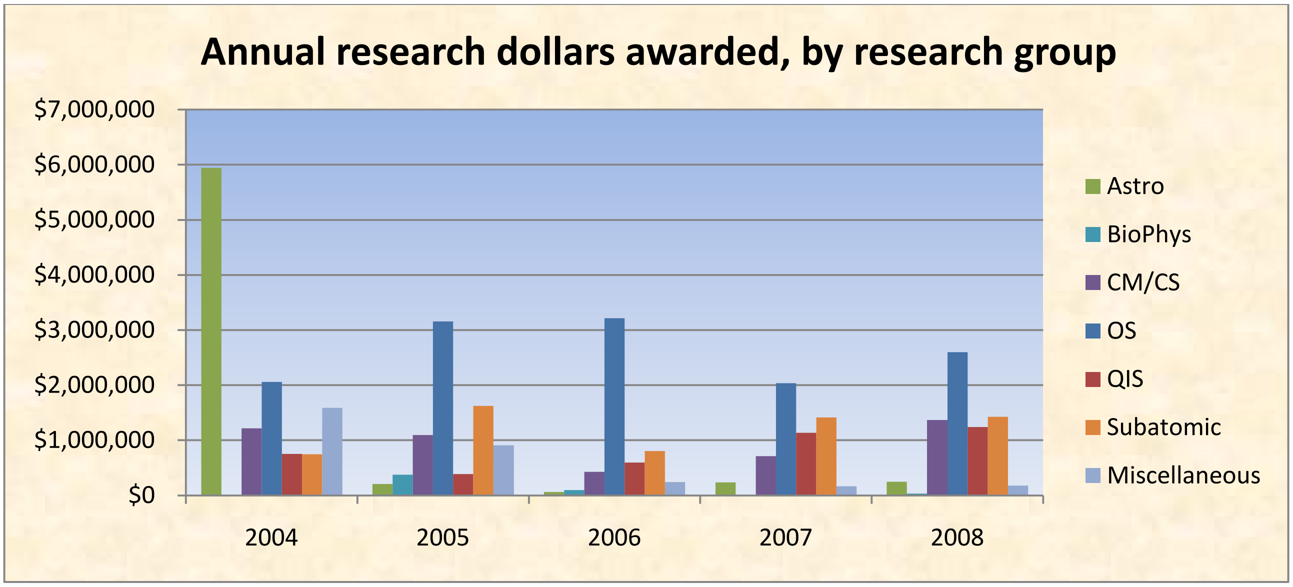
We mention briefly here another very important University resource, the University Libraries, the most important branch of which for P&A is the Centennial Science and Engineering Library (CSEL). The University Libraries and the libraries' resources and services are described briefly in Attachment K. P&A has a very productive relationship with CSEL and, specifically, with the excellent physics and astronomy librarian, Donna Cromer. CSEL has been very good in acquiring books that are necessary for our teaching and research functions. Increasingly, however, our main interests relate to online functions: access to databases to do online searches for research material, online access to journals that are used by our faculty and students in research and teaching, and special help in finding research materials and research articles that are not readily available online. Generally, the library's online services are quite good. Ms. Cromer, in particular, is a miracle worker at locating and getting access to hard-to-find materials. There have been and are gaps, some quite serious, in the library's online access to essential journals, but we find CSEL to be very responsive to our concerns in this regard. The chief constraint is always the resources made available to the University Libraries by the University. We have generally been able to work with CSEL to find a solution that, while it is not globally optimal, is generally the best that can be done within the budgetary constraints.

VII.3 Departmental research programs.

The current tenured and tenure-track faculty can be divided into six research groups: Astronomy and Astrophysics (Astro; 6 FTE, all observers), Biological Physics (BioPhys; 4 FTE, 3 experimentalists and 1 theorist), Condensed-Matter Physics and Complex Systems (CM/CS; 3 FTE, 1 experimentalist and 2 theorists), Optical Science (OS; 4 FTE, 3 experimentalists and 1 theorist), Quantum Information Science (QIS; 3 FTE, 1 experimentalist and 2 theorists), and Subatomic Physics (Subatomic; 7 FTE, 6 experimentalists and 1 theorist). One theorist works on general relativity theory and the general theory of partial differential equations outside of the larger research groups.

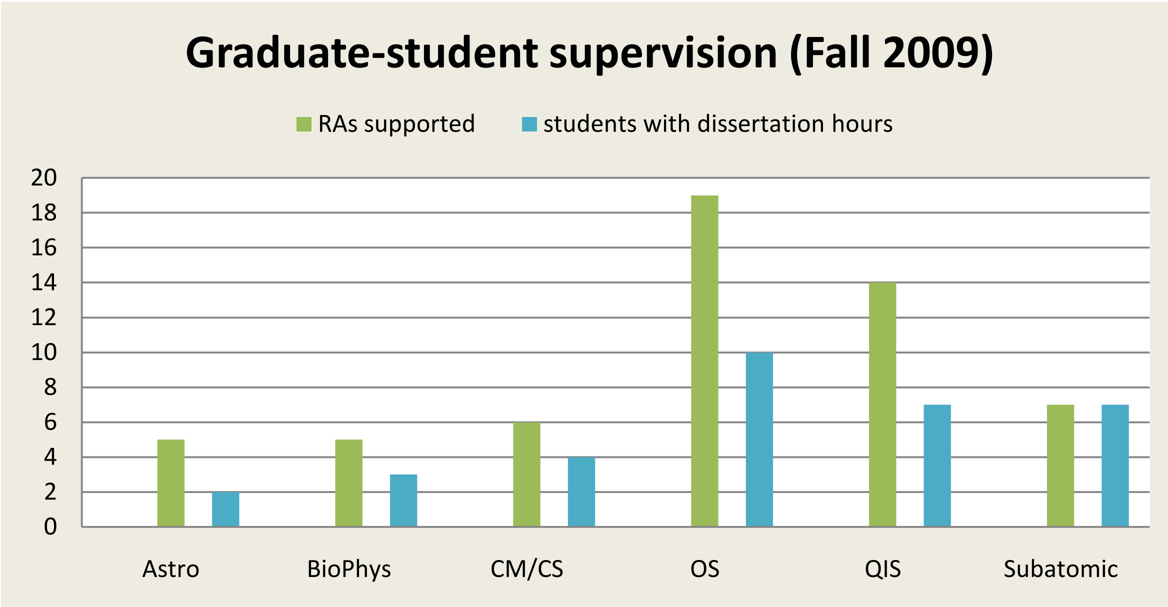
This section presents a report for each of the groups, including a brief history of the group, an assessment of its current position, and a statement of its goals and needs, particularly for faculty. Many of the Department's faculty work across group boundaries; such cross-group research efforts are noted in the group reports.

Before turning to those reports, however, it is useful to illustrate the vitality of our research programs by presenting several data sets, some historical and some snapshots as of the fall 2009. The first graph below gives annual research awards by group for the last five years (the Miscellaneous category includes funding run through the Department, but not associated with faculty in any of the several research groups).



The dollar figures in the above graph do not include contracts on which P&A faculty are participants, but which are run entirely through other units. A major example of this is the Long Wavelength Array, which is directed by P&A faculty member Greg Taylor, but is run out of a project office in the OVPR; funding for the LWA over the three-year period beginning in 2007 has been about $5.5 million. Another case is the Program in Interdisciplinary Biology and Biomedical Science (PIBBS), a UNM program for biologically inspired education of graduate students of exceptional quality, which is funded by the Howard Hughes Medical Institute; P&A faculty member V. M. Kenkre is one of four co-investigators on this three-year, $1-million grant, which commenced in January 2006. Yet another case, also involving Kenkre, here as one of three co-investigators, is an NSF-NIH grant to study ecological drivers of rodent-borne disease outbreaks; this four-year grant began in September 2004 and was funded at $1.6 million.

The graph below is a snapshot of current activity in each group in supervising graduate students, as measured by number of RAs currently supported and number of students taking dissertation hours.



The table below gives the numbers of refereed publications reported by tenured and tenure-track faculty in the annual activities report submitted to the department Chair for the calendar years 2004 to 2008. The numbers are aggregated by research group. An obvious conclusion from these figures is that the multi-investigator style of research in experimental subatomic physics means that publication numbers in this area cannot be directly compared with those in other research areas in physics or in the other sciences. Notice also that the publication numbers include multiple counting in cases where two or more faculty members are co-authors on the same paper; this effect is most pronounced in Subatomic Physics data. Outside of these general conclusions about Subatomic Physics, the publication numbers show stable publication rates in the other research areas, except Astronomy and Astrophysics, which has sustained a substantial increase.

Refereed publications by research group

VII.3.1.1 ***By calendar year, as reported in annual activities report of tenured and tenure-track faculty***

	2004	**2005**	**2006**	**2007**	**2008**
Astro	8	18	20	21	19
BioPhys	5	2	5	5	6
CM/CS	9	10	7	8	8
OS	17	25	15	22	23
QIS	9	9	7	11	12
Subatomic	65	102	76	96	95

The following table summarizes other historical and snapshot measures of research activity. The numbers for postdocs and research scientists include only personnel who are paid through UNM; these figures thus do not include the substantial number of postdocs and more senior researchers visiting the Consortium of the Americas for Interdisciplinary Science, for which at any time, six is a typical number.

Additional historical and snapshot data by research group

	PhD dissertations Total last decade	MS theses Total last decade	Undergraduate research students 2009	Research faculty Fall 2009	Postdocs and Research Scientists Fall 2009
Astro	12	3	12	2	0
BioPhys	0	1	4	0	0
CM/CS	11	1	5	3	0
OS	27	10	2	3	3
QIS	17	2	2	0	1
Subatomic	13	3	11	3	6

Research faculty associated with each group are listed in the group report. One research faculty member, Tim Thomas, was historically associated with the Subatomic Physics group, but is now the Deputy Director of UNM's Center for Advanced Research Computing (CARC).

There are two major externally funded research centers in the Department, which also receive internal support from I&G funds: the Consortium of the Americas for Interdisciplinary Science and the Center for Quantum Information and Control (CQuIC). The research emphases and activities of these two centers are described in the relevant research-group reports below, Secs. VII.3.3 and VII.3.5, respectively.

VII.3.2 Astronomy and Astrophysics.

Astrophysics is nothing less than the exploration of the Universe from its largest scales down to interplanetary dust, from the origin of the Universe, its evolution from a primordial soup of elementary particles and energy into galaxies like our own Milky Way, to the study of the life cycle of stars, birth through death, the creation of planets, and the likelihood of extraterrestrial life. To investigate these fundamental questions, astronomy makes use of new and more powerful observing techniques and instruments, which see the Universe in ways unimaginable not so long ago. The stunning discovery that the biggest part of the energy density of the Universe is of an unknown nature, with properties unlike that of any known forms of matter and energy, illustrates how dynamic astronomy is, despite being the most venerable of the scientific disciplines, and how discoveries in astronomy can shake the very foundation of physics.

There are presently six FTE tenured and tenure-track faculty members in the Astronomy and Astrophysics (Astro) research group:

Harjit Ahluwalia	**Professor**	**PhD, Gujarat University, 1960**

Patricia Henning	**Associate Professor**	**PhD, University of Maryland, 1990**
John McGraw	**Professor**	**PhD, University of Texas, 1977**
Ylva Pihlström	**Assistant Professor**	**PhD, Chalmers Univ of Technology, 2001**
Richard Rand	**Associate Professor**	**PhD, Caltech, 1991**
Gregory Taylor	**Associate Professor**	**PhD, UCLA, 1991**

In addition, Rouzbeh Allahverdi and Dinesh Loomba, counted in this document as in the Subatomic Physics group, do closely related research in astro-particle physics. Two research faculty members, Mark Ackermann and Pete Zimmer, are associated with the group, both working on McGraw's Measurement Astrophysics (MAP) project. The Department has a number of scientifically active adjunct faculty members working on astrophysics research, including Nick Arge [Air Force Research Laboratory (AFRL, Kirtland Air Force Base)], Jack Brandt (University of Colorado, retired), John Dickel (University of Illinois, retired), Lanie Dickel (University of Illinois, retired), Dean Hines (Space Science Institute), and Namir Kassim [Naval Research Laboratory (NRL)]. All this makes the group one of the two largest research groupings in the Department, about the same size as the Subatomic Physics group.

Since 2004 the group has lost two faculty members to departures (Neb Duric and Steve Gregory) and one to retirement (Marc Price) and has gained two new faculty members, Pihlström and Taylor, both of whom joined the Department in 2005. The hires of Pihlström and Taylor were a consequence of the Department's decision to focus our astronomy efforts on radio astronomy. This decision was prompted by explicit encouragement and promises of support from the Vice President for Research and the Dean of A&S. The objective of this decision and the new hires was that Department would become, as it has, the scientific and administrative leader in the effort to construct the Long Wavelength Array (LWA) and would be an important participant in other large radio-astronomy efforts.

Taylor and Pihlström, along with new adjuncts John and Lanie Dickel and Nick Arge, have added to the radio expertise of Henning and Rand to give the Department a very strong concentration in radio astronomy. Both Taylor and Pihlström were scientists at the National Radio Astronomy Observatory (NRAO) in Socorro before coming to UNM and retain adjunct status there now. Extragalactic astronomy and observational cosmology remain prominent among a broad range of research interests of our radio astronomers.

With UNM as the lead institution, the LWA is now coming into existence as a powerful instrument for research in astrophysics, space weather, and ionospheric physics. This facility will be open to users from around the world, be scheduled on a competitive basis, and have annual user subscriptions of hundreds of astronomers. Such a facility will establish P&A as one of the top departments in the country for students interested in radio astronomy. The LWA is currently being run from a project office inside OVPR, with Taylor as Director, but eventually the LWA should be moved to P&A and operated with participation from ECE, CARC, and other campus organizations, as well as external partnerships with the AFRL, LANL, NRAO, NRL, the Jet Propulsion Laboratory (JPL), the University of Iowa, and others. The first LWA station is currently under construction, with commissioning set to begin in December 2009. The attitude of UNM's central administration toward the LWA is presently unclear and urgently needs to be clarified.

The LWA is a scientific and technical pathfinder for the Square Kilometer Array (SKA), the most ambitious project in radio astronomy for the coming decade. The SKA, which is being planned by an international collaboration, will involve radio telescopes with a total collecting area of one square kilometer, spread over continental scales to provide by far the most powerful, highest-resolution instrument for radio astronomy. It will be the premier instrument in radio astronomy far into the 21st Century. UNM is a member of the US SKA Consortium (USSKAC), along with Caltech/JPL, Cornell/National Astronomy and Ionosphere Center (NAIC), Harvard/Center for Astrophysics, MIT/Haystack Observatory, NRAO, NRL, the SETI Institute, the University of California at Berkeley, the University of Illinois, and the University of Wisconsin. Henning currently serves as Vice Chair of the USSKAC and, along with Taylor, is a member of the USSKAC

Executive Committee. The USSKAC is concerned with the development of the SKA and, more generally, with strategic planning for the future of US and international radio astronomy at centimeter-to-meter wavelengths.

Ahluwalia continues research into space weather, heliospheric physics, and solar modulation of cosmic rays. His work involves international collaborations with groups in Russia, Poland, Australia, and Israel, as well as collaborations with the space physics group at the University of New Hampshire and the solar physics group at New Mexico State University.

McGraw leads a nationally recognized research program, the MAP project, in optical astronomy. MAP, which is carried out with research faculty members Ackermann and Zimmer, measures atmospheric extinction directly so that it can be corrected very precisely. The project aims to create a set of faint photometric and astrometric standard stars so that precise calibration of telescopes, including those equipped with adaptive optics to reduce the effects of atmospheric "seeing," is available anytime and anywhere in the northern hemisphere. MAP's precision measurement capabilities will also contribute to an understanding of atmospheric physics. Much of the initial work is being carried out at our Campus Observatory.

Over the last five years, ties to the astronomical community have strengthened significantly, both within New Mexico and nationally. Strong collaborations exist now with AFRL, Caltech/JPL, the University of Colorado, LANL, NAIC, the National Center for Atmospheric Research, the National Institute for Standards and Technology (NIST), NRL, NRAO, and Virginia Tech, among others. Taylor is an affiliated scientist with Fermi, a gamma-ray observatory that began operation in 2008. International collaborations also feature strongly in the group's research.

An annual average of 3.6 BS degrees in Astrophysics have been awarded in the last ten years, accounting for about 30% of the Department's undergraduate degrees. For the BA in Physics and Astrophysics, the average is 2.6 degrees, or 20%. Seven undergraduate honors theses, accounting for 50% of all such theses within the Department, have been completed under the supervision of Astrophysics faculty since 2001. Astro 101 remains crucial to the Department's service mission, accounting for 39% of the Department's undergraduate credit hours in the past five years.

The group has supervised twelve PhD dissertations (15% of the departmental total) and three MS theses in the last decade. During 2009, twelve undergraduates have worked on research projects with Astrophysics faculty.

The Friday Night Open House at the Campus Observatory remains the most important public-outreach function of the Department, reaching an average of about twenty people every Friday. Local visibility of the program has increased in the last two years through advertisement in the Albuquerque Journal and the Alibi. Special events, such as the "100 Hours of Astronomy" in March 2009 for the International Year of Astronomy, are also carried out.

Over the last five years, the Astrophysics group has significantly enhanced its national and international recognition, one of the goals set by LRP04. This can be seen in the leadership role that UNM faculty are playing in building the LWA and planning the SKA and in the area of atmospheric physics. The group's goal for the next decade is to see this trend continue, with UNM playing a growing role in the development and operation of major astrophysical instruments. This is vitally important for graduate-student recruitment, support for research, opportunities for collaboration, and national and international recognition.

The group would benefit strongly from additional hires. As stated in LRP04, a theoretical astrophysicist specializing in extragalactic astronomy and cosmology is necessary to support the work of the observational astronomers and to help publicize the results of astronomical work at UNM to the astronomical community. The addition of a theorist would have a positive impact on recruitment and retention of high-quality graduate students. An astrophysics theorist is included in the list of critical hiring needs of Sec. I.2. An additional observational astronomer with expertise in optical/IR techniques is also highly desirable. Collaborations with AFRL are of particular interest given the relocation of the Space Weather group from Hanscom Air

Force Base to Albuquerque's Kirtland Air Force Base by 2011. We hope that there will be an opportunity for at least one joint appointment between AFRL and P&A, possibly working on space weather using the LWA.

VII.3.3 Biological Physics.

The essential mechanisms of living systems depend ultimately on interactions between molecules, so physics lies at the heart of the most profound insights into the workings of life. The physical basis for life is nothing new, nor is the application of physics to biological and medical questions, but developments in both the physical and life sciences are converging to give physics-based techniques and methodology an increasingly important role in biology and medicine. Powerful tools of experimental physics reveal the fundamental workings of biological systems and provide increasingly sophisticated techniques for noninvasive diagnosis and treatment of disease. Methods from statistical physics find application in extracting useful information from large biological databases. Theoretical-physics methods for understanding complex systems find application in such areas as proteomics. Throughout biology and medicine, physicists trained in the use of sophisticated computational methods are providing the computational expertise necessary to investigate complex biological systems.

In LRP04 the Department committed to transforming a small group of faculty interested in biomedical physics into a viable research group with a critical mass of faculty members. The Department has fulfilled that commitment by taking advantage of opportunities for joint hires with other units to bring two tenure-track junior faculty to UNM: Steven Koch was hired in 2006 through CHTM, with P&A as his home department, and Keith Lidke joined the Department in 2007 as a joint faculty member with the UNM Cancer Center. With these additions, the Department now has four core tenured and tenure-track faculty working on topics in biological physics:

Kevin Cahill	**Professor**	**PhD, Harvard University, 1967**
Steven Koch	**Assistant Professor**	**PhD, Cornell University, 2003**
Keith Lidke	**Assistant Professor**	**PhD, University of Minnesota, 2002**
James Thomas	**Associate Professor**	**PhD, Cornell University, 1991**

One research faculty member, Susan Atlas, whose background is in condensed-matter physics, has substantial research interests and funding in biological physics.

Cahill, by training a theoretical particle physicist, has moved his research into various medical biophysical problems, such as the mechanisms of cell penetrating peptides, and has a strong interest in the many roles of RNA in cells. Thomas uses optical and ultrasound techniques to study the properties of the phospholipid molecules that are the primary constituent of cell membranes. Koch studies the forces generated by motor proteins, as well as DNA-protein interactions, using optical tweezers. Lidke develops and uses single-molecule fluorescence techniques for studying protein-protein interactions on and near cell membranes. Atlas devotes considerable effort to the computational biophysics of molecular motors.

Other faculty in the Department spend some time working on topics in biological physics. Rudolph has an interest in multiphoton microscopy, which has many potential applications in biological imaging. Kenkre employs methods of theoretical physics to study the motion of a variety of biologically relevant entities in processes ranging from microscopic to macroscopic. In the microscopic realm these entities are transmembrane molecules in cells and bacteria in Petri dishes; in the macroscopic realm they are exemplified by birds engaged in coöperative flocking and rodents in the context of the spread of epidemics. Bryant, a Professor Emeritus, works at a local company, Senior Scientific, on imaging and therapy using SQUIDs (Superconducting Quantum Interference Devices) and magnetic nanoparticles. Duncan and Duric, both of whom had interests in biological physics, left the Department during the last five years.

With the additions of Koch and Lidke, the Biological Physics group has reached a critical mass of faculty members and is now a viable and cohesive group within the Department. The core faculty's research spans the range from single molecules to the single-cell level. The various research efforts are largely complementary, but with several notable overlaps of interest. The use of optical techniques for observation or manipulation of molecular-level constituents of biological systems is common to all three experimentalists (Thomas, Koch, and Lidke). The primary focus of the Lidke research group is to develop and apply fluorescence techniques for the study of protein-protein interactions, and Thomas also uses several fluorescence-based techniques, such as fluorescence correlation spectroscopy, for the study of protein diffusion and membrane dynamics. Koch and Atlas both have interests in the mechanochemistry of molecular motor proteins and currently share a grant from the Defense threat Reducation Agency (DTRA) that supports these studies. Cahill, Kenkre, and Thomas share an interest in membrane dynamics, and Thomas and Rudolph have collaborated on multiphoton microscopy.

The group has chosen to change its name from Biomedical Physics to Biological Physics (BioPhys) to describe more accurately the broad research interests of the current faculty, which involve the application of physics-based concepts and techniques, both experimental and theoretical, to problems in biology and medicine.

Lidke and Thomas are members of the Center for the Spatiotemporal Modeling of Cell Signaling Networks (STMC). STMC is an NIH/NIGMS Center of Excellence in Complex Biomedical Systems Research located in UNM's HSC, with co-leaders and members in A&S and the SoE and at Sandia National Laboratories. Koch is a faculty member at CHTM and works closely with Evan Evans, a Research Professor in the Department of Chemical and Nuclear Engineering, who is also based at CHTM.

The group has established collaborations with researchers at a number of external institutions. Lidke and Thomas have an ongoing collaboration with researchers at SNL and in the SoM's Department of Cell Pathology to study the IgE receptor; this collaboration is now formalized through the STMC. Lidke works with the molecular imaging and biosensor group at Carnegie Mellon University to develop techniques for fluorescence super-resolution imaging as well as the quantitative imaging group at Delft Technical University for the development of dynamic super-resolution techniques. Atlas and Koch collaborate with researchers at LANL through their DTRA grant. Koch collaborates with researchers in the SoM's Department of Molecular Genetics and Microbiology and at NIH's National Institute of Environmental Health Sciences (NIEHS) to study transcription biology. Kenkre's work on cellular dynamics has led to an international collaboration with the Institute for Integrated Cell-Material Sciences in Kyoto.

The Department periodically offers an upper-level/graduate course in biophysics, which is taught by the members of the Biological Physics group. Kenkre participates in a team-taught interdepartmental course in the Biology Department, which introduces methods of theoretical physics to the solution of biological problems.

The Biological Physics group has supervised one MS thesis and presently supervises the research of three undergraduates and ten PhD students in P&A, six of whom have passed the Candidacy Exam. In addition, Lidke co-advises a student from the Biomedical Sciences program and a student from the UNM Nanoscience and Microsystems degree program. Seven of these twelve graduate students have been or are currently supported by one of the two NSF IGERT fellowship programs that are currently active at UNM: the Nanoscience and Microsystems (NSMS) IGERT and the Integrating Nanotechnology with Cell Biology and Neuroscience IGERT. Thomas and Kenkre currently co-mentor a graduate student, supported by PIBBS, who is studying membrane dynamics. The symposia for the two IGERT programs and a weekly biophysics seminar provide nuclei for interaction among the group's faculty and graduate students.

Biological Physics faculty participate in local community outreach via science fairs (such as the Central New Mexico Science and Engineering Research Challenge and other local events), research seminars for local residents and teachers, and tours of labs for local residents and students. Koch is a member and leader of OpenWetWare, an organization hosted by MIT to promote Open Science. Biological Physics faculty participate in the Biophysical Society, the main professional society for biophysics, as well as the American Physical Society and the Optical Society of America. Koch serves on the Membership Committee of the Biophysical Society.

Having seen rapid growth over the last five years, the Biological Physics group needs now to focus on consolidating and building on its strengths. There will be a need to consider hiring either a theorist or an experimentalist in biological physics, but the group has no other hiring plans during the life of this plan, although the complex-systems theorist contemplated in the hiring plan outlined in Sec. VII.4 might work partly or predominantly on topics in biological physics. A new P&A building with modern, bay-like laboratory units would greatly facilitate sharing wet-lab resources between the Thomas and Lidke groups and would provide the setting for an upper-level/graduate biophysics laboratory course, which would familiarize students with the wet-lab work that is important in much of biophysics research.

The group faces several issues associated with graduate education and research. There needs to be a concerted effort to attract high-quality graduate students interested in biophysics to UNM, perhaps through such avenues as advertising on the P&A web page and at national meetings, such as that of the Biophysical Society. There is a need for the biophysics laboratory course mentioned in the last paragraph. In the spring of 2003 the Department approved a Biomedical Physics concentration within its Physics PhD. No students have opted for this option, despite the increasing number of PhD students who are doing dissertation research in the Biological Physics group. The group is now discussing whether this concentration should be dropped or be modified in way that would attract PhD students, perhaps by changing the focus to biophysics and by delineating more carefully the course requirements. More ambitiously, the group needs to define the need for and resources required for a biophysics curriculum.

VII.3.4 Condensed-Matter Physics and Complex Systems.

Starting from just a few physical principles regarding the constituents of matter and their interactions, condensed-matter physicists formulate our fundamental understanding of matter in all its guises. They explore the world from the ordinary phenomena that occur in familiar solids and liquids to the exotic behaviors of superfluids, superconductors, and other ordered states of matter. They are actively engaged in the physicist's twin missions of reduction and synthesis, for they must synthesize from the principles governing the microscopic constituents of matter an understanding of the complex behavior of the macroscopic world. Thus, of all physicists, they have the most sophisticated understanding of complex systems and the emergent laws that govern their behavior and organization. Increasingly, they apply this understanding not only to physical systems, but also to other macroscopically complex systems such as those encountered in the social and biological sciences. A measure of the importance of condensed-matter physics is that it is the largest subdiscipline in physics, claiming roughly half of all the physicists in the world.

The Condensed-Matter Physics and Complex Systems (CM/CS) faculty consists of three tenured faculty:

David Dunlap	**Professor**	**PhD, University of Rochester, 1987**
V. M. Kenkre	**Distinguished Professor**	**PhD, SUNY Stony Brook, 1971**
Kevin Malloy	**Professor**	**PhD, Stanford University, 1984**

In addition, three research faculty, Susan Atlas, Stephen Boyd, and Paul Schwoebel, are associated with the group. Dunlap, Kenkre, and Atlas are theorists, whereas Malloy, Boyd, and Schwoebel are experimental physicists. Dunlap works on transport theory in the area of organic electronics and collaborates with Kenkre on hydrodynamics and combustion. Kenkre has a broad set of interests, including the foundations of statistical mechanics, transport theory, complex systems, nonlinear phenomena, pattern formation, and the dynamics of biological systems. Atlas, who is also Director of CARC, works on fundamental aspects of density-functional theory and charge-transfer interaction potentials for dynamical atomistic simulations, with applications to chemical physics, materials physics, and biophysics. Kenkre's interests in biological systems, which range from ecology and the spread of epidemics to cellular-level phenomena and bacterial evolution, and Atlas's work on problems in biological physics are noted in the Biological Physics report (Sec. VII.3.2). Malloy's work centers on the optical, electrical, and thermal properties of nanostructures. Boyd's research is in low-temperature physics; his interests include magnetism, the limits of measurement noise, low-temperature particle detectors, superfluid helium and magnetic refrigeration, and thermometry. Schwoebel works on topics in surface physics, and his interests include medical imaging, nuclear sensors, crystal growth, and nucleation phenomena.

Several changes, some programmatic and others regarding recognition of the Department's work in condensed-matter physics, have occurred since LRP04. The complex-systems aspect of the group's research has now been recognized and highlighted by adding that designation to its name. Rob Duncan left UNM in 2008 to become Vice Chancellor for Research at the University of Missouri; he had moved heavily into administration at UNM prior as early as 2002. Malloy has just joined the Department as of November 2009, having changed his home department from ECE to P&A. Malloy's research labs are at CHTM, and his research work has historically been and continues to be closely associated with the OSE degree program and with the Department's OS research group.

Kenkre's research and international activities have been recognized internally at UNM and externally. At UNM he was awarded the International Award in 2005 and the Annual Research Lecturership in 2004 and was made a Distinguished Professor in 2005. In 2005 he was elected Fellow of the American Association for the Advancement of Science (AAAS). With four UNM co-investigators, he was funded by the Howard Hughes Medical Institute to establish the PIBBS program mentioned above.

Both the theoretical and experimental efforts in condensed-matter physics and complex systems are well funded, and both have had sufficient funding to support postdocs, visiting scientists, and research staff/faculty. The group is a significant source of opportunities for undergraduate and graduate research: the group has supervised eleven PhD dissertations (14% of the departmental total) and one MS thesis over the last decade; during 2009, the CM/CS group has involved five undergraduate students in research.

The Consortium of the Americas for Interdisciplinary Science, founded (in 2000) and directed by Kenkre, is an interdepartmental research center within A&S. It has been supported by LANL since its inception and became an NSF-sponsored international center in the summer of 2003. Its research focuses, mathematical ecology and biology, computationally complex systems, novel materials, and nanoscience, include links to research that typically lies outside physics departments, such as in biology and granular science, but have overlap with disciplinary research interests in condensed-matter physics. Recognized by NSF as unique in the United States, the Consortium brings Latin American scientists working within its research focuses to UNM and P&A (there are typically six such scientists in residence at UNM), organizes workshops that are held both at UNM and at sites in Latin America, and sponsors international student exchanges through a program of Junior Consortium Fellowships.

There are many opportunities for ties to the research focuses of the Consortium and to other condensed-matter and materials research at UNM, ranging from the semiconductor physics at CHTM, to the materials research at the Center for Micro-Engineered materials, the NSF-supported NSMS IGERT graduate training program, and to biological and biomedical physics within the Department and at the School of Medicine (SoM). There are ongoing collaborations and potential for additional collaborative research with the large condensed-matter, complex-systems, and materials communities at LANL, the Santa Fe Institute (SFI), the Center for Nonlinear Studies at LANL, the nanotechnology research in the Center for Integrated Nanotechnologies at SNL/LANL, and materials researchers in the statewide New Mexico EPSCoR Nanomaterials Program. Strengthening all these ties would require hiring both theoretical and experimental faculty.

To build a prominent condensed-matter research group, with both theoretical and experimental components, over the next decade would require that the CS/CM group grow to a group of six tenured faculty, three theorists and three experimentalists. To move in this direction over the next five years, the group would need to add a theorist and an experimenter. The theoretical appointment might be directed at the physics of complex systems, nonlinear science, and statistical physics. The experimentalist's expertise might be in device physics, organic or inorganic semiconductors, or surface physics.

The Department has decided not to move in the direction of an additional experimental hire in condensed-matter physics and thus has not included the experimentalist in our hiring plan. Instead, we have decided to build on the complex-systems expertise in the CS/CM group, as is discussed in Sec. VII.4, by including a complex-systems theorist in our hiring plan. Such a theorist has excellent funding prospects and could provide links to the research emphases of the Consortium of the Americas, to the OS and QIS groups within P&A, and to other units at UNM, including the Department of Biology and the SoM.

VII.3.5 Optical Science.

Optical science (OS) comprises research that ranges from novel light sources and detectors to the interaction of light with matter to imaging and photonics. Historically based in physics, optical science has developed into a critical enabling discipline, impacting all of the natural sciences, engineering, and medicine. Recent advances in optics have engaged the best theoretical and experimental minds and have led to amazing new consumer products in the hands of engineers.

There are four core tenured faculty in the OS group:

Jean-Claude Diels	**Professor**	**PhD, University of Brussels, 1973**
Sudhakar Prasad	**Professor**	**PhD, Harvard University, 1983**
Wolfgang Rudolph	**Professor**	**PhD, University of Jena, 1985**
Mansoor Sheik-Bahae	**Professor**	**PhD, SUNY Buffalo, 1987**

Theorist John McIver had historically been associated with the OS group, but had moved into research administration prior to LRP04 and departed the University in 2008 to become Vice President for Research at the University of Idaho. Visiting Professor Krzysztof Wódkiewicz, whose research was in theoretical quantum optics, had spent every other year at UNM since the late 80s; his death in late 2008 was a major loss to the Department, especially for its graduate teaching mission, and to the OS research group. Several other departmental faculty, including Caves, Deutsch, Geremia, Kenkre, Koch, Lidke, Malloy, and Thomas, engage in optics-related research. Thomas, in particular, has played a very active role in teaching and service related to the OSE degree programs. Three research faculty members, Michael Hasselbeck (associated with Sheik-Bahae), Douglas Hope (Prasad), and Vasudevan Nampoothiri (Rudolph), are associated with the OS group and are supported from grants to the associated core faculty member. The group also supports three postdocs.

The group name has been changed from Optics in LRP04 to Optical Science in this document. This change reflects the broad scope of research activities, ranging from fundamental to applied, that the affiliated faculty conduct within the group. It serves also to distinguish the group from the "optical engineering" research efforts that are predominantly conducted by faculty on the engineering side of the OSE degree program.

Optical-science research in the Department covers a wide range of activities, from fundamental to applied aspects of the science of light and light-matter interactions. Diels, the senior member of the group, has an active experimental program focused on ultrafast phenomena, nonlinear optics, high-field interactions, and laser physics. Prasad is a theoretical physicist whose particular research interests lie in optical imaging and quantum optics. Rudolph does experimental research in ultrafast spectroscopy, imaging, gas lasers, nonlinear optics, and bio-photonics. Sheik-Bahae is an experimental physicist whose research includes laser cooling of solids, nonlinear optics, ultrafast processes in semiconductors, THz imaging, and laser physics.

The group is well funded, bringing in an annual average of $2.5M in external research funding. Notable among the funded projects in the last five years are a major Keck Foundation grant and two separate Multidisciplinary University Research Initiative (MURI) grants from the Department of Defense (DoD). OS faculty serve as principal investigators on all these projects, which involve researchers from various UNM departments, other universities, and national labs.

The group maintains strong, ongoing collaborations with researchers at US national laboratories and important research and academic institutions abroad, particularly in Europe. Prime examples of these collaborative research efforts include the following. Diels has long-standing collaborative research ties to groups in the Czech Republic, Italy, and France. Over the last 7 years Prasad has been the overall PI for three large research collaborations involving researchers from Duke, Wake Forest, Emory, AFRL, Boeing and Catholic University; these collaborations focus on development of modern imaging systems and have been funded by the Air Force Office of Scientific Research (AFOSR), AFRL, and the Intelligence Advanced Research Projects Agency (IARPA). Rudolph leads one of the MURIs mentioned above, which studies novel concepts for mid-infrared gas lasers and involves researchers from Emory University and the Air Force Academy to study novel concepts for mid-IR gas lasers. He participates in the other MURI grant, which includes researchers from Colorado State University, Stanford University, and Jefferson Lab. Sheik-Bahae has strong and fruitful ongoing collaborations with LANL scientists Richard Epstein, on laser cooling of solids, and Markus Hehlen, on a gamma-ray glass-scintillators project. These collaborations have resulted in UNM-led research funding exceeding $6 million from NASA, AFOSR, and DTRA. In another ongoing collaboration, Sheik-Bahae works with SNL scientists on ultrafast plasmonics in semiconductor nanowires.

In the last decade, the OS group has supervised 27 PhD dissertations (34% of the departmental total) and ten MS theses (half the departmental total). The group was the first to run an NSF-funded IGERT program at UNM (Cross-disciplinary Optics Research and Education, 2002–07); this is the only IGERT grant P&A has had. The group is active in supervising undergraduate research, having involved students from P&A, ECE, and the Department of Chemistry, as well as students from other institutions in the US and Europe.

As measured by data on research funding and supervision of graduate students, the OS group has unquestionably been one of the most successful and productive groups in the Department. The four core faculty members are well known nationally and internationally; they are all, for example, Fellows of the Optical Society of America. Together with other faculty in the OSE degree program and at CHTM, the OS research group has made UNM a world-class institution for optics and photonics research.

Despite this story of success, the number of core faculty in the OS group has not grown over the years and is now noticeably smaller than the Astronomy and Subatomic Physics groups. There have not been any new hires in OS since 1994, when Sheik-Bahae joined the Department. All four core faculty are Full Professors over 50 years of age; thus whereas the Department now has a relatively well-balanced rank and age profile, as is discussed in Sec. VII.4.2, the OS group certainly does not. There is a critical need for new junior faculty within the group. The group would also benefit from additional theoretical expertise to complement and supplement its one current theorist. The Department must address these problems if it intends to maintain optical science as a thriving research enterprise. The departmental hiring plan outlined in Sec. VII.4 responds by proposing 2.5 new hires within the OS group over the next seven years, with 1.5 of these hires, including an optics theorist, included in the five initial positions identified as critical in Sec. I.2.

The OS group, with its heavy emphasis on table-top experiment, would be a prime beneficiary of a new P&A building. Indeed, the need for a new building is particularly acute because of the current building's deficiency of the sort of high-quality laboratory space needed for table-top experimental research in optical science.

The OS research group in P&A is an entity within the Department, but it also exists within the context of the interdisciplinary OSE degree program, which will have for the first time its own separate and independent APR in March 2010. The OSE APR Self-Study discusses the scope of academic activities in optics at UNM and provides additional perspective on the contributions of the OS faculty within P&A and to the OSE degree programs. It is critical that the OSE degree program formulate a clear statement of its role within the University and a realistic plan for its future; in doing so, it will be important to keep in mind the strengths of existing OSE research at UNM, particularly at CHTM, the need to compete in a national environment that now includes several very large-scale and many smaller research centers in OSE, and the strength that comes from close association with both a physics department and an electrical engineering department. P&A is committed to supporting such a realistic vision, particularly by maintaining and enhancing our own outstanding OS research group and its research focuses. Our hiring plan seeks to address the critical need for new faculty to staff the OS research group.

VII.3.6 Quantum Information Science.

Quantum mechanics revolutionized physics at its birth over 80 years ago, providing a new universal framework for physical law and a fundamental understanding of the properties of atoms and molecules and the materials they comprise. This new theory of modern physics parted ways with the deterministic foundation of classical physics, replacing it with a radically different foundation of intrinsic randomness, uncertainty, nonlocality, and entanglement. Whereas these features were debated at the inception of the new theory and have all been established experimentally, their genuinely weird implications were generally viewed as a curiosity, relevant to philosophical discussions, but not central to physics research itself.

All this changed in the mid-90s when it was realized that the weirdest properties of quantum mechanics are a *resource* for information-processing tasks such as communication, computation, and cryptography. The result has been a second quantum revolution and the birth of a new interdisciplinary field, quantum information science (QIS), which draws from physics, computer science, and information science. Examples of research topics being tackled in QIS are absolutely secure secret keys tied to the fundamental laws of quantum mechanics, quantum computers capable of performing algorithms thought to be impossible with classical computers, simulations of quantum matter ranging from quantum chemistry of biological molecules to exotic condensed matter, and the exploration of the quantum limits of precision measurements.

UNM established a presence in QIS right from the start. When Carlton Caves joined UNM in 1992, he had previously been working in "information physics," a precursor to QIS that seeks to understand how physical laws and information processing are intertwined. The Information Physics Group (IPG) at UNM was established with the hire of Ivan Deutsch in P&A in 1995; this was followed by Cristopher Moore's arrival in 1999 in the Department of Computer Science (CS), with a joint appointment in P&A. JM Geremia joined the P&A faculty in 2005, fulfilling the call in the LRP04 to build an experimental presence in QIS at UNM. The QIS group in P&A thus consists of three tenured and tenure-track faculty:

Carlton Caves	**Distinguished Professor**	**PhD, Caltech, 1979**
Ivan Deutsch	**Professor**	**PhD, UC Berkeley, 1992**
JM Geremia	**Assistant Professor**	**PhD, Princeton University, 2001**

Caves continues to work on foundational questions in QIS, focusing particularly on acquiring a deeper understanding of the role of entanglement and quantum correlations in quantum-information-processing protocols and quantum computing. In addition, his current research emphasizes a return to his roots by investigating from a QIS perspective how quantum-mechanical noise limits measurement precision and how to design systems that can attain those fundamental limits. Deutsch's research focuses on theoretical atomic-molecular-optical (AMO) physics as a platform for QIS, with emphasis and on quantum control, open quantum systems, quantum chaos, and cold-atom physics. Geremia has established a cold-atom-physics and quantum optics laboratory, with an emphasis on quantum control via continuous quantum measurement and an eye toward applications in QIS and quantum metrology. Moore's research in QIS focuses on quantum algorithms and quantum computational complexity; this is a part of his overall research effort, which also includes studies of the computational complexity of physical phenomena such as phase transitions.

In addition to the tenured and tenure-track faculty, the QIS group previously included a research faculty member, Andrew Landahl, and an active adjunct, Paul Alsing, who supervised students and participated in the intellectual life of the group. Landahl joined the QIS group in 2005 and left UNM in May 2009 to take up a position heading the quantum-error-correction group at SNL; he remains an adjunct professor and is a very active member of the group, currently supervising two PhD students and participating in group meetings. Alsing left New Mexico in the spring of 2008 and no longer participates in UNM's QIS group. Visiting Professor Wódkiewicz also participated in QIS activities and contributed research expertise to the group up until his death in 2008.

Caves and Deutsch are both Fellows of the American Physical Society (APS), and both play an active role in APS affairs. Caves was in the Chair line of the APS Topical Group on Quantum Information (GQI) from 2006 to 2008, serving as Chair in 2007, and Deutsch is currently in the middle of a three-year term as Secretary-Treasurer of GQI.

Graduate education and research has been both the main focus and the chief strength of the QIS group from its beginning. In the last five years, QIS faculty in P&A have supervised seventeen PhD dissertations (21% of the departmental total) and two MS theses. In addition, Moore is currently supervising one P&A PhD student in QIS. PhD alumni of the QIS group from the 90s and the early part of this decade now rank among the leaders in the field, and more recent PhD graduates are now postdocs at leading centers of QIS research, such as Caltech's Institute for Quantum Information, the University of Waterloo's Institute for Quantum Computing, and the Perimeter Institute for Theoretical Physics.

Graduate-student education and training are carried out in a number of ways beyond dissertation research. QIS faculty teach a regular sequence of graduate courses relevant to QIS research: Quantum Optics, Quantum Information Theory, Quantum Computation, and Physics of Computation (the latter two are taught both in P&A and CS). QIS faculty organize a weekly joint group meeting, which consists of an hour of journal-club review of papers posted to the arXiv e-print archive and papers published in *Science* and *Nature*, thus keeping faculty, postdocs, and students abreast of current QIS research, and an hour-long research seminar, generally given by a student or postdoc in the group. These seminars serve to inform everyone in the group about ongoing research and also as a training ground for students and postdocs in delivering effective seminars. This format for the QIS group meeting has proven to be extremely effective and is an important tool for educating and training graduate students.

Undergraduate education in QIS has been carried out primarily through participation in research. QIS faculty have supervised four undergraduate honors theses; during 2009 two undergraduates have been involved in research with QIS faculty. An experimental undergraduate course in quantum information theory, with an emphasis on quantum error correction, was taught by Landahl in 2007. There is substantial room for further QIS involvement in undergraduate education, mainly through providing additional undergraduate research opportunities and perhaps by developing a permanent upper-division elective course.

UNM has supported QIS through the Center for Advanced Studies (CAS), which Deutsch directed from 2005 to 2009. The mission of the CAS was to advance interdisciplinary science and to foster connections to the local national laboratories, two tasks for which QIS is eminently suited. CAS supported an administrative assistant for the group and a high-profile weekly seminar series.

The CAS has now been subsumed in a new Center for Quantum Information and Control (CQuIC), which was founded in August 2009 in response to a three-year NSF grant from the Physics at the Information Frontier (PIF) program. CQuIC is directed by Caves; the NSF grant has Deutsch as co-PI and includes the experimental group of Poul Jessen at the College of Optical Science of the University of Arizona. The Center's mission is to bring a quantum-information perspective to physics-based research, with a strong emphasis on new ideas for quantum control, measurement, and metrology. CQuIC brings together under one umbrella existing QIS external funding. The founding grant funds a substantial visitors program and additional postdocs; the group expects to have four postdocs on board by mid-2010. The establishment of CQuIC also codifies strong existing research ties to four external partners: the Quantum Initiative at LANL; QIS groups at SNL; the Joint Quantum Institute (JQI), a joint undertaking of the University of Maryland and NIST Gaithersburg; and the Quantum Science Initiative at the University of Queensland.

The local concentration of QIS activity and early workshops sponsored by the CAS led to the creation in 1998 of the Southwest Quantum Information and Technology (SQuInT), a consortium of universities, national laboratories, and industry, with its main concentration in the US Southwest. The SQuInT Annual Workshop, now in its 12th year, is one of the longest running research workshops in QIS, attracting about 150 participants. SQuInT has a strong orientation towards serving its junior members, students and postdocs, and provides an opportunity for student and postdoc presentations alongside presentations by senior members of the Network and distinguished invited speakers.

For nearly a decade now, the QIS group has consistently attracted a sizeable fraction of the Department's best applicants for graduate study. With this student demand now consistent and clear and with the present QIS group unable to supervise effectively all of the qualified PhD students, there is a compelling case to expand the QIS group to serve this need, to allow the group to compete for national funding on a even larger scale than CQuIC, and to strengthen ties to LANL and SNL. Indeed, perhaps the most important local development of the last five years has been the growth of interest in QIS at SNL, which has now made a major commitment to QIS research with two research initiatives. One initiative, centered in AMO physics, is focused on ion traps for quantum information processing, development of quantum sensors, and high-precision measurements; the other is an SNL Grand Challenge to develop the technology for a silicon-based quantum computer. The QIS group has already taken advantage of LANL and SNL research to provide additional dissertation opportunities for P&A students. The next step is to leverage the major SNL commitment to make the case to the UNM administration for a major expansion of QIS research, in P&A and other departments.

The departmental hiring plan outlined in Sec. VII.4 responds to the need for new QIS faculty by proposing 3.5 new hires within the QIS group over the next seven years, with 1.5 of these hires included in the five initial positions identified as critical in Sec. I.2. New QIS hires in experimental AMO physics would greatly benefit from the promise and realization of a new P&A building and will require substantial start-up packages.

VII.3.7 Subatomic Physics.

Subatomic physics (nuclear and particle physics) explores the world at the smallest scales, investigating the properties and interactions of the fundamental constituents of matter and seeking to determine the most fundamental laws of physics. Studies of the shortest distances involve collisions of particles at the highest energies and are therefore intimately tied to cosmology and astrophysics. The elementary particles and the laws that govern them describe the evolution of the Universe in the first few minutes after the Big Bang, as well as phenomena in the present Universe, such as those occurring in the interiors of stars and within supernovae. The investigations of subatomic physics are carried out using natural sources of radiation, such as the cosmic radiation that strikes the Earth and the neutrinos that are produced copiously by fusion reactions at the center of the Sun, and using powerful machines to accelerate particles to produce high-energy particle beams for studying particle collisions in the laboratory. To build and operate the biggest of these accelerators and the associated particle detectors requires large, international collaborations and decades of planning.

The robust theory of elementary particles that has emerged as the result of the experimentation and theoretical work of roughly the last sixty years is known as the Standard Model (SM). The SM is based on three families of quarks and leptons interacting via three fundamental interactions, the strong-nuclear interaction, the weak-nuclear interaction, and electromagnetism. It is an enormously comprehensive and successful theory that has been verified experimentally to great precision. The three types of interactions are based on the same underlying principle, local gauge invariance, and within the SM, the weak and electromagnetic interactions receive a unified description. Despite its enormous success, however, crucial questions remain open: the origin of particle mass, perhaps via the postulated Higgs particle; the unification of all the forces, including the strong-nuclear force and, ultimately, gravity; the origin of matter in the

Universe (baryogenesis); and the nature of the dark matter and the dark energy that in addition to gravity, govern the evolution of the Universe following the Big Bang.

There are presently seven core, tenured and tenure-track faculty members working on topics in subatomic physics:

Rouzbeh Allahverdi	**Assistant Professor**	**PhD, University of Alberta, 2000**
Bernd Bassalleck	**Professor**	**PhD, Universität Karlsruhe, 1977**
Douglas Fields	**Associate Professor**	**PhD, Indiana University, 1991**
Michael Gold	**Professor**	**PhD, UC Berkeley, 1986**
Dinesh Loomba	**Associate Professor**	**PhD, Boston University, 1998**
John Matthews	**Professor**	**PhD, University of Toronto, 1971**
Sally Seidel	**Professor**	**PhD, University of Michigan, 1987**

The Subatomic Physics (Subatomic) group includes faculty working in traditional areas of subatomic physics, as well as those working at the intersection of particle physics and cosmology. Most of the group's members are associated with the New Mexico Center for Particle Physics. Allahverdi, the only theorist in the group, was hired in 2007 as the first step toward LRP04's goal of building a theory group in particle physics, cosmology, and astrophysics. The most recent previous hires before Allahverdi were Fields (2001) and Loomba (2002). There have been no retirements and no departures in the Subatomic Physics group since the retirement of theorist Colston Chandler in 2004. Three research faculty members, Igor Gorelov (associated with Seidel), John Strologas (Gold), and Imran Younus (Fields and Bassalleck), are associated with the core faculty, and there are currently (fall 2009) six postdocs and research scientists associated with the group. Adjunct Professor Gerard Stephenson, a retired theorist from LANL, is an active member of the group.

Experiments in subatomic physics are carried out by large groups of investigators assembled from many institutions and are usually centered at large national or international research facilities. It is essential that experimental particle-physics faculty be tied to such large experimental projects. The UNM subatomic physics group is involved in several of the flagship experiments in the field. The CDF experiment (Gold, Seidel) at Fermi National Accelerator Laboratory, credited with discovery of the top quark, is now searching for a totally new class of particles, the so-called supersymmetric particles, and is also probing the nature of the strong force at the smallest length scales presently achievable. The ATLAS experiment (Seidel) at the Large Hadron Collider (LHC) of the European Center for Nuclear Research (CERN) will look for the Higgs particle, the last missing piece of the SM, as well as for physics beyond the SM. Seidel is also a member of the CERN RD42 and RD50 Collaborations, whose goal is to develop new technologies for tracking fundamental particles with silicon and diamond detectors. The PHENIX experiment (Bassalleck, Fields) at the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory hopes to solve the "proton-spin puzzle" and continues to probe the formation and development of a quark-gluon plasma, a state of matter that likely existed just moments after the Big Bang. These two aspects of hadronic matter provide insight into the strong force, quark confinement, and quantum chromodynamics. At the brand-new Japan Proton Accelerator Research Complex (J-PARC) facility, experiments to probe the role of strangeness in nuclear physics are currently being assembled (Bassalleck). The Pierre Auger experiment (Matthews, Gold) observes the highest energy cosmic rays, the source of which remains a mystery; this experiment is now complemented by the unique High Altitude Water Cherenkov (HAWC) TeV gamma-ray experiment (Matthews), which is sited at 4100 m elevation in Mexico.

A number of independent astronomical observations lead to the conclusion that most of the matter in the Universe consists of some new particle(s) called "dark matter." The direct detection of dark matter is now the goal of a number of underground experiments worldwide. The DRIFT experiment (Loomba, Gold) at Boulby in the United Kingdom uses a low-pressure gaseous target to observe the nuclear recoils resulting from dark-matter interactions. The CLEAN experiment (Gold, Loomba, Matthews) at Sudbury in Canada uses a liquid argon target that is easily scalable to very large (10-ton) masses. The Deep Lens Survey collaboration (Loomba) maps the gravitationally lensed images of distant galaxies in order to determine the structure and evolution of the large-scale, massive, foreground lensing objects, which are mainly made up of the mysterious dark matter.

The recently started (2007) theoretical effort (Allahverdi) focuses on dark matter (models, direct/indirect/collider signals), inflationary cosmology (models, connection to particle physics beyond the SM) and prospective results from the LHC (new physics and its signatures).

The experimental efforts are in general well funded and are thoroughly integrated into the multi-institution style of research in experimental subatomic physics. They enrich the intellectual life of the Department by bringing in postdocs, research staff, and research faculty. Over the last several years there has been a noticeable trend by several members of this group to shift their research efforts more into particle astrophysics, including a strong involvement in various dark-matter investigations, as mentioned above. As of fall 2009, this trend includes Gold, Matthews, and Loomba, with strong collaborative efforts between them. The potential for major discoveries in all the subatomic efforts remains excellent.

The Subatomic Physics group is active in supervision of graduate and undergraduate students. The group has supervised thirteen PhD dissertations (16% of the departmental total) and three MS theses in the last decade. During 2009, eleven undergraduates have worked on research projects with Subatomic Physics faculty. In addition, Loomba has been teaching a workshop for K–12 teachers for four years now as part of his NSF CAREER grant plan.

LRP04 noted a lack of overlap between experimental and theoretical interests and efforts in subatomic physics; this was identified as a definite weakness of the program. At that time (2004), the program had almost no theoretical component, except for a small fraction of Cahill's effort and that of adjunct faculty member Stephenson. As a result, the experimental research efforts lacked the local discussions associated with closely coupled experimental and theoretical efforts. In addition, it was noted that the absence of a theoretical presence makes the recruiting of graduate students more difficult and limits the breadth of graduate-student education. LRP04 committed the Department to building a fundamental theory component, which it was recognized could only be met by building a theory group of more than one faculty member. A first step in that direction was taken in 2007 with the hiring of Allahverdi. This hire has been a very positive development for the group, and the hiring of a second theorist is a top priority both for the group and within the hiring plan of Sec. VII.4; an astro-particle theorist is included in the list of critical hiring needs of Sec. I.2. The theory group would also benefit from the addition of a theorist working on related topics in astrophysics. In addition to these high-priority theory hires, the subatomic group will almost certainly require the hire of an experimental physicist sometime during the life of this plan, to maintain the vitality and viability of the core experimental efforts in subatomic physics.

VII.3.8 Other research areas.

One theorist works on general relativity theory and the general theory of partial differential equations, topics that lie outside any of our established research groups:

Daniel Finley	**Professor**	**PhD, UC Berkeley, 1968**

It seems likely that Finley will retire during the life of this plan, leaving a major hole in the theoretical-physics and mathematical-physics expertise within the Department. In a time of stretched resources, the Department does not contemplate new hires outside the established research groups, despite the potential of such hires to enrich and broaden the intellectual life of the Department. Our current thinking is that the recent addition of Allahverdi, plus the several prospective theory hires in our plan, will maintain and perhaps even expand the overall mathematical-physics expertise in the Department.

VII.4 Faculty hiring.

VII.4.1 Hiring plan.

The size of the Department envisioned by our hiring plan is 31 FTE tenured and tenure-track faculty. Given reasonable, but of course not guaranteed, assumptions about retirements, the plan outlined here would take the Department to 31 FTEs within the next several years, from the current number of 28. Specifically, the plan assumes nine retirements and twelve new hires, five (six) experimentalists/observers and seven (six) theorists, bringing the Department from its current 28 FTE (20 experimentalists/observers and 8 theorists) to 31 FTE [20 (21) experimentalists/observers and 11 (10) theorists]. The two figures for numbers of experimentalists/observers and theorists refer to the option that our biological physics hire might be either a theorist or an experimentalist.

As in LRP04, we organize our proposed hires around a set of six challenges distilled from three National Academy of Sciences reports, *Physics in a New Era: An Overview* (2001), *Astronomy and Astrophysics in the New Millennium* (2001), *Harnessing Light: Optical Science and Engineering for the 21st Century* (1998, jointly sponsored with the National Academy of Engineering). These three reports set out the primary scientific challenges for physics, astronomy, and optical science in the early decades of the 21st Century. From the lists of challenges in the Academy reports, we have distilled a set of six challenges for our department in the light of our strengths and special opportunities we have within New Mexico. Within these six challenges, our proposed hires are aimed at taking advantage of research opportunities that exist within the research environment of UNM and the state of New Mexico and that can attract external funding, high-quality graduate students, and potentially postdocs and research staff/faculty.

We make three changes, one major and two minor, to the list of six challenges used in LRP04. The major change is that we have replaced “Creating new materials” with “Understanding complex systems.” This change reflects a departmental decision that since other units at UNM, especially CHTM and units in the SoE, have strong materials-research programs, P&A can and should instead build on the evident existing strengths in complex-systems theory in our CM/CS group. Such an effort has considerable potential for overlap and synergy with other research in the Department, particularly with the Biological Physics and QIS groups, but also with research in optical science. The two minor changes are made to describe more accurately, in our view, the primary optical-science and subatomic-physics challenges.

Organizing our thinking around these six challenges helps us to identify hires that provide bridges between the existing research groups within P&A and opportunities for interdisciplinary hires that provide bridges to other departments and units within UNM. Because we seek new faculty who can bridge between the several research areas in the Department, several positions are listed under more than one challenge here. In parentheses after each proposed position is the research group to which the position is nominally assigned (the quantum optics experimentalist is assigned half to OS and half to QIS).

- *Understanding quantum systems and developing quantum technologies*

  Atomic physics experimentalist (QIS)
  Laser physics experimentalist (OS)
  Optics theorist (OS)
  Quantum information theorist (2; QIS)
  Quantum optics experimentalist (OS/QIS)

- *Understanding complex systems*

  Biological physics theorist or experimentalist (BioPhys)
  Complex systems theorist (CM/CS)
  Quantum information theorist (2; QIS)

- *Developing and utilizing optical techniques for science and industry*

Laser physics experimentalist (OS)
Optics theorist (OS)
Quantum optics experimentalist (OS/QIS)

- *Applying physics to biology and medicine*

  Biological physics theorist or experimentalist (BioPhys)
  Complex systems theorist (CS/CM)

- *Exploring the Universe*

  Astronomy observer (Astro)
  Astro-particle theorist (Subatomic)
  Astrophysics theorist (Astro)

- *Investigating the fundamental particles and forces of Nature*

  Astro-particle theorist (Subatomic)
  Subatomic experimentalist (Subatomic)

The list of proposed hires is summarized in a box at the end of this section, where the twelve positions are divided into three groups from highest to lowest priority. Within each group, the positions are listed alphabetically, and the order of listing thus does not reflect any priority. The first set of five hires is critical to maintaining our research success and is included in the critical departmental objective set out in Sec. I.2. The remaining two groups are included in the continuing departmental goal of Sec. I.3, but are more susceptible to change as the plan proceeds; the Department will need to review these proposed hires in the light of developments in terms of retirements, departures, and targets of opportunity over the next seven years.

A distinctive feature of our current planning is an emphasis on three research-group-related objectives. These three objectives are meant to be served by the prioritized list of hires in the box below, but the goals are more important than the specific positions listed, particularly as one descends in the list of priorities.

The first objective is to build and maintain research groups of sufficient size to achieve a critical mass of expertise and collaboration within each research area, to take maximum advantage of external funding opportunities, and to serve the needs of graduate students attracted to the Department by each research interest. Given the success of our OS and QIS groups in attracting funding, the heavy demand of graduate students to work in these groups, and the relatively small numbers of faculty in these two groups, this first objective means, in practice, an emphasis on building these two groups. Thus our plan aims to grow these two closely related research programs so that they would together have eleven faculty, with a nice balance of six experimentalists and five theorists.

Our second objective is to achieve, within each research group, a balance of experimentalists/observers and theorists, with the balance chosen to match the research style in each group's subdiscipline. Achieving such balance is an objective made explicit in the hiring plan in LRP04; we commit to it again with the current plan.

The third objective, also carried over from LRP04, is to build small clusters of researchers who can work across group boundaries and thus can help to build bridges between our research groups. One example of this, carried over from LRP04, is a cluster of theorists working on fundamental topics in particle physics, astrophysics, and cosmology. This effort was begun with the hire of Allahverdi in 2007 and continues with our proposed hires of an astro-particle theorist and a theoretical astrophysicist. Another example is provided by our proposed hires of a complex-systems theorist, quantum-information theorists, and perhaps a biological physics theorist, to make up a cluster, with our current CM/CS theorists, of researchers with interests in modern complex-systems research. This cluster might also interact productively with some or all of our existing and proposed optics theorists. A third example is a cluster of table-top experimental physicists associated with the QIS and OS research groups.

Given our assumption of nine retirements by 2016, our plan would leave the Department's six research groups with the following configuration: Astronomy and Astrophysics (6 FTE, 5 observers and 1 theorist), Biological Physics [4 FTE, 3(4) experimentalists and 1(0) theorist], Condensed-Matter Physics and Complex Systems (3 FTE, 1 experimentalist and 2 theorists), Optical Science (5.5 FTE, 3.5 experimentalists and 2 theorists), Quantum Information Science (5.5 FTE, 2.5 experimentalists and 3 theorists), and Subatomic Physics (7 FTE, 5 experimentalists and 2 theorists). In this accounting, the quantum-optics experimentalist is counted as half in OS and half in QIS; the pairs of numbers for Biological Physics reflect the option of hiring either a theorist or experimentalist in biological physics. The impact of our hiring plan on research group sizes is detailed in Attachment L; the second page of the attachment spells out the effect of a stand-pat scenario that omits the last three positions on our list and thus leaves the Department at 28 FTE.

In most table-top experimental fields in physics, attracting first-rate experimental physicists requires substantial start-up packages; packages in excess of $1 million are not uncommon in atomic physics, quantum optics, and optical science. To be competitive, we must be able to offer such packages. To assemble such sizeable start-up packages will require the Department, the Dean of A&S, the Provost, and the Vice President for Research to begin planning several years in advance of a planned hire. It should be noted that the promise and realization of a new physical facility, with state-of-the-art laboratories, would be a major attractor and might directly depress the size of start-up packages by eliminating the need to renovate laboratory space.

VII.4.2 Hiring principles.

LRP04 formulated an enduring set of hiring principles, which this document repeats and endorses. In considering these principles, it is important to keep in mind the three research-group-related objectives formulated in the preceding subsection.

The Department seeks to strengthen existing research areas or to initiate new research areas that satisfy the following criteria:

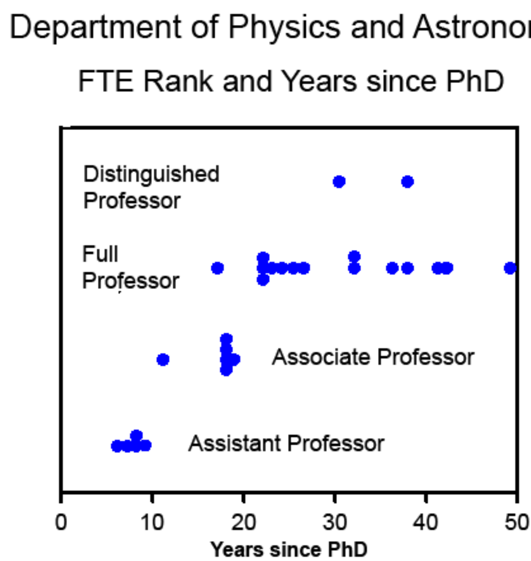
- Poses significant and enduring scientific and technological challenges.
- Takes advantage of opportunities that exist within the scientific and technical environment of UNM and/or the state or that arise from connections to national and/or international institutions.
- Enhances our undergraduate programs.
- Strengthens our ability to attract the best possible PhD students.
- Has high potential to attract external funding.

In evaluating particular individuals for tenure-track faculty positions, the Department seeks individuals who meet the following criteria:

- Has high potential or demonstrated ability to teach effectively, especially in the Department's introductory service courses.
- Has a record, appropriate to the number of years since the PhD and to the individual's life and work experience, of high-quality research that is recognized as such by the relevant community of researchers.
- Has high potential or demonstrated ability to create a research program that is attractive to graduate students and that can also secure external funding for support of graduate students and perhaps for postdocs and research staff/faculty.
- Shows evidence of willingness and aptitude to be a good departmental citizen.

The Department has three women faculty out of 28 FTE, one in each of the faculty ranks. While this does not look at all good by the standards of other disciplines, it is average compared to other physics departments—but unfortunately only average. The Department is committed to identifying and recruiting outstanding female and minority applicants for all the positions in our plan.

LRP04 noted with some concern the near absence of junior faculty within the Department and made it department policy to focus exclusively on hiring junior faculty. As a consequence of hires and retirements over the last five years, the situation is now much improved. Of the Department's 28 FTE tenured and tenure-track faculty, there are 2 Distinguished Professors, 15 Full Professors, 6 Associate Professors, and 5 Assistant Professors. The number of years since the PhD within the various professorial ranks is given in the graph below. If one assumes a professorial career of 36 years and a residence time of six years in the Assistant and Associate Professor ranks, a rule of thumb is that at least a sixth of the faculty should be in each of the two junior ranks; the Department's rank profile is now within the boundary set by this rule. This good news does not mean that the Department can abandon its focus on hiring junior faculty—if the junior ranks are not refilled consistently over the next decade, the rank profile will slip inexorably back into disproportion—but it does mean the Department can consider an occasional senior hire that represents an extraordinary target of opportunity.



Another way to assess the faculty's demographic profile is to examine the age distribution of the tenured and tenure-track faculty: there is presently one faculty member under 35; six between 35 and 44 inclusive; twelve between 45 and 54; five between 55 and 64; and four between 66 and 75. There are perhaps two lessons here. First, the noticeable bulge between 45 and 54 emphasizes that the Department must continue to take care to fill the junior ranks. Second, since the five faculty members between 55 and 64 are actually between 59 and 64, the Department is likely see nine retirements over the next decade and probably sooner. The Department and the Dean of A&S should plan proactively for these retirements; it is critically important that the Department avoid the kind of "demographic collapse" that can leave a department so weakened as to make recovery very difficult.

The Department re-affirms a policy formulated in LRP04 to explicitly disavow completely open searches whose stated rationale is to find the "best" person in physics and astronomy, although it might be a good idea to search for several related positions within a single search. Completely open searches are an admission of failure in departmental planning.

The Department understands that the University's straitened fiscal condition is likely to have a considerable negative effect on implementing our hiring plan, at least for several years and perhaps for the whole life of the plan. We understand that a good part of our hiring over the next seven years must be based on our own initiative: we must be aggressive in seeking out and finding initial funding for at least some of the positions in our list, and we must be responsive when potential hires with no need for start-up and perhaps some initial years of salary come to our attention. The several national laboratories in our vicinity provide one source for developing such targets of opportunity. The Department realizes that a major reason for formulating a detailed hiring plan, especially within this current UNM environment, is so that we can determine which sorts of targets to develop and how to respond to targets that fall into our lap. Departmental policy is that targets that come to our attention will be viewed favorably if they are on our hiring list or close enough to cross a position off our list. Otherwise, we will respond positively only if the new position is free, i.e., not counted against the Department's future hiring requests, or if we find substantial agreement within the Department that the target is more valuable than everything else on our hiring list.

Positions made available by departures do not automatically go back to the research group suffering the loss. They must be evaluated within the overall context of our plan, particularly within the context of our goals for group size, balance between experimentalists/observers and theorists, and cross-group clusters of researchers. It goes without saying, however, that a departure from a group has an immediate impact on that group's size, and that must be a major consideration in how to proceed.

As noted above, our plan is premised on the Department's suffering nine retirements by 2016. Retirements are not to be automatically replaced within the same area of expertise; instead any replacement will be considered within the overall context of our hiring plan. Retirements are notoriously difficult to predict, but nonetheless, it would be most useful for the Department if the Dean of A&S and the Provost worked with the Department in anticipating retirements and planning proactively for them.

Department of Physics and Astronomy
Hiring plan for tenured and tenure-track faculty

2010–2016

12 FTE hires: 5 (6) experimentalists/observers, 7 (6) theorists

Astro-particle theorist
Astrophysics theorist
Optics theorist
Quantum information theorist
Quantum optics experimentalist

Atomic physics experimentalist
Biological physics theorist or experimentalist
Complex systems theorist
Laser physics experimentalist

Astronomy observer
Quantum information theorist
Subatomic experimentalist

This plan assumes nine retirements and twelve new hires, five (six) experimentalists/observers and seven (six) theorists, depending on whether the Biological Physicist is an experimentalist or a theorist. This would bring the Department from its current 28 FTE (20 experimentalists/observers and 8 theorists) to 31 FTE [20 (21) experimentalists/observers and 11 (10) theorists]. The list of proposed hires is divided into three groups from highest to lowest priority; within each group, the positions are listed alphabetically. The first group is included in the critical hiring goals of Sec. I.2; the second two groups, included in the continuing objectives of Sec. I.3, will need to be reëvaluated and reëxamined in the light of experience and changing needs as the plan proceeds.

A distinctive feature our plan is an emphasis on three research-group-related objectives. First, we seek to build and maintain research groups of sufficient size to achieve a critical mass of expertise and collaboration within each research area, to take advantage of external funding opportunities, and to serve the needs of graduate students. Second, within each research group we seek to achieve a balance of experimentalists/observers and theorists, with the balance suitable to each research area. Third, we aim to build small clusters of researchers to work across the boundaries of our existing research groups. These three objectives are addressed by this prioritized list of hires, but the goals are more important than the specific positions listed, particularly as one descends in the list of priorities. The impact of our hiring plan on research group sizes is detailed in Attachment L; the second page of the attachment spells out the effect of a stand-pat scenario that omits the last three positions on our list and thus leaves the Department at 28 FTE.