Strategic plan for a 5 - 10 year time horizon
Department of Physics and Astronomy

DRAFT

Executive Summary

The next decade will be exciting and productive for the Department of Physics and Astronomy. Existing programs are all remarkably strong and vital, and the Department is poised for a powerful phase of expansion and progress, thanks in large part to the last two decades of faculty recruitments, research initiatives and bridge building with the rest of the University.
Even a modest increase in faculty size is assured to have dramatic impact on our scientific productivity and national ranking. Indeed, we believe that an increase of our national rank into the top twenty in the Nation is a realistic goal.

Our students, undergraduate and graduate alike, are among the best in the College and our education programs are strong, and will continue to improve.

There is much room for improvement in our home building, Bausch and Lomb Hall, which is among the shabbiest of all buildings on the otherwise beautiful Eastman quad. Its poor physical condition belies the world-class research that goes on within; a significant upgrade is not only required for the Department to maintain its high standards, but will also have a potentially huge payoff in sponsored research.

An interdisciplinary initiative in nanoscience, and in biophysics an ongoing faculty search, exemplify our broad, cross-departmental identification of the strategic frontiers of physics. Initiated before the recent request for the present report, a departmental strategic planning cycle is well underway and will produce a new faculty recruitment strategic plan in early 2006. As such, this report is labeled as a draft, having been generated by a separate process. As a supplement to this report, we therefore provide a copy of the result of our prior, 1997 planning effort. We also include the 2000 departmental diversity report and the 2001 report on our biological physics initiative.

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INTRODUCTION

Physics and Astronomy as fields attempt a daunting task: understanding the universe in all of its vast and complex splendor. Yet, it is more. It is an enabling science that has brought about tremendous technological advances that have dramatically changed our way of life. These range from the global positioning system (GPS) to medical MRI to nuclear weapons to the Internet – all inventions of physicists and astronomers. Throughout the second half of the last century, physics and astronomy held a special place in our national psyche with iconic figures such as Albert Einstein familiar faces to everyone; scientists and non-scientists alike. The Department's has been enormously successful in performing world-class research and educating not only future physicists but future doctors, scientists in other fields, and non-scientists.

In this document we present our plan to improve on our successes and create new ones for the next 5—10 years. In this Introduction we present our overarching goals, summarize the status of the department, and identify our view of the opportunities for University investment that will best help us achieve our goals. In succeeding sections, we discuss in detail our strategies for Faculty and Research, Attracting and Serving Students at All Levels, Department Advancement, Diversity, Department Administration, and Reputation and Faculty Advancement.

The Overarching Goals

In the broadest sense, the driving principles behind Departmental planning overlap strongly with those of the College and of the University as a whole.

- To encourage and enable the best possible scholarship and scientific contribution.
- To increase the ranking and recognition of the Department by increasing the visibility and success of its Faculty and Students.
- To increase the funding of individual research programs within the department, to increase the philanthropic contributions to the Department and its endowment, and to increase the funding of education and training programs for students at all levels both within and outside of the Department.
- To expand the department's research base by (1) making new faculty hires and coordinated faculty retirement-replacements in frontier areas of physics, (2) identifying and participating in emerging frontiers, and (3) continuing to leverage and nurture extra-departmental physics related activities throughout the University via initiating new inter/cross disciplinary programs and curricula, through joint faculty appointments, and through facilitation of multi-disciplinary federally funded centers.
- To improve the diversity of our Faculty and Students so that we may one day reflect the composition of the people of our Nation.
- To sustain and expand our outreach activities at all levels, from local K-12 programs to undergraduate summer internships to local and regional K-12 teacher programs.

Department of Physics and Astronomy: Status and Structure

From the bottom up

Consider the University's model of decentralization: "that decision-making (and implicitly responsibility) should be focused at the lowest competent level." In the context of the Department, we identify our faculty and students as the fundamental unit of competency and find that Department's mission is to be the champion of the faculty and students. Hence, Departmental decision-making aims to enable students and faculty to be as productive and well provided for as possible in all of their scholarly and academic efforts. To accomplish this, the Department provides strong and efficient infrastructure through, for example, internally maintained shops, facilities and staff.

The Department simultaneously acts to support the College's educational mission, creating plans that foster new and innovative educational approaches such as Workshops, and through establishing collaborative partnerships with non-PAS faculty, departments and units.

The Department serves the University in many other ways: through its generation of substantive indirect cost recovery on research grants, through outreach activities and through advancement of its reputation. The Department also serves as a vital link to alumni, especially graduate alumni, and through its efforts to strengthen other programs.

Simply put, we believe that strong students and faculty make for a strong department, and that a strong department makes for a strong College and hence a strong University.

Pound for pound applies here too

Research Dollars – Within the College, the Department of Physics and Astronomy (PAS) is *the leader* in research expenditures by a significant margin. For example, in the years 1995 – 2003, PAS accounted for 26% of the College research dollar expenditures while we accounted for only slightly over 8% of its faculty. University-wide, since 1995, our research expenditures have been exceeded only by the LLE and by departments in the Medical Center. Usually, we are in the top ten university-wide, sometimes even in the top five.

Prestige – Since 1995, two of the Department's graduates have been recipients of Nobel Prizes while all other UR alumni laureates have been in medicine. The Department has a long history of distinction (former faculty include Weiskopf, Marshak, DuBridge, Montrol, to name a few) and there are two major international conference series in Physics associated with the Department and the University's name (The "Rochester Conferences" in high energy physics and the "Coherence and Quantum Optics Conferences"). In the past few years department faculty and students have garnered national and international awards from prestigious professional societies. Overall, in the last NRC rankings we paralleled the Institute of Optics for a rank of 25 in the field of physics, and we rank number six in the Nation in the subfield of atomic, molecular and optical physics (AMO).

To borrow a concept from Thomas Jackson – "size normalized performance" – and a phrase recently adopted by Dean Bruce Jacobs, we are "pound-for-pound" one of the best places within the College for high return on resource investment.

A tradition of strategic planning

Over the last decade we have consistently planned our faculty recruiting strategy for the long-term health of the Department. Our last faculty recruiting strategy report was developed in 1997 (a.k.a. the 1997 FRS report - attached), and another is in progress. We have a long record of recruiting excellent young faculty, retaining tenured faculty, and managing graceful, respectful and coordinated retirements of senior faculty. Over the last decade we have had no senior departures and only one junior departure (which in turn was by mutual agreement with the individual). A more detailed discussion of our strategic planning efforts can be found in the section entitled Faculty and Research.

Achieving our Goals: Opportunities for Investment

People - With 26 FTE slots, we are the largest department in the College in terms of faculty count. In terms of national rankings (National Research Council 1995 rankings), however, we are small. And, in these rankings, faculty size matters. Consider the top 26 programs nationally. Only two of these departments have less than 30 faculty members, while ten have between 30 and 45, ten more lie between 45 and 60 and four others have over 60 FTE faculty. Indeed, with 26 FTEs, our Department is one of the smallest. The only smaller private university in the top 26 is Stanford, with 25 FTEs (and note that Stanford has *many* renowned, non-FTE research professors and one of the Nation's leading particle accelerators). Even when compared to the national average FTE size of 28 (AIP data, both public and private) we're small, and barely above the median of 24. It is also noteworthy that we graduate approximately the same number of bachelor's degree students per year as the largest third (by faculty size) of the departments nationally. (To be clear, however, the typical number of graduating majors per department is surprisingly insensitive to faculty size.)

In sum, the national ranking of a department is most heavily correlated with faculty size, and relatively independent of the number of undergraduate majors.

Given the constraints of the Renaissance Plan (PAS FTE = 26), so far we have addressed the desire to increase our NRC rankings in two ways. First, we have agreed together with the Institute of Optics and the LLE to be presented as one "unit" for the upcoming (2006) NRC ranking survey. Second, as part of a broader plan to leverage physics related activities across the University, we have increased our number of joint appointments and interdepartmental programs.

The obvious strategy for increasing our ranking comes from the NRC; "the best way to increase ranking is to appoint additional faculty." The unit size of impact in our Department is 2-3, with good examples being quantum optics (3 faculty sustain a well recognized and funded effort) and plasma physics (we have 2 highly successful faculty). Another excellent example is the "DOE" experimental particle physics team which, with only 5 faculty members, rates as one of the most powerful in the Nation. We contend that a carefully planned set of two to three appointments in a new area (e.g. Frank and Blackman in plasma astrophysics) can have visible and measurable effect on our overall productivity and output. At the same time, the increase in one or two FTEs in an area of recognized specialty is certain to affect our national reputation (e.g. quantum optics). Looking to the future, small increases in our total FTE number will make a difference and will build upon a University peak of excellence.

Space - Together with the Institute of Optics, we are unique in the College in that we occupy a dedicated building. Unfortunately Bausch and Lomb Hall is high on the University list of buildings in terms of deferred maintenance. Our electrical power capabilities are near their limits. For example, this past summer a substantial, extended power outage resulted from the failure of a heavily loaded transformer, paralyzing several major research programs. Much of B&L does not enjoy air conditioning, the hallways are drab mosaics of old, distinguished designs dotted with repair scars, pipes and stray wiring, and a substantial number of rooms are in embarrassingly poor shape. Bausch and Lomb Hall is among the most grim buildings on the historic Eastman quad.

What has been most noticeable is the high cost of research space renovation that has resulted from the “one-room-at-a-time” approach forced upon the College by budgetary constraints. This situation has been exacerbated by the fact that PAS has also experienced significant space pressure over the last decade, driven largely by the closing of the Nuclear Structure Research Laboratory (NSRL) and the razing of the cyclotron laboratory for construction of the new BME/Optics building.

The Department has worked diligently with the College to minimize building project costs and has a strong track record of “repaying” investments made in the B&L physical plant. In a recent example of College investment in B&L, a substantial renovation project was launched for research in quantum optics. This work was tied to the recruitment of Assistant Professor John Howell. Department leadership worked closely with College leadership and staff to cut more than 40% of the initial cost estimates by introducing design efficiencies. What is more, shortly after its completion, a single NSF grant was funded (Bigelow was the PI) that generated indirect cost recovery that exceeded the renovation costs. Further, since his arrival, Howell has garnered significant research funds, including a prestigious “PCASE” award of $500,000.00. Simply put, we pay excellent dividends on physical plant investments.

History has shown that we can expect approximately one appointment per year to occur due to retirements. Given the history of investment in Bausch and Lomb Hall, an effective investment will be to improve the physical plant in larger steps. Experience shows that, as resources permit, it is a better investment to improve larger portions of the building’s physical plant when making any given renovation, particularly in terms of research space. Over time, these investments are paid back in increased research revenues and in a substantial cost savings of scale. Comparatively minor cosmetic improvements also seem mandatory – Bausch and Lomb should present at least as well as, say, Lattimore Hall – as our facilities are visible to the many campus visitors, be they prospective undergraduates and their parents, or prospective donor alumni, or research sponsors.

FACULTY AND RESEARCH

Challenges

For more than a half of a century, physics researchers have experienced a solid base of governmental research funding that has spanned all scales: from the construction and operation of large national research facilities, to the launching of remarkable telescopes, to the support of myriad small, single-investigator research groups. Over the last decade, however, the place of physics on the scientific landscape has changed, and "physics for the sake of physics" no longer enjoys quite the same place in the focus of governmental funding or in the national view that it did some decades ago. In part this change reflects the dramatic advancements in life science and medicine that compete for national interest (and funding) and in part it reflects a lack of attention within the physical science community in terms of communicating the impact of physics to non-scientists. As the Department plans ahead for the next 5-10 years, its strategy for hiring and for program development must take into account the reality of these changes.

Until recently, government funding in physics and astronomy was highly compartmentalized with the agencies and their divisions organized along lines that paralleled faculty specialties: high energy physics; nuclear physics; atomic, molecular and optical physics; condensed matter physics; material science; observational astronomy for example. In this picture, theory and experiment were also usually factored into distinct areas. Over the last decade, this situation has started to change. Many of the newest frontiers of physics, and the resulting funding opportunities, are located at the boundaries between subfields of physics, and along boundaries with other fields. For example, consider high-energy nuclear physics, biological and medical physics, quantum information and computation, particle astrophysics, mathematical and topological physics, and plasma astrophysics. These are all interfacial sectors in physics and are frontiers where some of the most exciting work is being done. The strategic question is how to align the Department faculty to be key researchers at these frontiers.

Reshaping the department for the next millennium: phase I

Throughout strategic planning, the department has recognized the changing flavor of physics and this continues today. Following the 1997 Faculty Recruiting Strategy report (FRS-97; appended), the process began as the distribution of faculty slots among areas was shifted.

The table below shows the 1997 faculty distribution by subfield, the FRS-97 hiring strategy goal by subfield, and the present (2005) status.

	1997	2005	FRS1 Goal	1997	2005	FRS1 Goal	Δ (FRS1 Goal - 2005)
	Theory			**Experiment**			
AST	1	2 af, eb	2	3	3 dmw, wf, aq	3	0
BIO PHYS	0	0	0	0	0	1	+1
CM	2	2 ys, st	2	3	2 yg, dd	3	+1
HEP/NP	4	4 ad, sr, crh, lo	3	7+2	6 et, pt, ab, kmcf, rd, ps +3 sm, flhw, dc	5+2	-3
QO	1	1_{jhe}	1	3	2 jh, npb	3	+1
General THEORY	0	0	1				+1
Totals		9	9		16	17	

AST = Astronomy and astrophysics
BIOPHY = Biophysics
CM = Condensed matter physics
HEP/NP = High-enregy and nuclear physics
QO = Quantum optics
Faculty initials under 2005 shown. The last column labeled Δ is the change needed to achieve FRS-97 goals.

The FRS-97 goals represented the beginning of a deliberate process through which the sectors used to define the department's research directions are still being regrouped and reinvented. These new sectors reflected the commonality of science interests, needs and styles within the Department and share an emphasis on known strengths and emerging frontiers. In 2004, a new planning committee was formed ("FRS-2"). This committee is still working and developing a new planning report. **This new report, once presented to and approved by the Faculty, will replace the current strategic plans.** At this stage, the Department's vision for itself involves recognizing that our current six research directions (condensed matter, biophysics, astronomy, high energy / nuclear, quantum optics and theory) form four natural sectors:

Physics of the very small and very energetic: This is the combination of high energy and nuclear physics. Researchers in this area often have projects that have 5+ year horizons, are carried out at large facilities, are often off-site, and usually require substantial managerial and administrative infrastructure.

Physics of medium energies and the quantum world: This is physics of the world in which humans live. The physics of atoms, photons, solids, liquids and gaseous matter are all here, and many of the efforts involve a Rochester signature: optics. This is also the area where physics touches most other sciences, for example in bio/medical physics.

Physics of the very large: This is where astronomy and astrophysics are found. These researchers also often operate on longer timescales associated with large instruments, often use massive computational technologies, yet often also include many on-site personnel.

Theoretical Physics: Each of the above sectors has both a theoretical and an experimental component. Yet from the point of view of intellectual atmosphere and stylistic needs, "theory" has its own collective identity. In our department, for example we have Mathematical Physics seminar series together with Math that are uniquely "theory" driven.

In the table below, we show an extension of the FRS-97 table, defined in terms of these four primary sectors.

	Theory	Experiment
Small & Energetic	3	7
Mesoscale & Quantum	3	7
Large and Complex	2	3
Theory	1	
Total By Mode	9	17
Total	26	

<u>*The benefits*</u>

The most immediate consequence of the FRS-97 redefinition was to consolidate infrastructural needs – secretaries, shops, etc. However the an equally important plan was to prepare for resource changes faced by the Department, and specifically, the closure of the Nuclear Structure Research Laboratory (NSRL) along with the consequential integration of its faculty into Bausch and Lomb.

In a more visionary framework, the regrouping allowed for a systematic hiring plan by field and area that is still in place today. The consequences of this strategy are best illustrated by example. In implementing the first phases of this strategy, several key hires were made: Eric Blackman, Regina Demina, John Howell, Steve Manly, Kevin McFarland, and Alice Quillen. In some cases, the hire was directly outlined in the plan (i.e. Howell, Manly and Quillen) while in other cases hires were a consequence of coordinated retirements along with FRS group size re-planning (i.e. McFarland and Demina), designed to maintain our strength in areas where we already excelled. During the 1995-2005 period, one of the best illustrations of *innovation* in departmental recruiting can be seen in the hiring of Adam Frank and Eric Blackman. These two hires were aligned with the Department's tradition of excellence in astronomy, yet represent a deliberate decision to move the department towards a new frontier: plasma astrophysics. Furthermore, the Department reached out and leveraged the plasma physics strength at Rochester provided by the LLE. Both appointments were coordinated with the LLE and have been enormously successful.

How are we at reading the crystal ball? The "Grand Challenges" of physics according the National Academy of Sciences

The six grand challenges identified by a blue-ribbon National Academy panel are:

developing quantum technologies;
understanding complex systems;
applying physics to biology;
creating new materials;
exploring the universe; and
unifying the forces of nature.

The NAS committee identified the six areas "based on their intrinsic scientific importance, their potential for broad impact and application, and their promise for major progress during the next decade."

In our recent hires, we are nicely aligned with these challenges:

Eric Blackman – plasmas and complex systems at astrophysical scale
Regina Demina and Kevin McFarland – forces of nature
John Howell – quantum technologies
Steve Manly – new materials and new states of matter (quark-gluon plasma)
Alice Quillen – exploring the universe

At present we have two parallel searches underway: one for a theoretical physicist and a second for a condensed matter/biophysicist with emphasis on a person who uses optical techniques. The department's interest in nucleating a biophysics program was clearly described in the 1997 FRS report and in 2001 a Biological Physics Committee, including a representative from outside of the Department, presented a framework for understanding trends and developments in the field. This report (attached) was supplemented by a series of visits and lectures from some of the Nation's leading biophysicists and extensive consulting with faculty leaders throughout the College and in the Medical Center. The result of this study is being used to guide our current recruitment effort. We also note that some of our tenured faculty (Bigelow and Teitel) have also developed interest in the field (Bigelow through collaborations and Teitel during a recent Bridging Fellowship).

Shaping the department for the next millennium: phase II

Turnover

The Department is particularly proud of its record of retention; essentially all of our turnover is a result of retirement of senior faculty. Over the last ten years we have made eight junior appointments and experienced only one non-planned departure (i.e. non retirement). On average then, looking at Departmental demographics and past performance, we can expect to make one appointment per year during the next 5-10 year period. Our goals in making these appointments are to expand frontier areas and preserve known strengths.

Finding the best and the brightest

First a recent lesson: Approximately six months ago we tried to recruit a talented junior female candidate in the late phase of a post-doc with a famous Nobel Laureate. Her interests are in a new area for the Department (string theory) which has close ties to mathematics. This recruitment was coordinated with a second (two-body) recruitment in Math and success would have allowed Rochester to become an "instant powerhouse" in the field, benefiting PAS, Math and the University. Shortly after we began the recruitment, some of the Nation's leading institutions learned of our efforts and began to compete with us. As a result we did not succeed. While the odds of winning in such a recruitment were small, the payoffs, had it been successful, were disproportionately large. The moral of this story is that when an unanticipated yet exceptional opportunity arises, as a department, we are prepared to and will move on it.

Reviewing the past decade of hiring, we make several key observations:

- When seeking to hire in a given subfield, we have been rewarded for our patience. That is, we have good examples where running the search for more than one year has allowed us to "find the best person."

- A vital path to hiring a first-rate junior person in an established subfield of excellence is to be prepared to act decisively when an outstanding candidate is identified, even when the possible recruitment is out of synch with the current plan.

- When moving into new subfields, or when recruiting women and minorities, we must be alert for targets of opportunity.

- When we carry out searches, we benefit greatly from the inclusion of both experimentalists from the relevant sector and theoretical research faculty. We also benefit from the inclusion of joint appointment faculty, both in terms of search input and workload and in terms of cultivating interdepartmental ties.

Simply put, in recruitment, timing is everything. But how to respond?

Hiring Strategy: The power of parallel processing

This year we have translated these lessons into a new core component of our recruiting strategy. Within the framework of the new four "sectors" described above, we have launched two parallel searches. We are able to do this because our long range planning is clear: we seek soon to hire in condensed matter/optical physics/biophysics and also to add to the theoretical physics strength of the Department. To assure that we can find the best and the brightest, we negotiated with former Dean Leblanc and were given the authority to search in parallel and fill the current available slot in whichever area we first find the best person. We hold that, on average, in the time that it takes to negotiate and complete even one recruitment, a new opening is likely to arrive, and by parallel processing we will be ahead in our searches and be ahead in finding the best candidate. We stress that our ability to run parallel searches is new for our department and that it rests on the collegial quality of our Faculty.

Hiring Strategy: Leveraging with other departments and units

It is often said that at the University of Rochester, and specifically in the College, "we are small and cannot afford to do everything, so instead we choose carefully what we do and we do it well." In PAS we believe that this philosophy can be vastly expanded if one softens the boundaries of "the department." We believe that the College not only has peaks of excellence, but, euphemistically, it can and does have "mountain ranges of excellence." For example, optical physics spans PAS, the Institute of Optics, the LLE, Mechanical Engineering, Chemistry, etc. Likewise, research on physics of condensed matter systems can be found in several departments. Recognizing that research in physics and astronomy takes place across several departments and units, we adopt, as a fundamental part of our strategic planning, cooperative, coordinated and collaborative programs with other departments. And, specifically, in current faculty searches, and in future recruitments, we seek to (1) involve members of other departments, particularly those with joint appointments in PAS, in our search committees and (2) hire faculty whose interests have benefit to other departments and units. Recent examples mentioned earlier include the theoretical plasma astrophysics hires in connection with the LLE and Mechanical Engineering.

The Department not only seeks to leverage its own recruiting efforts across University strengths, but to support recruiting and retention efforts in other departments. Examples of the latter include recent joint appointments such as Ren from Mechanical Engineering (who is also a plasma physicist) and Tarduno in Geology (who is also a geophysicist) as well as PAS faculty help in the recruitment of Nick Kuzma (an atomic /condensed matter physicist by training) as a junior faculty member in BME.

Growing the research base through collaboration

As noted above, (1) some of the most exciting frontiers of physics and astronomy are at the borders between physics and other fields and (2) given our small size, collaborative efforts that reach outside of the Department are effective approaches to improving our reputation and performance. Over the next 5-10 year period we will aggressively seek partnerships within and external to the University. Examples of such initiatives include:

- In theoretical physics and specifically, high-energy phenomenology, Lynne Orr has in recent years formed a regional phenomenology center of excellence with SUNY Buffalo. With her colleague at Buffalo she has recently spearheaded a nationwide Large Hadron Collider Theory Initiative and assembled a multi-university team including Rochester, Buffalo, Johns Hopkins and Michigan State that has made a coordinated request to fund the Initiative.

- In quantum optics, John Howell has teamed with Bob Boyd in Optics in a Department of Defense MURI (Multi University Research Initiative) on quantum imaging and information.

- In nanoscience Bigelow has teamed-up with Stroud (Optics) and Feldman (ECE) to create a nanoscience research team funded within a National Science Foundation multidisciplinary initiative.

- PAS faculty joined a group of faculty interested in a brain institute that would involve broad development including a center for imaging science. In a not unrelated effort, PAS faculty helped prepare a proposal for a training center for the Howard Hughes Medical Institute. This latter project included Optics, BCS and BME. These efforts are in direct support of our departmental initiative in biophysics.

- PAS has provided leadership creating a DoEd GAANN graduate training program in Chemical Physics and is in the planning stage of expanding this to include Chemical and Biological Physics, recognizing the increased national interest in chemical and biosensor science and technology.

PAS has been a leader in assisting other departments and units seeking student training grants and in creating NSF Research Experience for Undergraduate (REU) sites. This will remain a core part of our College-wide vision of education.

To enable faculty initiatives in creating new group programs, grants, etc. the Department will use income from its endowment to bootstrap new efforts, facilitate faculty meetings and coordination trips, etc.

We note that a common idea in the above examples is that the Faculty, the Department, the College and the University can benefit from creating a form of “branding” when it comes to multi-investigator research and funding initiatives – be it quantum imaging or high-energy phenomenology.

While it is not realistic to predict exactly what new initiatives will be mounted over the next decade – they depend on a confluence of people, ideas and funding agency opportunities – the above examples reflect our strategic commitment to finding new research directions, and to finding innovative ways to support these activities.

ATTRACTING and SERVING STUDENTS AT ALL LEVELS

Challenges

A prime concern of the Department is recruiting the best students, be they undergraduates, graduates or post-doctoral associates. For undergraduates, the class size is good and stable. New approaches to increasing the number of undergraduate students in Physics and Astronomy programs are being developed. In terms of graduate students, the situation is also positive and, on average, approximately one-third of the students are supervised in groups outside of the Department. Attracting the best students, particularly women and minority students is an ongoing challenge and a departmental priority. Student support remains a prime concern for the Department and new interdepartmental programs are being developed to broaden the support base. Of particular concern is competition in terms of graduate stipends offered by peer institutions. At the level of post-doctoral students, the situation has become particularly competitive with increasing salaries at peer institutions and national facilities making recruitment challenging.

Undergraduate Students

Recent American Institute of Physics (AIP) data show that our current average undergraduate class size is typical for a Ph.D. granting institution and that we are slightly above average based on our FTE faculty size. Given the typical entering College class size, it does not seem easy for us to change our number of majors significantly (i.e. by more than the random $\sqrt{N}$ fluctuation $\sim\pm 4$). Indeed we note that our undergrad class size remained approximately constant through the Renaissance downsizing. Nevertheless we seek to broaden the degree earning PAS major and minor pool. We will accomplish this through an increase in the number of double majors, special program participants, etc. Indeed we are already seeing some success, as reflected in substantially increased enrollments in our courses for majors. The Department's REU and Teaching Internship programs are important components of our undergraduate recruitment and retention efforts, present and future.

Through our REU programs, the WISE program (including the Teaching Internship program), and other efforts we also seek to make the Department as welcoming as possible for women and minorities. Progress in this arena is a hard to quantify yet it is a particularly high priority.

Interdepartmental coordination - By working closely with other departments, for example Math and Optics, we have already created well thought-out "standard" programs through which students can add a degree in Physics without requiring crippling overloads. Over the next decade, we will extend this approach to include double degrees not only with other sciences but also with the humanities. We find that key strategies for enrolling double majors involve early advising and information campaigns. Students are more likely to double major if they can see a "typical" four year schedule as early as possible in their program, and if they can see the options and trade-offs spelled out clearly. We have also aggressively expanded the cross listing of courses with allied departments. The primary goal here is to offer to majors in Physics and

Astronomy, and to students in our partner departments, a broader range of upper-level course electives. We also seek to leverage cost-intensive laboratory investments made in various programs and to minimize unnecessary duplication (i.e. courses in electronics, computer interfacing, and scientific computation are often taught in many departments).

In a related effort we have created certificate programs (e.g. Biological and Medical Physics) and created 3+2 and 4+1 BS/MS programs in Physics and Education, and Medical Physics. These are excellent examples of cross-unit collaborations (Physics+Warner and Physics+Medical Center) that we will seek to grow in the next decade.

Workshops - The College has been a national leader in the research and development of the peer-led Workshop model of undergraduate education in science, math and engineering. This model is a response to the well-known deficiencies of the lecture/recitation format that assumes that understanding can be transmitted from teacher to student by show and tell. Faculty are the primary actors in the lecture model; students are the primary actors in the Workshop model. Several faculty from our department have a significant investment in Workshop teaching, dating back to 1999. The Workshop is now "the way we teach" in several courses for beginning students and we now see some 400+ students per year learning physics within the model. It is also the way we want to teach in the future. The consequences for our department have been significant in terms of learning and student satisfaction, yet it has not come without a price. We have invested significant staff time in working through the challenges of finding and scheduling teaching space suitable for Workshops and our staff have helped train staff in other departments in these areas. We see as a strategic priority for the College the need to centralize and formalize support for Workshop based courses.

Graduate Students

Over the past several years we have put into place an aggressive program to increase the graduate student stipend to be on par with our peers. The decision to do this was not without “pain” as research budgets in existing grants had to absorb unexpected increases in costs, as did the teaching budget of the Department. Although initially these changes do not affect indirect income to the University, in the long term the increased stipend is reflected in an increase in research dollars requested in new grants and thus in an increased indirect stream. So far the impact is clear and positive: Incoming students interviewed indicate that our more competitive stipend was a real factor in their decision to come to Rochester.

We have also broadened the cross-listing of graduate courses in Physics with other Departments, specifically Optics, to provide more course options for physics students working in optics. We now have a tightly coordinated two-year quantum optics graduate specialty cycle taught by Institute and PAS faculty. Similarly, for students in plasma astrophysics we have expanded course offerings coordinated with Mechanical Engineering. In addition we plan to expand the double degree options by negotiating “typical” programs with other departments. Recent examples (existing) include joint Ph.D.s in Physics and Optics, Physics and BCS, and Physics and History. The latter offering is particularly novel in that it has also involved successful negotiations with the College Writing Center.

Post-doctoral students and fellows

Post-doctoral fellows play a vital role in the research and academic enterprise. They provide an intermediate level of experience between faculty and graduate (and undergraduate) students, they bring prestige to the Department and, on occasion, they become candidates as new members of our faculty (see faculty recruitment above).

In terms of external reputation, named post-doctoral fellows can be *very* significant. Consider for example the Millikan Fellowship at Cal Tech. These prized and highly recognized fellowships attract some of the most energetic young talent in physics to Cal Tech, are competitive and bring a valuable sense of exclusivity, and past Fellows report their appointments on CVs and résumés for the duration of their careers. We have started similar programs in PAS. In high-energy physics we have created the Marshak Fellow and we are currently negotiating with the LLE for a similar distinguished post-doctoral fellowship in plasma physics. A key element of the fellowships is an increased stipend and hence the key is to establish a funding method. In the case of the Marshak, it was created by executive decision by the PI of a large federal grant, together with Departmental support, and for plasma physics the intention is to have the PI supervisor of the fellow provide the core funds while the LLE would provide the supplement. Similar fellowships can also be envisioned as named fellowships provided, for example, through philanthropic gifting into the dedicated Departmental endowment (see below).

DEPARTMENT ADVANCEMENT

Throughout the University, strategies for adding coherence and muscle to the University's development / advancement efforts are a top priority. The Department seeks to play an important role in the emerging effort. At this stage, it is not appropriate to second-guess the advancement structure that Jim Thompson will create, but we offer some strategic points.

At a high level of giving, donor management and philanthropy are of direct University and College concern. However, we believe that there are some situations in which advancement efforts at a Departmental level are important.

For example, Departmental alumni and friends sometimes wish to contribute specifically to the Department. Commonly, this occurs when the person or persons had a memorable learning experience (e.g. in the Physics of Music class) or when the person had a particular teacher or mentor they wish to honor. This situation is most common when the graduate was a masters or doctoral student.

As an example of this latter case, Professor Leonard Mandel is regarded by many as the father of quantum optics and he supervised more than 30 Ph.D. students. When he died, a special symposium was held in his honor and his students banded together to contribute to a departmental fund in his honor. Through numerous modest donations, many tens of thousands of dollars have been accumulated in the "Mandel Fund." These sorts of funds are an ideal starting point for a named graduate or post-doctoral fellowship (see previous section). The Department is fortunate to have several other faculty members who have developed strong and large student followings (Bodek, Eberly, Knox, Okubo, Wolf, etc.) and through events at major professional meetings, departmental newsletters, etc., we will strive to keep the Department and its members fresh in our graduate's memories.

Another area where Departmental involvement can be key is in the case of an endowed College fellowship held by a student, for example and undergraduate. In this situation, direct contact between the Department and the donor can be highly reinforcing, fostering future giving possibilities.

As part of our effort to maintain a strong relationship with our graduates, the Department publishes a newsletter in which giving opportunities are mentioned.

DIVERSITY

Nationally, Physics and Physics and Astronomy departments are overwhelmingly populated with white males. We are proud to have three women faculty members out of 26 FTEs, placing us in the top 15% in the nation. However, women remain dramatically under-represented. Although we have an international faculty, we have no person of minority status.

To address this situation, we place the recruitment of women and minority candidates as a top priority. Specifically, within the department's recruiting strategies, we identify any highly qualified woman or minority candidate as a "target of opportunity" and as such we will consider redirecting any existing search into the area of the underrepresented candidate's specialty. The rationale here is simple: there are few such candidates and we must pursue every opportunity so that we can on occasion succeed. In a similar fashion, when filling named post-doctoral fellowships, we make extra effort to attract underrepresented candidates.

As we work towards creating a more diverse Faculty, it remains a challenge to create an environment that is welcoming, comfortable and attractive to women and minority students. Female faculty members are particularly important, for example, as role models for our students.

DEPARTMENT ADMINISTRATION: A FLAT LEADERSHIP STRUCTURE

Administrative leadership in a small research and teaching department is an arduous and often under appreciated job. A simple review of the tasks needed to keep a department such as ours running shows that there is a substantive base-line of work, regardless of the FTE size. Unfortunately, economies of scale saturate as the department size shrinks, and in PAS, we are at such a limit.

Our strategy in managing Departmental administration is (1) to have a flat, open leadership structure in which a strong group of faculty work closely with the Chair, managing many of the day-to-day internal tasks (grad student support planning, long term departmental planning, technical and shop services, educational grant authorship, etc.), (2) to rotate the responsibility for administrative tasks among several faculty, thus assuring that expertise is not uniquely built up by only a few individuals, and (3) to develop a strong highly skilled and empowered staff. This approach is in keeping with a decentralized view of the department, and has the advantage of keeping substantial power in the hands of the faculty while not overburdening a single faculty member. We will sustain this as a core departmental strategy.

REPUTATION AND FACULTY ADVANCEMENT

As individual faculty members, the primary measure of our success is our scientific output, as measured through publications, etc., our external funding, the success of our students and our professional recognition. All of these in turn affect the College and the University reputation. As described in detail above, the Department's strategy of support for research and education is a key enabler for the first three of these categories. What is often overlooked, however, is a department's support for the latter category – professional recognition.

The Department strategy here is to use a committee of senior faculty – the Faculty Awards and Nominations committee (FAN Club) – who review the performance of each faculty member and search for recognition opportunities (awards, prizes, fellowships etc.) available in the various subfields of physics. This committee then submits nominations on behalf of our faculty and/or encourages colleagues to do so. Experience shows that many awards and prizes are not as well subscribed with nominees as one might think (the members of the Physics and Astronomy community are very busy!) so that the odds of success in any given nomination can be quite high, assuming of course that the nominee is worthy. Our FAN Club Committee, like other departmental committees, includes some external, joint appointment faculty. As evidence of our success, we point to the large number of our faculty who have been named Fellows of the American Physical Society in recent years. In light of our success, the Institute of Optics has also created an analogous committee.

2005 Planning Report
Physics and Astronomy
Appendix A

Report of the Faculty Recruiting Strategy Committee (FRS) on the faculty recruiting strategy for the Department of Physics and Astronomy for the next decade.

N. Bigelow
Y. Gao
S. Rajeev
P. Tipton
D. Watson
F. Wolfs (chair)

April 1997
Department of Physics and Astronomy
The University of Rochester

EXECUTIVE SUMMARY

The University of Rochester (UR) administration has recently targeted the future faculty size of our Physics and Astronomy Department to be 26 for the year 2001 and beyond. The Faculty Recruiting Strategy Committee (FRS) of the Department of Physics and Astronomy was charged with ascertaining how these 26 appointments should be distributed across research fields in order to maintain and build upon the department's excellent research reputation.

To that end the FRS gathered information from inside the Department of Physics and Astronomy, interviewing nearly all associated faculty. The chairs of closely related departments at UR were also asked about their long-range planning strategy. The FRS also interviewed the chairs of physics departments at many leading universities, inquiring about how their long-range plans are developed, and what their current long-range hiring strategy is.

We found a rather broad consensus among the current UR Physics and Astronomy faculty on key points concerning our future. We also found that this vision for the evolution of our Department was quite consistent with the long-term plans of the best physics departments in the nation.

The FRS concludes that the Department has maintained excellence by focusing on a few areas of physics, and that this should continue to be the Department's general policy. Many of the departments that have risen in the NRC rankings have done so by adhering to this strategy. Currently, the Department conducts research in Astrophysics, Condensed-Matter Physics, Quantum Optics, Nuclear Physics, and Particle Physics. There is also a single-investigator effort in Biological Physics. The FRS does not think there are essential omissions in the Department's research effort that would require new groups and initiatives. Our Department currently has 27 FTEs, distributed over Astrophysics (4 FTEs), High-Energy and Nuclear Physics (14 FTEs), and Quantum Optics and Condensed-Matter Physics (9 FTEs). The FRS concludes that the research efforts in our Department are currently unbalanced, with more then 50% of the FTEs associated with High-Energy and Nuclear Physics. Note that due to the retirement of Knox, the effort in Biological Physics is not included in the current FTE distribution.

The FRS has set asymptotic sizes for the research efforts in our Department. These asymptotic values, which are given in Table 5 (Section VII, page 19), will improve the balance of research efforts in our Department, with 5 FTEs in Astronomy, 10.5 FTEs in Particle and Nuclear Physics, and 10.5 FTEs in Quantum Optics, Condensed-Matter, and Biological Physics. The asymptotic values given in Table 5 are meant to guide the Department as new appointments are made. Given the fact that it will take more then a decade to evolve to these target values, the FRS realizes that our planning must remain fluid. It must allow us to respond to the evolving nature of our research itself, the potential for targets of opportunity, and possible departures. The more immediate recruiting strategy can be summarized as follows:

- The Relativistic Heavy Ion Collider (RHIC) project at Brookhaven offers a chance to study matter at extreme densities and temperatures, and moves the current Nuclear Physics effort into an area of overlap with High-Energy Physics. The search of the Quark-Gluon Plasma is by many already considered a combined Nuclear and High-Energy Physics effort. The FRS recognizes that a viable effort in Quark-Gluon Plasma Physics requires more than one investigator and recommends adding another faculty member to this effort before data-taking at RHIC starts in 1999. The FRS also recommends a gradual consolidation of the High-Energy and Nuclear Physics efforts, reflecting convergence of the aims and techniques of these two fields.

- Because of discoveries inevitably to be made by the new generation of observational facilities, the years ahead will be very exciting in theoretical astrophysics. There is broad consensus that we are below critical mass in this area and should add a faculty member. It is our view that the best investment would not be in the direction of computational plasma physics, since that program already has critical mass.
- There is a rather broad consensus within the Department to add a faculty position in Biological Physics. We find that many of the better outside departments are expanding in this area. Moreover, there are many internationally recognized efforts in Biological Physics that are carried out with a single physics FTE; specifically, Knox's program is an excellent example of the external visibility that a single FTE can have in this field. A single-investigator effort in Biological Physics can have substantial impact as a result of coordinated activities with other related initiatives within the University. The program in Biological Physics can also be strengthened by seeking future appointments in Condensed-Matter Physics and Quantum Optics which have a potential for overlap with the Biological Physics program. The FRS therefore recommends that a thorough study, examining the possibilities of starting a new activity in Biological Physics, precedes any future appointments in Condensed-Matter Physics, Quantum Optics, and Biological Physics.
- Because of inevitable discoveries expected at the Tevatron and/or LHC, the long tradition of excellence in High-Energy Physics within the department must be maintained. The FRS thinks that this can be done with a smaller size group, but notes that this reduction will have to be carried out very carefully to avoid seriously weakening one of the department's premier research activities. In particular, special care will need to be taken to preserve the financial strength of the department's largest, and most comprehensive, research grant. This will require acting promptly in response to, and if possible in anticipation of, faculty departures from within the ranks of the DOE-supported High-Energy Physics experimentalists. In addition, the age profile in experimental High-Energy Physics is far from optimal and needs to be addressed.
- The rich tradition in theoretical physics at Rochester should be reinforced through the appointment of a formal theorist.

The FRS recommends that the next two appointments be in the area of experimental high-energy nuclear physics and theoretical astrophysics. The other three appointments mentioned above have approximately equal priority and should follow as soon as is possible, given the constraints on the Department size.

I. INTRODUCTION

In November 1996 the Department of Physics and Astronomy approved the formation of a Committee that was charged with developing a faculty recruiting strategy for the next decade. The member of this Faculty Recruiting Strategy Committee (FRS) are N. Bigelow, Y. Gao, S. Rajeev, P. Tipton, D. Watson, and F. Wolfs (chair). This report is a summary of the conclusions of the FRS and an outline of the procedures used to obtain the information on which these conclusions are based.

The boundary conditions imposed by the UR Renaissance Plan are summarized in Section II. The procedures used by the FRS are discussed in Section III. In Section IV, important current and future research initiatives in each of the research areas currently pursued in Rochester are summarized. In Section V a summary of the interviews of faculty members associated with our Department is provided. Information collected about recruiting strategies at other institutions and other UR departments is described in Section VI. The conclusions of our study are summarized in Section VII. Finally, in Section VIII, the proposed recruitment strategy and priorities are discussed.

II. BOUNDARY CONDITIONS

The Rochester Renaissance Plan requires that the Department of Physics and Astronomy reach a size of 27 FTEs in 1998 and 26 FTEs in 2001. Currently our Department has 26 FTEs. Assuming the successful completion of the current Condensed Matter and Quantum Optics recruitments, and one retirement (Knox), our Department will have 27 FTEs in the 1997 - 1998 academic year, distributed as shown in Table 1. This table also shows the acronyms that will be used for the various research areas discussed in this report.

III. PROCEDURES

The FRS conducted interviews with almost all faculty members associated with the Department of Physics and Astronomy (full-time faculty, adjunct faculty, and emeriti). The basis of each interview was a series of questions that were distributed to all faculty members in December 1996 (see Appendix A).

The FRS also collected information from other University of Rochester Departments/Institutes that have ties to the Department. The FRS contacted the chairs of the following Departments:

Department of Chemical Engineering
Department of Chemistry
Department of Electrical Engineering

Field	Theory		Experimental	
Astronomy (ASTT, ASTE)	1	Frank	3	Forrest Pipher Watson
Condensed matter (CMT, CME)	2	Shapir Teitel	3	Douglass Gao TBA
High-Energy Physics (HEPT, HEPE)	4	Das Hagen Orr Rajeev	7	Bodek Ferbel Lobkowicz Melissinos Slattery Thorndike Tipton
Nuclear Physics (NUCT, NUCE)	1	Koltun	2	Cline Wolfs
Quantum optics (QOT, QOE)	1.5	Eberly 0.5 Mandel	2.5	Bigelow 0.5 Mandel TBA
	9.5		17.5	

Table 1. Current distribution of 27 FTEs in the Department of Physics and Astronomy.

Department of Mathematics
Department of Mechanical Engineering
Institute of Optics
Laboratory of Laser Energetics

Each of the Chairs was asked to comment on 3 or 4 specific questions which are shown in Appendix II.

During the faculty interviews the FRS collected information about which physics and astronomy departments at other research universities our Department should compare itself with. After the completion of the interviews, the FRS asked the chairs of the physics and astronomy departments at Berkeley, Caltech, Carnegie Mellon, Harvard, Johns Hopkins, MIT, Northwestern, Ohio State University, Santa Barbara, Pennsylvania, and Yale to comment on the questions shown in Appendix III.

The FRS also looked at physics departments for which the NRC rankings changed significantly between 1982 and 1993. Most of the departments that made the biggest gains are members of the 1993 top 40, and many of those that suffered the biggest losses are members of the 1982 top 40. The five departments in each of these categories with the biggest ranking changes are listed in Table 2. On the principle that the reasons for some of the big losses might be as instructive as those for the big gains, the FRS has contacted the Chairs of the Departments

NRC ranking increments				NRC ranking decrements			
University	1993	1982	change	University	1993	1982	change
Boston University	39	69.5	30.5	University of Arizona	45.5	36	-9.5
University of Florida	36	55	19	Pittsburgh	40	30	-10
Ohio State University	24	39	15	SUNY Stony Brook	22.5	12	-10.5
Rutgers University	20	33	13	Brandeis University	42.5	29	-13.5
UC Santa Barbara	10	19	9	Rockefeller University	40	15	-15

Table 2. List of physics departments whose NRC ratings changed significantly between 1982 and 1993.

listed in Table 2 and asked them to comment on the questions shown in Appendix IV. The FRS notes that several of these Institutions have separate Astronomy Departments (Boston University, Ohio State University, and the University of Arizona) whose ratings were not included in the NRC rankings shown in Table 2.

Relative to the 1982 study, no private university doctoral program in physics moved from being rated less highly than Rochester to being rated more highly. Two private university programs, Rockefeller and Carnegie Mellon, went from being rated more highly than Rochester to being ranked lower; two public university programs, Rutgers and Ohio State, have taken their place within the top 25 research-doctorate departments. Overall, Rochester was tied with Brown at rank 25 in 1982, and is still tied with them, although the decision to rank Rochester's optics program separately has resulted in the Rochester physics department's nominal ranking being artificially lowered to 26.5.

IV. CURRENT AND FUTURE RESEARCH INITIATIVES.

In this Section we describe important current and future research initiatives in the fields currently pursued in our department, and discuss the level of effort (number of active faculty) required to have a substantial impact on each field. Our primary sources for this information are the department faculty themselves, and long-range planning documents generated by committees of the various funding agencies and of other agencies such as the National Research Council. For simplicity we analyze each of the fields currently pursued in our Department separately, and discuss theoretical and experimental work in each field together. It should be borne in mind that this dimension-reduction has a tendency to obscure the traditionally strong interactions among theoreticians working in different fields; we attempt to redress this shortcoming with a separate item on theoretical physics in which a scan is taken "along the theory axis," assuming transparent boundaries among fields in this direction.

Our objectives are to identify the major themes in research in the several fields of physics and in particular in the fields for which the intellectual appeal and scope are a good match to our Department; to determine as precisely as we can the critical mass (the number of faculty required to have a decisive influence on more than one main theme) in each field; and to explore the implications of external funding forecasts for our efforts. In the first of these three activities we have avoided extensive discussion or laundry-lists of topics, since these can be found in the field-wide long-range planning documents. In the second activity we have tried to keep in mind the considerable uncertainties in the definition and determination of critical mass, but have striven to characterize the scope of typical research projects in each field and thus to identify number thresholds and the potential for "constructive interference" of faculty efforts in research groups. A summary of our determinations of critical mass is presented in Section IVh; this is used throughout our planning to identify the minimum investment of faculty resources required in each area, and the areas in which investment will produce the greatest returns.

IVa. Astrophysics (ASTT and ASTE)

In Astronomy and Astrophysics, we seem to be on the verge of a burst of discovery and synthesis, driven by the convergence of sophisticated technology - advanced detectors and instrumentation, and supercomputers - with new platforms of unprecedented power, like the NASA Great Observatories, 8-10 meter ground-based telescopes, and a revitalized (though smaller) NASA Explorer satellite program. These facilities will affect many of the most fundamental studies of *origins* - the origins of large scale structure in the universe, of galaxies, of stars, of planetary systems, and of objects on all scales in between - and will lead to advances of deep scientific importance and powerful public appeal. There is even a new NASA program called, appropriately enough, Origins, which will embrace (and fund) many of these studies. Full discussions of the scientific justification for Origins can be found in the current field-wide long-range planning documents for astronomy (see, in particular, the 1996 report for the Association of Universities for Research in Astronomy (AURA), called *HST and Beyond* (A. Dressler, chair), and the latest (1991) once-per-decade NAS/NRC report, *The Decade of Discovery in Astronomy and Astrophysics* (J. Bahcall, chair)).

Because of the complexity of modern observatory and satellite systems, the scope of a research project in observational astronomy that would contribute substantially to one of the fields themes is far larger than the scope of research undertaken by an individual investigator. Critical mass would thus consist of a group sufficiently large to have a significant influence within a multiple-institution collaboration that conducts a major observatory or satellite project - comprising at least 10 - 20% of the co-investigators - and to carry out supporting ground-based observational programs and analysis involving at least a few of the field's themes. In that sense our Departments infrared astronomers are perhaps the best example the FRS has found of a research group just at critical mass. Because it is a good example we will elaborate a bit further on it here, and use it to define what we call the **large scope** critical-mass paradigm. The infrared astronomy group has a substantial presence on the fourth of the Great Observatories, the Space Infrared Telescope Facility (SIRTF), which is expected to contribute crucially to all of the "Origins" studies. The foundation of the group's strength is its development, in collaboration with several industrial entities, of a variety of the most sensitive focal plane detector arrays for infrared wavelengths, and expertise in the development of imaging and spectroscopic instruments. This has led to opportunities that may not have occurred otherwise for involvement in large collaborative projects. The variety of the group's research projects - concentrated on star formation, galactic structure and the origin of active galactic nuclei - by no means embraces all of astrophysics, but is broad enough to attract good graduate students and postdoctoral researchers. The resources of the infrared astronomy group are sufficient to continue to provide leverage for UR participation or direction for many future initiatives in ground-based and space infrared astronomy, even if the group remains at its present size.

With a single theoretical astrophysicist at present, however, ASTT is below critical mass, even considering the smaller scope of projects in theory (see Sections IVg and IVh). Adam Frank's research has strong ties both to the Infrared Astronomy group and to the Computational Plasma Physics group in the Laboratory for Laser Energetics, and is thus stable.

The Astronomy group has been very successful in attracting research support, both in experiment and theory. This has been fortunate; overall, budgets have been tight in astrophysics even while new initiatives are undertaken. Actual NASA funding of space science and astrophysics has been shrinking during the last decade, under pressure from the manned space program (notably the Space Station). However. the advent of the Origins program has recently resulted in budget forecasts that are flat for the next decade. NSF funding for single-investigator programs has also declined under pressure of expenditures on large, new facilities and overall flat funding.

IVb. Condensed Matter Physics (CMT and CME)

Condensed-Matter Physics (CM) is the largest and in many senses the most diverse field in physics. It is also characterized by strong connections to many other fields such as Biological Physics, Materials Science, and Microelectronics, and therefore has a particularly direct impact on society. CM is presently in the midst of an extended period of discoveries and invention of new measurement techniques. Some of the exciting themes within CM include (1) highly correlated systems, such as high temperature superconductivity, fractional quantum Hall effect, and heavy Fermions; (2) mesoscopic systems and nanostructures; (3) giant magnetoresistance or colossal magnetoresistance; (4) "soft" systems such as polymers, organic or biological materials; (5) non-linear dynamics, chaotic or disordered systems, and self-organizing systems. The UR CM group has been regaining strength after having recruited three junior faculty members, two in theory and one in experiment, between 1985 and 1988. As a result, our CM activities have been enhanced in selected areas such as statistical mechanics of highly-correlated systems and interfaces in soft materials. Strong collaborations with researchers in other UR departments and in industry have been established.

Lately there has been a tendency for the creation of central facilities such as synchrotron light sources, neutron sources, and large magnets for use by CM experimenters. There are also strong CM activities in research centers such as the NSF Science and Technology Centers and Materials Research Science and Engineering Centers. Nevertheless it remains the case that decisive advances in any given theme of CM require experiments or theoretical work of a scope that fits within the scope of activities of individual faculty investigators. The issue of critical mass is thus very different from that discussed above for Astrophysics: concentration of faculty effort on a given facility or within a given theme is not absolutely necessary for success. There are many examples of physics departments with highly regarded programs in CM for which there is relatively little overlap in research among the faculty. Without endorsing the notion that research-interest overlap is dispensable in CM, the FRS recognizes that at least to some extent impact in CM increases with the number of themes represented, and therefore the critical mass is taken to be the number of faculty it takes to cover a substantial fraction of the important major themes: approximately two theoreticians and three experimenters. (In the following we will take this example to define what we will call the **small scope** critical-mass paradigm.)

The funding sources for CM are quite diversified and include most of the research-supporting federal agencies. Consequently, CM enjoys limited protection from harm by abrupt shifts of policy which may affect one or two funding sources. Funding for our CM group reflects the national trends. Support of CMT at Rochester has been steady despite the strong competition in this area. Funding of CME in our Department has been good in the past few years and has significantly increased recently even though the general funding trend is declining. This level of support may not be sustained in the long run unless the group can be brought up to critical mass in the near future.

IVc. High-Energy Physics (HEPT and HEPE)

The Standard Model of elementary particles and their strong, weak and electromagnetic interactions has been successful, but leaves many free parameters undetermined from first principles and leaves many fundamental questions unanswered. Filling these gaps, searching for particles and interactions beyond the Standard Model - phenomenology of the top quark and Higgs boson, supersymmetry, grand unification, quantum gravity, string theory - will be the main themes in High-Energy Physics (HEP) for quite some time. Experimental tests of the Standard Model will be performed predominantly in the top- and bottom-quark sectors. Currently, the only facility that can produce top quarks is the Tevatron at Fermilab. Bottom-quark (B) Physics will be done predominantly at the B factories, CESR, PEPII, and KEK, all of which are currently under construction. Direct searches for new particles and interactions (SUSY, etc.) will continue at the Tevatron and later at the Large Hadron Collider (LHC) at CERN. Among non-accelerator forms of HEPE, the emerging field of particle astrophysics is considered by some to be a promising way of probing for new physics at very high energies, as well as potentially contributing to advances in our understanding of the very early Universe.

In virtually all cases the scope of single projects in HEPE is beyond the scope of groups the size of entire academic departments, and the next generation of accelerators will almost certainly be beyond the scope of particle physics for entire nations; thus this field can be considered under the same "large scope" critical-mass paradigm introduced above in our discussion of astrophysics. In HEPE, it typically takes a group of 2 to 3 investigators to begin an effort, but once underway, a single investigator can continue and complete the project. In order to maintain Rochester's excellent reputation and continue to attract good students, post-doctoral candidates, and adequate funding, a variety of projects (3 - 5) should be maintained. Assuming that each faculty member is involved in two projects, the FRS estimates that the critical mass for an HEPE effort is 3 - 5 faculty. Rochester has excellent programs in HEPE, with groups working at the Tevatron (CDF and D0), at CESR on CLEO, and at the LHC. This excellence is due primarily to the fact that the HEPE group is somewhat larger than critical mass.

HEPT tends not to be driven by large groups or facilities, but by individual initiatives and ideas; the scope of theme-level research projects tends to be within the grasp of individual investigators. Again this leads prima facie to the "small scope" paradigm introduced above in the discussion of CM, and a critical mass of about two faculty. However, one must recognize that in HEPT it is important to try to maintain programs both in formal theory and in phenomenology. The HEPT faculty at UR each tend to have a long-term focus for their research, but they also keep up on the short-term trends that routinely sweep the field as theoretical breakthroughs occur.

Funding levels in HEP continue to be relatively good, and the Rochester group has done well at maintaining its traditionally high level of support. Over the last five years the funding profile of the DOE-supported HEP group has been flat.

IVd. Nuclear Physics (NUCT and NUCE)

Nuclear Physics (NUC) has as its objective the understanding of the properties of nuclear matter under both normal conditions and conditions of extreme temperature and density. Research in NUC can, broadly speaking, be subdivided into four themes: (1) nuclear structure and dynamics, the area in which our department has traditionally been strong; (2) the quark structure of matter, as can be probed with electron, photon, and proton beams; (3) nuclear matter at extremely high densities and temperature, the deconfinement of quarks and gluons and the formation of the quark-gluon plasma as can potentially be studied in high-energy heavy ion collisions; (4) fundamental symmetries, high-precision experiments and nuclear astrophysics. NUC is currently making a transition from a mode of operation with many small university-based accelerator laboratories to a mode of operation with several large national user facilities. Several powerful user facilities have just been completed or are currently under construction to address the scientific questions outlined in the preceding paragraph. These include the Relativistic Heavy-Ion Collider (RHIC), radioactive ion-beam facilities at Oak Ridge and MSU, the Continuous Electron Beam Accelerator Facility (CEBAF), and the Solar Neutrino Observatory (SNO). The new facilities will drive the field for at least the next 10 years. The scientific justification for each of these major initiatives is described at full length in the 1996 report of the DOE/NSF Nuclear Science Advisory Committee, entitled *Nuclear Science: A Long Range Plan.*

The new, user-facility mode of operation has brought NUCE even closer than before to the "large scope" critical-mass paradigm we have applied to ASTE and HEPE. Critical mass for an effort in any of the four themes described above therefore turns out to be 2 - 3 faculty. The NUCE group is currently active in nuclear structure research and high-energy nuclear physics, with one faculty member principally involved in each area. The NUCT group studies the quark structure of matter, also with just one faculty member involved. The FRS notes that there are examples of single-investigator efforts in NUC that are superb, but nevertheless considers each of our present single-investigator groups, and thus NUC as a whole, to be subcritical.

The NUCE program is supported by the NSF. The umbrella grant that previously covered the entire NUCE program, including the operation of the NSRL tandem accelerator, has recently been converted into single-investigator grants, since there is no overlap in the programs in nuclear structure physics and high-energy nuclear physics. Although the total level of funding for the NUCE program has decreased in recent years, mainly as a result of the phase-out of the operation of the NSRL tandem accelerator in 1993, the funding per faculty member has been flat.

IVe. Quantum Optics (QOT and QOE)

As a field, Quantum Optics (QO) is concerned with the exploration of the nature of light, its propagation, and its interaction with matter. Many advances in QO have enabled dramatic advances in the manipulation and control of both light and matter at the quantum level. Examples of current important themes in QO are: the creation, investigation and application of non-classical states of light; coherence theory; quantum control of matter; fundamental tests of quantum mechanics (e.g. quantum locality and reality, cavity QED), non-classical states of matter (e.g. laser cooled atomic vapors), and atom optics. Some of the really "hot topics" this year include quantum computation, Bose-Einstein condensates, quantum state measurement, atom lasers, and induced transparency. The Rochester group covers the majority of these topics and has a long and distinguished tradition of excellence; QO is the field in which our University comes closest to world leadership. It is worth noting that research in QO is often highly multi-disciplinary in nature. Recent examples at Rochester include ties to atomic and molecular physics, physical chemistry, solid-state physics, high-energy physics, computation, biological physics and materials science.

QO is a "single-investigator" field in which most projects are lead by a single faculty member and most QO faculty have multiple projects, although faculty collaborations at UR appear to be increasing in number. In terms of critical mass, QO is therefore best described by the "small-scope" paradigm introduced above in the discussion of CM. It is hard to make a clear distinction between theoreticians and experimenters in QO. Considering therefore the confluence of theory and experiment in QO and the number of important research initiatives outlined above, the FRS estimates a critical mass of about 3 for this group (theory plus experiment). At the completion of the current faculty search, the largest concentration of QO at UR will be in our Department; however, Rochester's reputation in QO reflects on FTE faculty with appointments in other departments as well as those in our Department, with the second highest concentration of QO FTEs being in the Institute of Optics. In any case, this effort is populated in excess of critical mass, as befits its world-leadership position.

As a result of the single-investigator nature of QO, there are no real large-project initiatives which should be taken into account in Departmental planning. There are periodic examples of "mini-initiatives" within the field such as the recent NSF funding of the Rochester Theory Center for Optical Science and Engineering (RTC). For the most part, however, these initiatives represent the effort of a single individual to promote a specific project. There have also been some recent programmatic initiatives targeted at the promotion of research growth in optical physics. Examples include the NSF Optical Science and Engineering (OSE) program; however, this initiative also emphasized single investigators and small groups. Overall, the funding base for QO, as compared to many fields, is in stable state and perhaps shows some indications of growth. Massive funding growth, however, seems unlikely.

IVf. Biological Physics (BP)

Biological and Medical Physics are diverse and often interdisciplinary fields that include a wide range of basic and applied problems. As a result, it is not easy to obtain a consensus on a few themes that the field as a whole would consider urgent. Nevertheless the vast majority of our faculty, and those elsewhere who were contacted by the FRS, asserted firmly that BP is one of the most interesting and important new fields of physics, and one likely to increase dramatically in importance during the next few decades. Currently, physicists work on problems at the molecular level (for example, energy transfer in photosynthesis, macromolecular structure using NMR and X-ray crystallography), the cellular level (for example, structure and function of membrane bound ion channel proteins, signaling), and the tissue level (medical imaging, tissue optics) levels. A glance at recent issues of *Physics Today* indicates that post-doctoral and faculty opportunities for physicists in these areas is relatively good, both in physics and increasingly in other departments such as Bioengineering, Radiology, and Neuroscience; BP is a growth field, and will be for the foreseeable future.

Within our Department, Knox has been specializing in the chromophores involved in photosynthesis and the energy transfer processes in which they participate (BP at the molecular level). Foster (joint with Radiology) works on physical aspects of photodynamic therapy and on optical spectroscopy and imaging in strongly-scattering systems. Undergraduate and graduate student interest in these areas has been consistent. Knox's research program has been based on undergraduates for several years, and he has sponsored several senior theses. For the past 5 years or so, from one to three undergraduate majors per year have done readings courses and/or senior theses with Foster. Prospective graduate applicants show consistent interest in Medical Physics. Beyond our Department, three things related to BP are happening at the University that may be worth noting. First, the Institute of Optics is currently searching to fill an endowed professorship in medical optics, so there will be increased activity in this area. Second, the University has established a PhD granting program in Bioengineering, with support from the Whitaker Foundation. Third, the Provost's office has launched a University wide initiative in "Biomedical Imaging".

Research in BP tends to be individual-investigator initiated (rather than involving large collaborations), and to be relatively small in scale. Thus the "small scope" paradigm for critical mass would seem to apply. However, since there is no consensus on what constitutes the major initiatives and directions of the field as a whole, the critical-mass issue is even more ambiguous for BP than in other areas. Until our Department as a whole is better educated in BP, the FRS will respectfully decline to estimate a critical mass in this field. We will note, however, that many single-investigator efforts exist that have great impact and international recognition; no better example of this exists than Knox's research program. We also note that the vast opportunities for collaboration represented by the UR Medical Center could provide a great deal of leverage for any program in BP that our Department initiates.

At UR, research in BP is funded principally by the U. S. Department of Agriculture (Knox) and the National Institutes of Health (Foster).

IVg. Theoretical Physics

Our Department has had an excellent tradition in theoretical physics, originally in High-Energy Theory and then expanded into Theoretical Astrophysics, Nuclear Physics, Optics and Condensed Matter Physics. The confluence of High-Energy Theory and Mathematical Physics is one of the most exciting areas in theoretical physics at the moment, with cross-pollination of ideas originally developed in string theory to the theory of critical phenomena (conformal field theory) and even to topology. Fundamental themes of physics (What is the quantum theory of gravity? Is there a unified field theory of all the forces in the standard model? What is the nature of quantum geometry?) attract ambitious and talented theoreticians into this area. Even in Mathematics, fundamental advances have been made by physicists to the extent that they have received some of the most coveted prizes in Mathematics (e.g. the Fields medal). Theoretical astrophysics is currently addressing fundamental problems (What is the nature of active galactic nuclei? What happens near the horizon of a black hole?) and attracts the very best theoreticians. The intersection of Statistical Physics, Many-Body Theory, and Quantum Optics is another exciting area in theoretical physics. The recent advances in the trapping of atoms and their Bose condensate (atom lasers) opens up new theoretical challenges. Quantum Chaos and Quantum Computing is another area of overlap between these fields.

Theoretical physics is a single-investigator effort; thus all of the theoretical efforts in our Department fall under the "small scope" critical-mass rubric. Theorists are also generally broader than experimenters, in the sense that their research tends to cover more of a given field's themes than is possible for a corresponding experimenter, and in fact often cross the boundaries separating the experimental fields. This might lead one to infer that the critical mass in our Departments theoretical divisions is a single investigator, were it not for the following additional considerations. First, a given theoretical physics group needs to be concerned with more themes than a corresponding experimental group to have as great an impact in the long term, in order to offset the greater propensity of experimental groups to make important serendipitous discoveries. Second, the relative isolation and long time between hiring "new blood" makes single-investigator efforts in anything look undesirable. Third, the rising importance of phenomenological and computational aspects of theoretical research in many of the fields of physics suggests that the critical mass can be no smaller than two (one formal theoretician, one phenomenologist). The FRS thus considers the minimum critical mass of a theory group, in any field in which experiment and theory are sharply distinguished, to be two.

IVh. Critical Mass

The critical mass for each of the fields currently pursued in our Department is summarized in Table 3. In QO the close relation between experiment and theory indicates that the critical mass for this field can not easily be broken down into experimental and theoretical categories. We have entered a "1" for BP in Table 3 in recognition of the fact that a stable single-investigator program is possible, but we do not know what it takes to put us on the BP map, either in theory or experiment.

Although all areas of theoretical physics are single-investigator efforts, the Department must recognize that to create a good intellectual climate in any area of theoretical physics 2 FTEs are required. In addition, one must recognize that an effort on HEPT above critical mass is required in order to maintain programs in both formal theory and phenomenology.

In experimental physics a distinction must be made between single-investigator efforts (like CM) and collaborative efforts (like HEP). In either case, a visible effort in each experimental field requires at least 3 distinct projects. In single-investigator fields this usually requires 3 FTEs. In fields with collaborative efforts, usually 2 - 3 faculty are required for each project, although each investigator is usually involved in two different projects. From this information one might conclude that an HEPE group size as small as three could possibly sustain critical mass, but in practice, we know of no successful HEP group this small. In NUCE there are still many real single-investigator efforts, but projects like the search of the Quark-Gluon Plasma are true collaborative efforts. Consequently, the critical mass for a viable NUCE program is somewhat less then that for HEPE.

The FRS notes that our Department can not be at critical mass in all areas and we need to be at least above critical mass in some areas of excellence. In general, being above critical mass will extent our visibility.

Field	Theory	Experiment
Astronomy	2	3
Biological Physics	(1)	
Condensed Matter Physics	2	3
Nuclear Physics	2	3 - 4
Particle Physics	2	4- 5
Quantum Optics	3	

Table 3. Critical mass in research areas covered in our Department.

V. PHYSICS AND ASTRONOMY FACULTY INTERVIEWS

The FRS conducted more then 30 interviews with faculty members associated with our Department. Each interview was conducted by two members of the FRS, and the typical interview lasted around one hour. Each faculty member was asked to give her/his opinion on how to distribute the 26 FTEs that our Department will have 10 years from now. A statistical analysis of the distributions that emerged is shown in Table 4. The results of these interviews can be summarized as follows:

1. There is very broad support for our Department's efforts in astrophysics. In particular, the need for an additional appointment in theoretical astrophysics is generally felt to be urgent. Several faculty felt that our current excellence in computational astrophysics should be complemented with an appointment that emphasizes the analytical aspect. The Department holds the infrared astronomy group in high esteem, and, as we mentioned above, considers it to be exactly at critical mass with three faculty. Some Department members said they would consider it unprofitable either to undertake a new effort or to increase the size of the present group. (A new and different research initiative would of course take 2 - 3 appointments.) However, there were faculty who pointed out the potential desirability of capitalizing on our strength and involvement in SIRTF to make an additional appointment.

2. The Department recognizes that experimental Condensed-Matter Physics (CM) is below critical mass and needs to be strengthened. Most of the faculty agree that the target size for CM should be 2 theorists and 3 experimentalists. Opinions are divided, however, on whether new experimental CM appointments should be mostly basic research inside the Department, or connected to other programs, such as the Materials Science effort. The potential for CM appointments that have an overlap with Biological Physics has been mentioned by several faculty members.

3. The Department has a very strong program in experimental High-Energy Physics (HEPE) which dates from before the Rochester Cyclotron. All agree that excellence in this field should be maintained. There is a consensus in the department, however, that in order to reach a better overall balance of research efforts, the asymptotic size of the HEPE group should decrease from its current size of 7.

   In considering how to decrease the HEPE size and simultaneously preserve the excellence of the group, the FRS has considered several factors. First, although it is possible to have single-investigator driven programs in HEPE, these programs usually grow out of multiple-investigator efforts. Second, information obtained from the HEPE group during the FRS interviews suggests that a 5 FTE effort in HEPE can maintain visibility and funding strength in this field, and therefore defines the critical mass required to maintain our excellent tradition in HEPE. However, such a reduction from 7 FTEs to 5 FTEs will have to be carried out very carefully to avoid seriously weakening one of the department's premier research activities. In particular, special care will need to be taken to preserve the financial strength of the department's largest, and most comprehensive, research grant. This will require acting promptly in response to, and if possible in anticipation of, faculty departures from within the ranks of the DOE-supported HEP experimentalists. The HEPE group also told us that their age distribution is far from optimal, with only one member below the age of 50. Coordinated hires and retirements will be essential to establishing an appropriate age distribution within this group.

4. The Department has a rich tradition in Nuclear Theory. Recent efforts have focused on statistical spectroscopy, using random-matrix models for the study of the chaotic behavior of quantum systems. In addition, the department continues to have an active theory program at the border between Nuclear and Particle Physics. Included in this program are studies of meson interactions with nuclei and specific mesonic effects on nuclear structure. The current nuclear theory program has only one investigator and maintaining a strong single-investigator effort is a challenge. While Nuclear Theory remains an active field, in light of more compelling priorities, there is a broad consensus within the Department not to invest further in this program.

   There is strong support in the Department for the expansion of the effort in Quark-Gluon Plasma Physics. Given the size constraints our Department is facing, it is impossible to simultaneously expand in nuclear structure physics or to startup of new programs in electron physics and radioactive beam physics, since in the latter case a multi-faculty effort is required to have an impact. Many faculty members therefore recommended focusing the Nuclear Physics efforts on a single area, that of Quark-Gluon Plasma Physics.

Field	Aver	Min	Max	Aver Field	Min Field	Max Field
ASTT	1.9 ± 0.4	1	3	2.3 ±0.5	2	3
ASTE	3.1 ± 0.3	3	4	3.3 ± 0.5	3	4
CMT	2.1 ± 0.3	2	3	2.0 ± 0.0	2	2
CME	2.8 ± 0.8	2	4	3.3 ± 0.6	3	4
HEPT	3.6 ± 0.6	2	4	3.8 ± 0.4	3	4
HEPE	5.3 ± 1.2	3	7	5.9 ± 0.9	5	7
NUCT	0.2 ± 0.5	0	2	0.5 ± 0.6	0	1
NUCE	2.0 ± 0.9	0	4	3.3 ± 0.6	3	4
QOT	1.8 ± 0.5	1	3	1.7 ± 0.6	1	2
QOE	2.2 ± 0.4	2	3	2.0 ± 0.0	2	2

Table 4. Summary of the FTE distributions proposed by the faculty members interviewed by the FRS. The error bars reflect ±1σ. The columns labeled Aver., Min., and Max. show the average number, the minimum, and the maximum number of FTEs for a given field that emerged from the interviews. The remaining columns illustrate how a given field looks at itself.

5. The faculty unanimously believes that the Quantum Optics group is a major Departmental strength and that this strength must be maintained. Furthermore, the faculty recognizes Quantum Optics as a sub field which helps to single out our Department when compared with most other first rank research universities, making Quantum Optics one of the Department's vital assets. Several faculty recommended a modest expansion in the group size based on the idea that the Department should invest in its strengths.

6. The Department has had an excellent tradition in theoretical physics and this vitality can be maintained only if new intellect is added to the mix from time to time. The constraints posed by the overall size of the Department and the current composition of theory faculty imply that possibly three new positions in theoretical physics can be anticipated in the next decade. It is essential that these appointments be made in a way that connects the different theory groups into a unified entity, while at the same time strengthening the individual efforts. The Department must be on the lookout for the appointment of a proven leader who can provide the impetus for a unified theoretical physics group. This goal can also be achieved by making junior appointments that will maximize the connections that already exist between the different disciplines. Any joint appointments with for example the Department of Mathematics may best made at the confluence of High-Energy Theory and Mathematical Physics. The remaining appointments should be made in theoretical astrophysics and at the intersection of Statistical Physics and Field Theory.

7. There is strong support in the Department to maintain a program in Biological Physics. It appears to be wise to focus on a program in experimental Biological Physics.

8. The interviews indicate that at some time in the future, the High-Energy and Nuclear Physics groups should be combined to form and a Nuclear and Particle Physics group. Opinions on the implications of this merger of efforts differ.

VI. RECRUITING STRATEGIES AT OTHER INSTITUTIONS

The FRS contacted the chairs of 14 physics or physics and astronomy departments. Those contacted were meant to be a sampling of both the best departments in the country (Berkeley, Caltech, MIT), and the Universities to which UR is most often compared (Johns Hopkins, Northwestern, CMU, etc.). The chairs were first contacted by e-mail, a copy of which is given in Appendix III. Most of the information was eventually gathered through telephone interviews.

We found the chairs of the departments we contacted to be rather forthcoming with helpful information. All spoke freely about their planning procedure; most spoke freely about their resulting plan, volunteering information about the sub-fields targeted for future appointments.

All the Universities contacted had some sort of a 5 to 10 year plan. Many described it as a "rolling plan," meaning it was routinely re-evaluated as ground rules and conditions changed. One Chair reported that five-year plans are demanded of them by their University's administration, which also submits them to visiting committees every five years. Despite the evolving nature of their plans, the consensus was that the planning process was quite valuable and the resultant plan was generally adhered to. Four recurring themes came out of these interviews:

- The choices of field apparently have little to do with recent changes of standing among these schools in the last two NRC rankings. All of the departments who dropped precipitously in the standings decreased in size, presumably due to general university downsizing. All of the departments whose standing improved substantially were expanding dramatically, some by entering new fields but some by restricting their investment to a surprisingly small number of areas. Rutgers University, for example, has increased from 45 faculty to 62 in the past fifteen years, and has added a strong astrophysics effort in the process, but besides astrophysics has groups only in elementary particle physics, nuclear physics and "hard" condensed-matter physics.

- Although there is great variety in the sub-fields that the top NRC-rated departments cover, all of the top rated departments have strong HEP and CM groups.

- Almost all of the departments contacted are interested in starting or expanding programs in Biophysics. Caltech is planning a particularly concerted, Institute-wide, effort in this direction. Many are as much in the dark as we are about how to accomplish this, however. Some chairs expressed the hope that these efforts could arise from "soft" condensed-matter physics research within their departments.

- More than half of the institutions polled targeted astrophysics - particularly theoretical astrophysics and observational cosmology - as an area of recent or future growth. Most already have very strong astrophysics efforts, both within physics and in separate astronomy departments.

It was our sense that most chairs were cagey (properly so) about which sub-fields would be contracting within their departments. Three stated they were decreasing their efforts in nuclear physics. It was pointed out that parallel recruitment searches can put great strain on even the most collegial of departments. In addition, these searches are time consuming and have a mixed track record for success.

The various departments at the UR all were interested in our effort, and in general supported recruitments in the areas of overlap. However, none of these departments indicated a change in their effort in the areas of overlap. It became clear that most of the UR departments surveyed were unwilling to be nearly as candid about their plans as the external physics departments we contacted.

VII. FTE DISTRIBUTION

Aside from a few faculty who discussed more radical visions of a Department with 26 FTEs, most of the faculty ultimately advocate a strategy that emphasizes current strengths with the modifications representing modest corrections to the current distribution. The Department realizes that composition is a zero sum game and that even over a 10 year period, there is little chance to make radical changes. Areas of strength that must be maintained include Astronomy, High-Energy Physics, and Quantum Optics. On this time scale, the Committee envisions that the High-Energy and Nuclear Physics groups are combined to form a Particle and Nuclear Physics group. Based on the information collected by the FRS we believe that the 26 FTEs our Department will have 10 years from now should be distributed according to the distribution shown in Table 5.

The FTE efforts for most of the fields listed in Table 5 are at critical masses (see Table 3 and Section IV). Only Quantum Optics and High-Energy and Nuclear Physics are above critical mass, but since these areas are vital assets to our Department, their current strength must be maintained. Although the single-investigator effort in Biological Physics may appear to be below critical mass, the FRS has observed that many recognized efforts in Biological Physics are carried out with a single physics FTE. Specifically, the program of Knox is an excellent example of the effect that a single FTE can have in this field. Such an effort can have a substantial impact as a result of coordinated activities with other related initiatives within the University. The program in Biological Physics can also be strengthened by seeking future appointments in CM and QO which have a potential for overlap with the Biological Physics program. The FRS therefore recommends that a thorough study, examining the possibilities of starting a new activity in Biological Physics, precedes any future appointments in BP, CM, and QO.

Given the size constraints of our Department, it is impossible to maintain a "stand-alone"

<table>
<tr><th>Field</th><th colspan="2">Theory</th><th>Experimental</th></tr>
<tr><td>Astronomy</td><td colspan="2">2</td><td>3</td></tr>
<tr><td>Biological Physics</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>Condensed matter</td><td>2</td><td rowspan="2">1</td><td>3</td></tr>
<tr><td>Particle and Nuclear Physics</td><td>3</td><td>7 (5 Particle + 2 Nuclear)</td></tr>
<tr><td>Quantum optics</td><td colspan="3">4</td></tr>
<tr><td></td><td colspan="2">9</td><td>17</td></tr>
</table>

Table 5. Proposed FTE distribution for a Department of 26 FTEs.

program in Nuclear Physics. However, the issue of critical mass and visibility can be addressed if the Nuclear Physics effort focuses on areas of overlap with Particle Physics. In fact, the FRS has already observed such a shift of the Nuclear Physics program and the current effort in Quark-Gluon Plasma Physics, is by many already considered a combined Nuclear and Particle Physics effort. The FRS strongly recommends that over the next ten years the High-Energy and Nuclear Physics efforts are combined to form a Particle and Nuclear Physics group.

The effort in Theoretical Particle and Nuclear Physics includes one phenomenologist, to provide a bridge with the experimental program in Particle and Nuclear Physics, and two formal (field) theorists. In Table 5 we have also indicated one theoretical physics appointment that can span more than one group in our traditional alignment. This reflects the conclusion of the FRS that nurturing of the theoretical physics group is an important consideration in future hires, and that synergy of theoretical physics across disciplinary boundaries will significantly strengthen the Department. The FRS also recognizes that the single FTE listed in this table can be leveraged into two appointments if such appointments are considered jointly with other Departments (e.g. Mathematics).

VIII. RECRUITMENT STRATEGY AND PRIORITIES

The proposed recruiting strategy for our Department was guided by a set of "golden rules". The first and most important "golden rule" states that the goal of each recruitment is the preservation of the strength and excellence of our Department. The "golden rules" that are associated with scientific opportunities for our research groups:

- Respond to scientific urgency (RHIC, FNL, SIRTF).
- Make timely investment in new fields (e.g. Biophysics).
- Pursue targets of opportunity (e.g. Shapiro-like events).

The "golden rules" that are associated with the "health" of our research groups are:

- Maintain critical mass and replace key personnel.
- Plan for a sensible age distributions in groups and throughout our Department.
- Preserve the funding stability of our groups.

Finally, the "golden rules" that are associated with Departmental planning are:

- Preserve both the quality and supply of superior graduate students.
- Strengthen teaching and mentoring at both the undergraduate and graduate level.

Based on an assumed rate of one retirement every two years, the FRS obtains the following ordered list of recruitment priorities:

1. **Quark-Gluon Plasma Physics**. Our current effort in this field is, with a single FTE, below critical mass. There is strong support in the Department for a recruitment in this area of overlap between Nuclear and Particle Physics. The FRS concludes that the best time to make this appointment is before RHIC starts its experimental program since it maximizes the

impact that a newly appointed assistant professor can have on this field. The FRS recommends that the search committee for this appointment has balanced representation from both the Nuclear and Particle Physics groups.

2. **Theoretical Astrophysics**. Our current effort in this field is, with a single FTE, below critical mass. The FRS notes that the promise of SIRTF to make important discoveries in many areas of astrophysics, and the privileged position of our present astronomers with respect to this facility and its stream of data, comprises a unique and exciting opportunity for a newly-appointed theoretical astrophysicist to make a mark in a wide variety of astronomical fields. This combination of subcriticality and scientific urgency (SIRTF will be launched in 2001) outweighs the somewhat non-optimal age distribution in ASTT that will result from a near-term appointment. The FRS also concludes that the best investment would not be in computational astrophysics, since our present program is stable, but instead from one of the many complementary disciplines.

3. **High-Energy Physics, Theoretical Physics, and Biological Physics**. The FRS gives equal priority to recruitments in these areas of physics and the actual ordering of these three recruitments will be affected by factors other than scientific priorities. The Department should take into account the need to maintain the continuity of research programs in the event of retirements and the need to maintain a healthy age distribution in each group (six years between appointments in the same field has been the historical norm). The Committee recognizes that a recruitment in Biological Physics must be approached with appropriate caution and the Department will have to be educated how to recruit in this field.

The FRS notes that any change in the retirement rate from the assumed rate of one every two years will effect the number of recruitments that can be carried out over the next 10 years. At the assumed rate, the Department will not obtain the proposed FTE distribution until sometime after 2006.

U N I V E R S I T Y O F
ROCHESTER

COLLEGE OF ARTS AND SCIENCE
NUCLEAR STRUCTURE RESEARCH LABORATORY

Rochester, December 18, 1996

To: Faculty of the Department of Physics and Astronomy

From: Faculty Recruiting Strategy Committee
N. P. Bigelow, Y. Gao, S. G. Rajeev, P. L. Tipton, D. M. Watson, F. L. H. Wolfs

Subj: Faculty Interviews

The Faculty Recruiting Strategy Committee has been charged with developing a faculty recruiting strategy for the next decade (through 2006-7). Factors to be taken into account in this process include:

- The department's historical strengths and traditions
- Current trends and future expectations in research in Physics and Astronomy:
- Intellectual considerations
- Funding considerations
- Reputation considerations
- Existing size constraints and potential recruiting opportunities:
- Assume that the department's size remains 26 full-time Physics and astronomy faculty
- Recognize that 10 of the department's 14 current full professors will have reached age 70 by the end of the 2006 - 7 academic year.

As part of this process we will be conducting interviews with all faculty members associated with the Department of Physics and Astronomy during January and February. We are currently collecting schedule information to arrange these interviews.

Attached you will find a list of questions that will form the starting point for the interview. We would appreciate it if you could respond to these questions in writing in advance. This will allow for a more focused discussion during the interview.

University of Rochester
Rochester, New York 14627, U.S.A.
Tel: (716) 275 - 4937
FAX: (716) 473 - 5384
INTERNET: wolfs @ nsrl31.nsrl.rochester.edu

Questions to be used as a starting point for the interviews:

1. What are the important research problems and new initiatives in your field ?

2. What defines critical mass of University-based groups in your field (faculty size, number of projects, etc.) ?

3. To which University-based groups should our department compare itself in your field ?

4. What are the funding trends in your field ?

5. Are there any recent long-range planning reports in your field ?

6. Are there any emerging fields in Physics and Astronomy that Rochester should get involved in ?

7. What is your opinion about the current composition of our department ?

8. If one considers the possibility of expansion or contraction of the spectrum of activities of our department, what are the tradeoffs between breadth and depth of our programs ?

Prof. ....
Department of ......
University of Rochester

Dear .....,

The Department of Physics and Astronomy (PAS) is currently reviewing its composition in order to bring our faculty size into alignment with the Renaissance Plan over the next decade. Over this period some retirements are anticipated and, therefore, so are new faculty appointments. An important question therefore is how to make these appointments. To help in developing a long-range plan for our Department we are collecting opinions both from inside and outside our Department. Since your Department has ties with our Department we would very much appreciate your input. We would appreciate it if you could comment on the following specific questions:

(1) Are there areas of research commonality and overlap between our departments which should be taken into account by us in developing our plan? Do you have any plans to change the number of faculty members in any of these allied areas?

(2) What kinds of faculty hires in PAS would have the most positive impact on your Department and on the University?

(3) Are you aware of any funding trends or other related issues which the Committee should take into account?

(4) Do you have a vision for joint Mathematics - PAS faculty appointments ?

In addition to these specific questions we welcome any additional recommendations that you would wish to make.

Thank you very much for your input,

Frank

for the PAS Faculty Recruiting Strategy Committee
(Nick Bigelow, Yongli Gao, Sarada Rajeev, Paul Tipton, Dan Watson, and Frank Wolfs)

Dear ....:

I am on a special long-term planning and faculty-recruitment strategy committee for the Dept. of Physics at the University of Rochester. We are contacting some of the best Physics departments in the country in order to understand where these leading departments envision the field heading over the next decade.

Below we have listed three questions. Your response to these would be greatly appreciated. Feel free to respond either via e-mail, or I can follow up this contact with a telephone call later this week.

We greatly appreciate you taking a few minutes to help us in our task.

Sincerely,

Paul Tipton
Associate Professor
Dept. of Physics and Astronomy
University of Rochester
tipton@urhep.pas.rochester.edu
716-275-5445

****

1) What sub-fields of Physics do you see becoming more important over the next decade? Will your department be expanding its effort in these sub-fields?

2) Are there sub-fields in which your department is planning on contracting its effort over the next decade, i.e., these areas will have a smaller percent of the total number of overall faculty positions in 10 years? If so, why?

3) How is long-term planning done in your dept? Are there documents (reports from outside review committees, planning committees, etc.) that guide the way, or is it more random and short-term? We hear from some departments that long range plans are often ignored; If you have long range plans, to what extent have they been adhered to?

Dear Prof. ....,

I am a member of the long-range planning and faculty-recruitment strategy committee in the Department of Physics and Astronomy at the University of Rochester. As part of our process we are contacting a selection of the best departments in the country in order to understand better how these leading departments came to be where they are, and how they see themselves, and Physics itself, changing over the next decade.

Your response to the following four questions would help us a great deal in this effort. A brief e-mail response, in reply to this note would be fine. If you prefer telephones, let me know of a time I could call during the next week, or call me at 716-275-8576.

Our department greatly appreciates your taking a few minutes to help us in this matter.

Sincerely,

Dan Watson
Associate Professor
Department of Physics and Astronomy
University of Rochester

dmw@isis.pas.rochester.edu
716-275-8576

****

1. How has the FTE size of your department, and distribution of your faculty into the several research specialties of Physics, changed during the last fifteen years?

2. What sub-fields of Physics do you see becoming more important over the next decade? Will your department be expanding its effort in these sub-fields?

3. Are there sub-fields in which your department is planning on contracting its effort over the next decade (i.e. areas will occupy a smaller percentage of your faculty FTEs)? If so, why?

4. How is long-range planning for faculty recruitment done in your department? We hear from some departments that long range plans are often ignored; if you have formal long range plans, to what extent have they been adhered to?

2005 Planning Report
Physics and Astronomy
Appendix B

March 2000 Diversity Report to the Dean
Department of Physics & Astronomy
University of Rochester

We commend the Dean's Office for taking the initiative on the issue of the diversity[1] (or lack of it) in the College's faculty, and our goals for its achievement. Recently, we used the Dean's request as an opportunity to discuss diversity during a department meeting. The Dean's request gave legitimacy to the issue, which is important since some of the faculty may not be comfortable in discussing diversity. Our report has several sections, as outlined below.

1. **Current status:** Women and minorities on the faculty of the Department of Physics and Astronomy and current efforts to increase diversity at the undergraduate and graduate student levels. **1**

2. **Programs elsewhere**: What other departments of physics and astronomy are doing nationwide and what can we learn from them (based on 12 responses to my e-mail survey of physics department chairs, attached as an appendix, Section 6). **2**

3. **Analysis:** An analysis of the problem regarding the diversity of the faculty in Physics and Astronomy, and what we propose to remediate the situation. **5**

4. **Recruitment and retention**: What the University should do for all departments to increase diversity and retain women and minority faculty at Rochester. **8**

5. **References** **9**

6. **Appendix I:** E-mail survey of efforts at other institutions. **11**

7. **Appendix II:** Dual-Career Couples Survey Results (APS-DPF) **19**

1. Current status: Women and minorities on the faculty of the Department of Physics and Astronomy and current efforts to increase diversity at the undergraduate and graduate student levels.

We have had little success in the recruitment of women or minority faculty. Currently we have only two women faculty and no underrepresented minorities. We have four (male) faculty of Asian descent, two from China and two from India. Judy Pipher will retire from teaching in two years. We were lucky to get Professor Lynne Orr as the University was forward-thinking enough to allow us to hire her at a time when we had no open positions (her husband was recruited at that time by Biology). Therefore, two years from now we will have only one woman and no minority faculty in a department of 26 faculty. This constitutes a reduction of the fraction of women in our department from 8% to 4%, with no underrepresented minority faculty.

Nationwide, the fraction of women faculty in physics Ph. D.-granting institutions[2] was 5% in 1994 and 6% in 1998. In contrast, the fraction of women faculty in physics B. S.-granting institutions rose from 7% in 1994 to 11% in 1998. This situation may make four-year colleges more attractive to students from underrepresented groups. As a department in a research university, we obviously need to do more to recruit women and minority faculty, and a plan to do so is described in Section 3. A goal that may be possible to achieve in the next five to ten years is to have at least three women faculty and one minority faculty in our department.

We have been much more successful in programs for women and minorities at the high school, undergraduate, and graduate levels. This has been achieved with the assistance of the WISE program (headed by Priscilla Auchincloss) and Lynne Orr. We offer the PREP program for young women high school students, the REU program (which explicitly aims for 50% women and minority participation) and the Teaching Internship program for undergraduates, and the GAANN program for graduate students. In 1999 we began to visit minority institutions to increase our recruitment for the REU and GAANN programs. The TA training program in physics has included a component on diversity and classroom climate since 1989. As a positive reflection of our efforts toward increasing diversity, all of these programs assist us in the recruitment faculty from underrepresented groups.

2. Programs elsewhere: What other departments in physics and astronomy are doing nationwide and what can we learn from them (based on an e-mail survey of physics department chairs).

My survey of other physics departments found that, nation-wide, universities are working towards increasing diversity among their faculty in two ways. The first way is to create "add-on" and target-of-opportunity positions for women and minorities and provide incentives *to departments* regarding these faculty hires. The second way, possibly much less financially intensive, involves promoting special services and forward-thinking policies, in particular spousal recruitment, hiring, or placement, and family-friendly faculty leave policies. This second approach to minority recruitment focuses *on the candidate* and, of course, may be combined with the first approach. The second approach can make offers from the institution highly appealing to the candidate and begins to address the critical issue of *retaining* women and minority faculty once we have recruited them successfully.

A summary of recruiting efforts taking place at specific universities is given in Table 1. Copies of the e-mail messages from chairs in physics at the other departments are included in the attached appendix. The two approaches are described in more detail in this section, with some examples of how they are being implemented.

"Add-on" and target-of-opportunity incentive programs for women and minority faculty recruitment

In many of the physics departments responding to my query, a significant fraction of institutional overhead charged on research grants is returned to the department for discretionary purposes. In addition, many departments receive annual funding at the level of $300 to $400K (from the institution) dedicated for faculty recruitment. By contrast, here at Rochester no such funds are given. Our department in contrast has to rely on significant additional contributions from our grants just to balance our budgets. Without change in the University's financial state and allocations, much of what other departments do cannot be done here.

Some universities have programs in which women or minority faculty hires are targeted "add-ons" to the faculty, fully funded by the university. If and when these faculty leave, the slots may be taken only by other persons from underrepresented groups. The downside of such programs is that they are sometimes viewed as creating a "second class" of faculty. Such programs are effective, however, in increasing the number of underrepresented faculty very fast in the short term. I note that limiting add-on faculty to truly exceptional candidates would solve the issue or perception of creating a "second class" of faculty.

Some universities allow add-ons, but split the additional cost of each faculty hired between the university, the college, and the department (using departmental discretionary funds). This tends to make the department more selective in recruiting faculty for these slots because of the cost to the department.

Spousal placement services and forward-looking family leave policies

In physics, spousal hiring and placement has recently received attention as critical to increasing the proportion of women faculty, many of whom are in dual-career marriages to physicists. At the same time, many male physicists are married to highly educated and professionally trained women who will need jobs in other fields if and when their spouses are hired by us. Table 1 indicates that many institutions are also initiating special services, in particular spousal recruitment, hiring, or placement, as well as family-friendly faculty leave policies, in their efforts to attract and retain women and minority faculty. A more extensive survey which primarily focuses on the issues of women in science (and spousal placement programs and policies nationwide) is given in this year's Division of Particle and Fields report[3] on dual career couples in physics (which is attached as Appendix II). In addition, there is widespread concern about the low number of women faculty in physics departments nationwide[4].

For example, the University of Wisconsin at Madison has an Office of Spousal Placement and Diversity Hires (for details see attached e-mail from the chair in physics at

Wisconsin in the attached appendix and page 22 of Appendix II). In 1999, their physics department got two new (men) faculty who were spouses of women faculty hired in other departments. I note that our department lost a faculty candidate to Wisconsin when that institution's provost called the candidate's wife and told her that Wisconsin would guarantee her a job in the Madison area. She was a computer professional, so the guarantee may have been easy to give (assuming the spousal placement office also maintains information about local position openings). In recent years, we have found that spousal issues are important in more than 50% of our recruitment efforts.

An example of how faculty leave policies can impact recruiting comes from Cornell University. There, the physics department has encouraged new women faculty to take advantage of a family leave policy that allows the faculty member to go on half-time leave at half-salary to take care of a child (or a family member). During that half-time period the faculty member continues to do research, but is relieved of teaching responsibilities. The faculty member also may request a delay in the tenure clock.

It is important to note the distinction between the existence of such policies and explicitly encouraging faculty to use them (and protecting those faculty from subtle penalties later on, e. g., for working half-time). But if faculty are actively encouraged to use them, the institution can inspire great loyalty on the part of the faculty member. A woman physicist on the faculty at Cornell points out that when she was hired the chair of physics recommended that she make use of the policy for a year after having a child and made sure that her career would be unharmed because of it. (Her promotion to tenure came early so the question of slowing the tenure clock did not come up.) She states that she has turned down several job offers from other institutions because of this gesture on the part of her chair and department. (See e-mail at the end of Appendix I, from Professor Persis Drell to Priscilla Auchincloss, who recently visited Cornell's College of Engineering to speak on women in science issues).

Table 1
Recruiting Efforts used in Physics Departments at Other Institutions
(Based on an e-mail survey of physics department chairs in March, 2000)

INSTITUTION	PROGRAMS TO INCREASE DIVERSITY AND COMMENTS
Penn State	Formal add-on program for which the provost, dean, and dept share the cost forever. Dept has $400K annual faculty recruiting budget.
Rutgers	Informal target of opportunity add-on program
SUNY	Presidential Special Fund (add-on program)
U Illinois (UC)	A formal target of opportunity add-on in perpetuity and a formal add-on spousal hiring program
Colorado	Formal "Competitive Special Opportunity in Protected Classes Program"; 5 to 6 add-on FTE's per annum
Wayne State	Informal target of opportunity add-on program; EEO office is developing a formal program.

MSU	Informal target of opportunity add-on; informal add-on spousal placement program.
Ohio State	Formal shared cost add-on program.
Northwestern	Informal target of opportunity add-on; allowed to have 2 final candidates in each search if one is from an underrepresented group; plus an informal spousal add-on program.
Notre Dame	Target of opportunity and spousal add-on programs
Wisconsin	Provost-level office for spousal placement and women and minorities in science. Formal add-on programs for both.
Purdue	Diversity is part of the dept's long range strategic plan. Dean's office has agreed to support the goal of adding 10 women and 3 minorities over the next 10 years. Also an add-on spousal hiring program (e.g., in areas which are not among the dept's priorities).

3. Analysis and proposal: An analysis of the problem of faculty diversity in the Department of Physics and Astronomy and what we propose to remediate the situation.

Our goals are as follows:

a) To increase the diversity of the faculty in Physics and Astronomy
b) To get the best available candidates, thus improving the national rank of the department and the University, in preparation for the next National Academy ranking study of graduate departments
c) Accomplish the above while maintaining a fixed faculty size (in the long term)
d) Accomplish the above within the framework of the department's long-range plans[5] pertaining to specialty subfields
e) Accomplish this as quickly as possible

If we achieve these goals we will also make the University as a whole more attractive to women and minority undergraduate and graduate students. In physics, this is particularly important because women undergraduates who are interested in science are now a large fraction [6] of the entering undergraduate class at Rochester (42% in 1994).

Analysis

In 1997, there were 12% women, 2% African-American, and 2% Hispanic graduate students among all those awarded Ph. D'.s in physics nationwide[3]. The fraction of women Ph. D'.s in astronomy was higher (19%). In any given year that we have a faculty search in Physics, the number of non-minority males is on average 7.3 times the number of women candidates and 24 times the number of minority candidates. Statistically, therefore, the best candidate in any single given year is likely to be a non-minority male. Over a period of 7 years, however, the number of women candidates is equal to the number of non-minority male candidates in a single year. And over a period of 24 years, the number of minority candidates is equal to the number of non-minority male candidates in a single year.

In 1999, the average size of departments that were ranked in the top 10% was 58, and the average size of departments that were ranked in the top 20% was 36. Rochester's Department of Physics and Astronomy, was ranked[5] in the top 18% (26^{th} out of 150 departments), with a faculty size fixed at only 26. Large departments can afford to take more risks in the quality of the junior faculty they hire; they can hire faculty from underrepresented groups and decide later if those faculty should get tenure and only keep the best. Due to our department's relatively small, fixed size; we cannot afford to hire several faculty at once. Furthermore, any new hire must be the very best that we can attract, if we are to maintain or improve our ranking. Similarly, we must focus on selected subfields for which we have a history of excellence[8] or subfields, which may be in the forefront in the future.

It is clear that if we continue the present policy of waiting to have an opening in the faculty ranks and then search for a year to find the best candidate, the statistical probability is that there will be *no change* in the diversity of the faculty. On the other hand, if we could search for underrepresented candidates for roughly a decade prior to any position actually opening, we could increase diversity in the faculty at the same time as fulfilling the goal of recruiting the best candidates. This is without consideration, however, of the intense competition from other institutions in any given year.

Because the pool of underrepresented candidates is small to begin with, and the most exceptional of these get several offers, the yield for our recruiting efforts is expected to be low. We can respond to this situation with a recruitment plan that extends over a long period of time. Ideally, we would be prepared to hire an exceptional person at any time. Furthermore, it is crucial that we retain the women and minority faculty we are able to recruit successfully.

To accomplish our goals, therefore, we need a long time-frame for recruiting. In addition, our efforts will benefit from active assistance from the University in areas like spousal placement and faculty leave. This kind of support from the University will make our offers more attractive and more competitive with other institutions, in terms of both recruitment of the best candidates and retaining them in the long term.

Proposal

As a first step in responding to the Dean's request, I have encouraged all faculty to the department to search actively for exceptional minority and women candidates to bring to Rochester for seminars and colloquia. These persons should be viewed as "targets of opportunity" for faculty positions.

Each case should be considered on its own merit. In every case that we plan to consider, however, the proposed minority or woman candidate would be viewed as a future replacement of a faculty member in our department. The department already has applied the concept of pre-replacing retiring faculty with new junior faculty on a short time-scale. We also have applied the "target of opportunity" concept to exceptional senior and established faculty (at other institutions) whose hiring represents are a long time-scale pre-replacement for some future faculty retirement. I propose to combined these two concepts and have long time-scale pre-replacement of faculty in selected subfields by outstanding junior faculty from underrepresented groups (minorities and women). My analysis above indicates that this time-scale must be up to 10 years. The average age of the faculty at the rank of full professor in our department is 59 years. This is higher than the average age of 54 for our competitors[4] (i. e., departments ranked in the top 10th percentile nationwide). We are likely, therefore, to experience a number of faculty departures over the next decade, which makes the 10-year time-scale reasonable.

Under this plan, the department would propose to the University the recruitment of a woman or minority faculty for a junior faculty position under the following scenarios:

a) In any given year, the proposed candidate is the best candidate such that had there been an open search, the minority candidate or woman would have been the first choice based solely on merit.

b) The proposed appointment is in a subfield, which is considered a key part of the department's long-range plan[8]. In highly exceptional circumstances women and minority faculty in new subfields might be hired.

c) The appointment by default can be considered the early replacement of a faculty member who is likely to retire in the next decade within the same subfield. Again, in highly exceptional cases, this criterion might be relaxed.

d) The candidate has a very impressive visit that results in overwhelming support among the department's faculty.

The above proposal has the following positive features.

1. There is a long-time scale, supported by a clear rationale, to find the best minority or women candidates.

2. There is a net increase in faculty quality at the same time that diversity is improved.

3. By making the position a target of opportunity slated against a future retirement, there is no "second class" status attached to the position.

4. The long-term size of the department remains the same, although in the short-term the number of faculty increases incrementally.

5. The plan does not distort the subfield composition of the faculty with respect to the long-range plan[8].

6. If successful, the plan will result in a younger and more diverse faculty.

7. Faculty can be actively looking for targets of opportunity (in the past we only acted on two obvious targets of opportunity).

8. There will be many more seminars and colloquia by minorities and women, even if our recruitment yield is low.

I consider this to be the bare minimum and least expensive plan, and one that should be incorporated into the University's Diversity Plan for the next 10 years. If the University wants to do more, it can do more. The University might, for instance, start a "target of opportunity" program of the kind already in place at other institutions.

4. What the University should do for all departments in order to help increase diversity and retain faculty?

As an institution, we need to look at faculty hiring in the broader perspective of both the changing concerns of professionally trained people and the positive features of living and working in Rochester. As noted above, spousal hiring and placement has recently received attention in the physics community as critical to increasing the proportion of women faculty, many of whom are in dual-career marriages to other physicists. The same is undoubtedly true in other science and engineering fields. At the same time, many male physicists are married to highly educated and professionally trained women who will need jobs in other fields if and when their spouses are hired by us. In this respect, we should be cognizant of the advantages the University and the city of Rochester afford to such couples through the number of high tech industries and neighboring institutions of higher education. We should also consider that over time, other factors may emerge as critical in making the University as attractive and competitive as possible. For instance, if the housing market shifted markedly, finding or affording a house could be an important factor to junior faculty recruited here.

My analysis makes clear that the Department of Physics is "doing more with less" -- doing more high quality research with fewer faculty -- than most of the departments in its league. The same is undoubtedly true of other departments and programs in The College across all disciplines. This is a situation that puts us collectively under strong pressure to hire only the best candidates. My analysis also points out that the competition is intense among physics departments nationwide for the best women and minority candidates, and again this is true for other departments and programs in The College. My proposal thus calls for a committed and proactive role (though not necessarily a financially onerous one) for the University regarding increasing the diversity of The College's faculty as a whole.

To realize the goal of hiring exceptional minority and women faculty while maintaining The College's strengths, the University should

1. Be receptive to proposals *at any time* from departments to recruit specific individuals who are exceptional minority and women faculty, recognizing that such recruitment must take place over a long period of time. This does not mean saying "yes" every time; it means hearing the case in the light of the internal pressures, difficulties, and costs that departments face in such recruitment efforts.

2. Create a position at the assistant provost level position dedicated to developing diversity in the faculty, and responsible for encouraging, sustaining, and tracking faculty diversity in The College. One aspect of this position, for example, would be to implement mechanisms for spousal placement (as done at Wisconsin through its Office of Spousal Placement) and for hiring dual-career academic couples, as well as other initiatives found to be working elsewhere, as appropriate to our institution. Another aspect would be maintaining data to track the effectiveness of these initiatives, both directly in increasing faculty diversity and indirectly impacting student diversity and institutional climate. As mentioned earlier, this is also discussed in this year's Division of Particle and Fields report[6] on dual career couples in physics

3. Develop and promote a forward-looking policy for family-related faculty leaves (such as that in use at Cornell University), with the aim of making the University as attractive as possible to exceptional women candidates or other candidates with particular family concerns.

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3. REPORT ON THE DUAL-CAREER-COUPLE SURVEY , Laurie McNeil and Marc Sher, prepared for the Division of the Particles and Fields of the American Physical Society (1999), http://www.physics.wm.edu/~sher/survey.html , and http://www.physics.wm.edu/~sher/survey.pdf (attached as Appendix II)

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5. Report and Prospectus: The Program on Women and Science and Engineering, Office of the Dean, The College, Univ. of Rochester, May 1994 (P. Auchincloss, Director).

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9. Report of the Faculty Recruiting Strategy Committee (FRS) on the faculty recruiting strategy for the Department of Physics and Astronomy for the next decade. May 1997 (N. Bigelow, Y. Gao, S. Rajeev, P . Tipton, D. Watson, F. Wolfs[chair]).

10. Note, this Diversity Report may be accessed at: http://server-mac.pas.rochester.edu/yigal/diversity.html and at http://server-mac.pas.rochester.edu/yigal/diversity.pdf

Appendix:
E-mail Survey of Efforts at Other Institutions

Arie Bodek's message to the Midwestern Physics Department Chairs E-mail list (sent on 18-Feb-2000)

I would appreciate help in getting this information.

What special efforts are made by your Department and College to increase the diversity of its faculty? Does your college provide special incentives, e.g. financial support? Is it a priority at your university?

We have been asked by our Dean to provide him with a description of what should be done to increase the diversity of the faculty. This would include special efforts during recruiting searches, where the department advertises positions, which meetings faculty attend to identify potential candidates, and other attempts to reach out to women and minority candidates. Or what can the College do to help departments achieve this goal. For physics, this means increasing the number of women and minority faculty.

He would also like to know what departments at other institutions are doing in this regard and if there are any ways that the Dean's Office can help departments to achieve the goal of a more diverse faculty?

At Rochester, the university provides a year's salary to recruit a year earlier than the nominal start date of a position if the position also increases the diversity of the faculty. What does your department or College do?

Thanks for your help
Arie Bodek (bodek@pas.rochester.edu)

Sent to members of the organization of Midwestern Physics Department Chairs (Rochester and some other eastern institutions are members also).

hirsch@physics.purdue.edu,
bodek@urhep.pas.rochester.edu, Brock@chip.pa.msu.edu,
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From the Chair at Penn State University
From: SMTP%"jayanth@phys.psu.edu" 18-FEB-2000 10:46:56.59
To: bodek@urhep.pas.rochester.edu
Hi Arie,
Here for an appropriate candidate, the dean and the provost contribute a third of the salary each, so that the department pays only a third of the usual cost.
Best, Jayanth (Penn State)

From: URHEP::BODEK "Arie Bodek, U of Rochester" 18-FEB-2000 10:53:58.87
To: SMTP%"jayanth@phys.psu.edu"

For how long? Arie

From: SMTP%"jayanth@phys.psu.edu" 18-FEB-2000 10:51:01.35
To: bodek@urhep.pas.rochester.edu

For ever! J

From: URHEP::BODEK "Arie Bodek, U of Rochester " 18-FEB-2000 10:53:58.87
To: SMTP%"jayanth@phys.psu.edu"

Where does the department get the 1/3 salary (all our faculty salaries from the Dean) does it have to use non faculty salary lines
Thanks, Arie

From: SMTP%"jayanth@phys.psu.edu" 18-FEB-2000 11:07:03.71

The way it works here is that each department is allocated X dollars (X varies from department to department and is a historical figure -- which is subject to change by the Dean but never has been) for future faculty recruitment. X is typically of the order of several 100K. Money from these unfilled positions resides in the Dean's office and is used for startup costs etc. which are then matched by the provost. When someone is recruited in a department, that department's account goes down by an amount equal to the person's salary. If someone retires or leaves, that person's salary is added back. When a candidate improves the diversity, only a third of the person's salary is subtracted. Hope this is not too confusing.

On another subject, have you made an offer to Chris Monroe?
At what level?

Best, Jayanth

From the Chair at Rutgers
From: SMTP%"leath@physics.rutgers.edu" 18-FEB-2000 11:11:26.90

Dear Arie,

At Rutgers there is no formal program for the recruitment of minority and women faculty, but the dean and the higher administration regularly urge such hires and invite requests for help with such qualified candidates. They will usually come up with startup funds and sometimes a new faculty line for such a candidate. But it's on a case by case basis.

Paul Leath (Rutgers)

From the Chair at SUNY Stoney Brook

From: SMTP%"kirz@xray1.physics.sunysb.edu" 18-FEB-2000 11:24:28.35

Arie,
To recruit African American or Native American faculty, the president has a special fund. The candidate can get hired using salary support from this fund. We were able to add one faculty this way.

Janos (snsb)

From the Chair at University of Illinois Urbana Champaigne

From: SMTP%"dkc2@mail.physics.uiuc.edu" 18-FEB-2000 12:24:02.55

Dear Arie,
Here are some very brief responses to your questions about diversity.

"What special efforts are made by your Department and College to increase the diversity of its faculty. Does your college provide special incentives, e.g. financial support? Is it a priority at your university?"

The UIUC has a special "Targets of Opportunity" (TOP) program aimed at recruiting and retaining minorities. This program provides the salary, in perpetuity (!)for hires in certain categories aimed at increasing diversity. Historically, this program has applied only to "standard" ethnic minorities, but 2 years ago Physics (based on our track record in having attracted 4 women faculty in the previous few years) was "rewarded" with the chance to propose 2 additional positions for women, with salary funding again provided in perpetuity. We have filled one of these positions and are currently looking to fill the other. Earlier, we had successfully applied for one TOP appointment for a male African American. The TOP program is funded by a campus-wide tax on the state recurring budget.

In addition, because of the "two-body" problems of many two-career couples, the UIUC has an excellent spousal hire program. In effect, this tends to increase the diversity across campus by increasing the number of female faculty. The program is easiest to explain by an example. Suppose a male physicist whom we want to hire has a wife whose speciality is linguistics but whom the linguistics department can not hire, for reasons of "wrong field", lack of money, etc. [If the spouse is not of sufficient quality, then nothing can be done.] Physics and linguistics get together and propose to the Provost that the spouse be hired in linguistics with 1/3 of her salary coming from the Provost, 1/3 from linguistics, and 1/3 from physics (all again in perpetuity). The actual funding division can be different on occasion, even to the point where the receiving department (in this case, linguistics) actually pays nothing. Two cases in our department, where we have both spouses, we hired the second spouse under this program, so that the Provost is paying 1/3 of the salaries and we are paying 2/3.

Hope this helps,

Best, David (UIUC)

From the Chair at Colorado

From: SMTP%"jcumalat@bierstadt.colorado.edu" 18-FEB-2000 12:54:29.44

Dear Arie,

Like Rutgers, the University of Colorado also has no formal recruitment of minority and women faculty, but we are encouraged identify qualified candidates. (I am well aware that it is not easy.)

We do have tremendous incentives to identify outstanding candidates. Each year the Vice Chancellor makes available between 5-6 Special Opportunity hires for all disciplines and colleges targeted at Protected Classes. The positions are highly competitive, but if a candidate is identified and a unit is successful with the hiring, then the unit gets an FTE that doesn't count against its quota. (ie the department is allowed to grow by 1.) If the candidate leaves for any reason, then position reverts back to the Vice Chancellor.

This sounds pretty good, but the administration really pushes to identify candidates as part of ongoing searches.

John Cumalat (Colorado)

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From the Chair at Wayne State

From: SMTP%"lwenger@sun.science.wayne.edu" 18-FEB-2000 13:09:49.57

Arie:

At Wayne State, our efforts in minority and women faculty recruitment are very similar to that at Rutgers. No formal program but a willingness by the upper administration to assist in our recruitment effort. The head of the EEO is developing a more formal process to assist in the identification of potential sources for minority and women faculty hires. Thus far, it basically consists of informing the EEO of the faculty positions that have been authorized, and our proposed plan of attack for recruitment. Subsequently, we must describe in some detail our recruitment process and provide rationale why we are unsuccessful in reducing the number of underrepresented faculty in these categories before the upper administration will approve any tenure-track hire. When successful in finding a qualified minority or women that we wish to make an offer to, additional sources of start-up moneys from the upper administration (Provost's office) can usually be tapped for such qualified candidates. A few years ago, an additional tenure-track authorization and start-up funds were provided during our search process to accommodate the hiring of a very qualified minority physicist to a tenure-track position in area that was not being sought at that time.

A "best practice" that chemistry has successfully employed in hiring qualified minorities is to begin the courtship with outstanding senior-level graduate students prior to the completion of the Ph.D. In fact, they even permitted the person to take a one-year postdoctoral fellowship while they held the position for him.

Lowell E. Wenger
Wayne State University
===

From the Chair at Michigan State University
From: SMTP%"brock@pa.msu.edu" 18-FEB-2000 14:21:11.74

Hi Arie,
MSU doesn't have a formal program either. However, on a case-by-case basis arrangements can be made. I found myself in a position 5 years ago with a search in which we had a male candidate who was far and away superior to the pack, but a female candidate who was above the final cut. I got the administration to allow me to pre-replace a named, pending retirement and to split the bridging salary with the department. Startup was considerable for both and the university participated in both as they would normally. We therefore hired two.

Spousal situations are very aggresively encouraged here as well, especially when the 'primary' hire is female. This is very sensitive, obviously, because of the near impossibility of avoiding the second-class label for the 'secondary' hire. We stumbled onto a successful situation when both parties were hired in two different departments (both scientific)...with two different last names. We didn't know.

I'm intrigued with John's description of a university-wide competitive pool of positions which could deal effectively with a quality issue which unfortunately sometimes can haunt a woman hired in a competitive, 'regular' search. By that I mean, the 'only reason you were hired...' slap, which must be awful.

Best,
Chip Brock (MSU)
==

From the Chair at Ohio State University
From: SMTP%"saam@mps.ohio-state.edu" 18-FEB-2000 18:31:14.37

Arie,

The current policy on diversity hires is in flux, and it is undergoing a reevaluation. For this year, departments make proposals (for women and minorities) to the Provost, and if approved the Provost will contribute up to 1/3 of the salary line (or $25K, whichever is smaller). The College will try to contribute another 1/6. Senior-level hires get priority. This year's policy is a step backwards in that it used to be routine to get 1/2 of the salary, independent of level, and sometimes more than 1/2 of the salary was available. As far as I know, there is no additional help on startup beyond that ordinarily available (between 1/2 and 2/3).

Will (Ohio State)
==

From the Chair at Northwestern

From: SMTP%"dbuchholz@nwu.edu" 21-FEB-2000 16:58:21.38

Dear All,

At Northwestern we are encouraged to hire women and minority candidates. In any search we must identify all such candidates and explain if they were not chosen, why not. As for an incentive we can usually get the dean's office to allow us to bring in one additional candidate for an interview. There are no other formal programs and it is pure speculation to assume that the administration is more likely to increase its support for minority candidates.

Last year we successfully recruited a female candidate (she was our top candidate). After we offered a position to her, her husband (also a physicist) indicated a potential interest in Northwestern. We were authorized for one position only but in this case we were allowed to make 2 offers.

Dave Buchholz (Northwestern)
==

From the Chair at Notre Dame

From: SMTP%"bunker.1@nd.edu" 21-FEB-2000 17:07:34.84

David et al.:

This method of leveraging positions has also taken place a number of times at Notre Dame in the past few years. The spousal hiring issue has been used to good advantage in both the Physics Department and others across the University. Needless to say, both candidates have to be very good, but it is a great way to get resources if the administration is behind you.

Bruce (Notre Dame)
===

From the Chair at University of Wisconsin, Madison

From: SMTP%"pondrom@wishep.physics.wisc.edu" 21-FEB-2000 17:16:15.30

UW has an office at the provost level which expedites 'spousal hires', and also women and minorities in the sciences. The spousal hiring encourages academic positions for husband-wife teams, and has had an impact campus wide. Physics has recently acquired two faculty members (males) who were spouses of faculty in other departments. We have created a non-tenure track position in physics for the spouse (male) of a recently hired tenured female professor. In that instance both members are in the same department. We are recruiting for faculty now, and I will try to make two offers where one was previously authorized and the other is a female physical scientist. Success is not guaranteed, but we have a good case. We shall see. LGP (Wisconsin)

==

From the Chair at Purdue

From: SMTP%"hirsch@physics.purdue.edu" 21-FEB-2000 17:41:27.40

Dear Colleagues,
Purdue as a university does not offer an official statement of the steps the administration will take to increase diversity of its faculty, over and above, of course, statements from the Affirmative Action Office of the university. Within the School of Science, however, we have developed a stategic plan which deals with this particular issue, among others. The entire stategic plan can be found at
http://www.science.purdue.edu/StrategicPlan.html

The particular section relevant to this issue is Goal #3 under Faculty Research and Graduate Education. We have a goal of adding at least 10 women and three minorities to the faculty in the next 5 years. There is an explicit statement that the Dean of the School of Science and department heads will give priority to such efforts when distributing resources.

In physics, we have added two women in the recent past who happened to be:
a) excellent physicists, and b) spouses of physicists already hired by the department. It is likely that in at least one of these two cases, the woman would not have been hired had not the Dean not made it very clear that this would not "count against" our faculty total. In this case the individual was an excellent researcher/teacher, but was in an area that was not one of the department's priorities. As it has turned out, this has been an excellent hire, developing into collaborations with others in the department leading to major research grants.

Andrew S. Hirsch, Purdue University

From Persis Drell, Cornell University regarding leave policy

From: SMTP%"PERSIS@lns62.lns.cornell.edu" 28-MAR-2000 09:34:12.79
To: IN%"psa@urhep.pas.rochester.edu"

Hi,
I looked up my letter and it is quite vague but I'll give you
the wording:

"The usual teaching assignment in the Department is one course per semester. We would try to make this a fairly light assignment in the first year or two. In addition, you might want to consider a reduced time commitment for one or more terms, as we discussed on the phone, in order to have more flexibility and time with your new child. I have received assurances from the Dean and the central administration that this can be done; it leads to a slight time dilation on the tenure clock."

In practice, if I went to 3/4 time, I had an administrative affiliation with a course but very little (if any) in class teaching. At 1/2 time I had no course obligations whatsoever. The sabbatical clocks went slow (and I got the fractional salary) on the semesters at reduced time. The tenure clock could also have gone slow but in fact I was tenured early, even by a 'normal' clock so that was not an issue.

Hope this helps!

It is a system that has worked wonderfully for me.
Persis

Persis S. Drell
Professor of Physics
Director of Graduate Studies
118 Newman Lab
Cornell University
607-255-5197

Report of the Committee to Explore the Future of Biological Physics in the Department of Physics and Astronomy

Nicholas Bigelow
Tom Foster
Yongli Gao
Bob Knox
Adrian Melissinos
Yonathan Shapir
Steve Teitel

submitted April 24, 2001

I - Introduction

In the Fall of 1998 the Chair appointed a committee to advise the Department on Biological Physics. The charge to the committee is to be found in Appendix A. We also note that the 1997 report of Faculty Recruiting Strategy (FRS) concluded that there was "a rather broad consensus within the Department to add a position in Biological Physics".

The committee considered in particular, the following:

i) The rationale for an appointment in Biological Physics in a department of Physics and Astronomy

ii) The environment at the University of Rochester in support of activity in Biological Physics

iii) The funding opportunities in Biological Physics

iv) The impact of a position in Biological Physics upon the Department

To address these questions the committee invited several distinguished researchers in the field of Biological Physics to visit campus as colloquium speakers, and to consult with the committee (see Appendix B for a list of these visitors). The committee further carried out an extensive set of meetings with faculty at the University in other departments, both in the College and in the Medical Center, whose research activities have a strong overlap with Biological Physics (see Appendix C for a list of faculty consulted).

As a result of these meetings the committee concludes that:

Biological Physics is an exciting and rapidly growing sub-field of physics that is actively being pursued by a large fraction of the top physics departments in the country.

that:

A very favorable environment currently exists at the University for a successful appointment by the Department in the field of Biological Physics.

and therefore recommends that:

The field of Biological Physics be given high priority for the next available faculty recruitment.

The remainder of this report is organized as follows: In section II we outline some of the recent scientific developments in the field of Biological Physics that have made it a clear growth area for top physics departments worldwide. In section III we summarize ongoing research activities at the University that serve as natural intellectual support, and potential research collaboration, for an appointment in Biological Physics. In section IV we discuss the prospects for external funding. In section V we present our recommendations for a recruitment in Biological Physics.

II - Recent Developments in Biological Physics

The last decade has seen an explosion of growth in the application of the methods and ideas of physics to systems of biological interest. Many leading universities -- Princeton, Cornell, Chicago, Stanford, Rockefeller, Caltech, Berkeley -- are aggressively seeking to establish major cross-disciplinary initiatives in this direction [1]. Physics Nobel Laureate, and UR Trustee, Steven Chu (B.S. physics/math '70) has been one of the leaders of this effort at Stanford.

A brief list (obtained by personal contacts, scanning ads in Physics Today, online sources) of other physics departments that have recently recruited, or are presently recruiting, in the area of biological physics include: Ohio State, U. Minnesota, U Illinois-UC, U. Pennsylvania, Purdue, Syracuse, Northeastern, U. Texas at Austin, U. Arizona, Dartmouth, Michigan State U, Rice, Vanderbuilt, Dartmouth, U. Guelph, U. Missouri-Columbia, U. British Columbia. In preparing its report in 1997, the FRS contacted the chairs of 14 representative physics departments and reported, "Almost all of the departments contacted are interested in starting or expanding programs in Biophysics." After attending this year's Meeting of the Physics Chairs of Midwestern Universities, Bodek reported a similar wide spread interest in establishing programs in Biological Physics among the represented departments.

Not only has physics shown an increased interest in biology, but there has correspondingly been an increasing realization in the biomedical community, and at the federal funding agencies [2,3,4], of the expanded role that physicists can play in biological/medical research. To quote from former director of NIH Harold Varmus' address to the Centennial meeting of the American Physical Society in March 1999, "... the NIH can wage an effective war on disease only if we ... harness the energies of many disciplines, not just biology and medicine. These allied disciplines range from mathematics, engineering, and computer sciences to sociology, anthropology, and behavioral sciences. But the weight of historical evidence and the prospects for the future place physics and chemistry most prominently among them.... I would argue that we need to show our appreciation of physics-based technology by investing NIH funds more aggressively in its development." [3]

This recent growth of physics into biology is due primarily to two complementary developments:

(i) Biological mechanisms are increasingly being studied at the molecular level; one seeks to identify the molecular structures responsible for key reactions, and then to relate their properties to the behavior of the larger biological structure. Traditionally, this is an area that has been advanced by the procedures and technology arising in experimental physics, such as x-ray crystallography and magnetic resonance spectroscopy.

In recent years, new physical techniques have been developed that allow for the direct observation and manipulation of individual macromolecules and complexes of large molecules. The ability to study individual molecules (in contrast to previous methods that only measure averages of statistical ensembles) is particularly important for biomolecular applications where heterogeneous environments are common and where molecules may be found in different configurations or folded states. Single molecule techniques further allow for the direct study of time dependent processes without the need to synchronize the behavior of a large ensemble. Stochastic fluctuations, which may play an important role in the function of particular biomolecules, can also be directly studied. Finally, the manipulation of single molecules offers the promise of constructing artificial molecular machines.

Examples of such single molecule techniques include: laser induced fluorescence spectroscopy, in which fluorescent probes (often a small dye molecule) are covalently bonded to specific sites of larger biomolecules. Analysis of location, polarization, time dependence and spectral content of the emitted photons provides structural and dynamical information about the molecule's diffusion, conformational state, and biological activity; laser traps (also known as optical tweezers) in which tightly focused laser beams are used to trap tiny dielectric plastic beads which have been linked to biomolecules of interest. By manipulating the laser beams to pull or push on the beads, one can make precision measurements of the mechanical properties of the biomolecules. Optical tweezers have been applied to studies of enzyme-DNA interactions, molecular motors, and protein folding; scanning probe techniques, in which one probes the nanometer scale interactions between a surface of interest, and a sharp tip that is scanned across it. Scanning tunneling microscopy (STM) has been used to make direct real space images of biomolecular conformations, as well as to manipulate molecules to create supramolecular assemblies. Atomic force microscopy (AFM) has been used to measure mechanical properties of biomolecular forces to pico-newton sensitivity. Examples of current work in the area of single molecule techniques can be found in recent special issues of *Science* [5] and of *Chemical Physics* [6].

Leading groups in this area include Chu [7], Block [8] and Moerner [9] (Stanford), Quake (Caltech) [10], Bensimon (Ecole Normal) [11], Weiss (LBL) [12], Libchaber (Rockefeller) [13].

Also in the realm of new physical techniques in the service of Biological Physics is the use of artificially fabricated micro- and nano-scale environments for studying biological systems. Groups in this area include Craighead (Cornell) [14] and Austin (Princeton) [15].

(ii) There is an increasing appreciation of the fundamental role that statistical concepts and complex networked interactions play in biological systems, and in the problem of analyzing large and complex data sets to infer these underlying interactions. Statistical and condensed matter physics has experienced an increasing migration into biological areas related to such issues.

Problems in this category include understanding the neural networks by which the brain and nervous systems of higher organisms process and store information; the functioning of membranes and protein-membrane interactions; understanding the protein and enzyme networks that control cell functioning; protein folding and the relation between structure and biological function ("proteomics"); the relation between gene sequence and function ("genomics").

The latter topic, often referred to as "bioinformatics", has been greatly stimulated by new DNA microarray technologies which allow the simultaneous "measurement of the extent to which different genes are read to form RNA (and subsequently protein) in different tissues and under different environmental conditions" [3]. Such microarray experiments have resulted in a glut of data, the quantitative understanding of which poses new theoretical challenges for biologists.

The generic and conceptual statistical issues arising in understanding such biological networks, such as optimization, partitioning, pattern recognition and data clustering, share many common themes with ideas concerning complex and critical behavior in statistical physics. The growing interest within the statistical and condensed matter physics community in such topics is witnessed by the fact that two of the premier national conference centers of physics have recently hosted workshops in this area: "Genetic and Biochemical Networks" Jan. 23-29, 2000 at the Aspen Center for Physics, and "Statistical Physics and Biological Information" Jan. 16 - June 15, 2001 [16], and "Dynamics of Neural Networks" July 23 - Dec. 22, 2001 [17], both at the Institute for Theoretical Physics, UCSB.

Leading experimental groups in this area include Leibler (Princeton) [18], Libchaber (Rockefeller) [13], Kas (Texas-Austin) [19], Kleinfeld (UCSD) [20]; in theory they include Shakhnovich (Harvard) [21], Onuchic (UCSD) [22], Hwa (UCSD) [23], Siggia (Rockefeller) [24], Maritan (SISSA).

III - Related Research at the University of Rochester

To explore the local activity at the University that could act in support of a position in Biological Physics, the committee conducted over the past year an extensive series of meetings with faculty from other departments, both on the River Campus and at the Medical Center. The committee was greatly impressed with both the breadth of this activity, and with the general enthusiasm that was displayed at the prospect of an appointment in Biological Physics in the Department of Physics and Astronomy. Below we summarize some of this existing activity, as well as the impressions we gathered from our meetings.

A - River Campus

Chemistry Department

In many respects chemistry provides a natural bridge between physics and biology. Physical chemists have scientific and analytical training similar to that of physicists, yet they are accustomed to dealing with the more complex molecular problems such as are encountered in biology. At the UR, several faculty have direct research interests in topics relating to Biological Physics. <u>Turner</u> studies RNA folding and prediction of RNA secondary structures, with applications to questions involving bioinformatics (he is a co-PI on the University's MD/PhD training grant, and has other close collaborations with the Medical Center). Krugh and Bren conduct NMR studies of DNA and RNA structure, and metallo-protein folding, respectively. Miller's group is involved with the design of small molecules capable of specific binding to selected protein, RNA, and DNA sequences. Krauss is a new experimentalist studying the optical properties of nanometer scale materials (nanocrystals, nanotubes), including their potential for use as markers for imaging in biological systems. Mukamel is well known theorist working on ultrafast dynamics and relaxation processes in large molecules and biological complexes. Dellago is a young theorist carrying out simulations of dynamics in complex systems, such as chemical reactions in solution and conformational changes in biomolecules. Krauss and Dellago both have their PhD's in physics. Turner, Krugh, Bren and Miller are members of the Medical Center's cluster on Biophysics and Structural Biology (see below). In our meeting, Turner, Krugh and Bren spoke positively of their interactions with the Medical Center and felt that the climate at Rochester was conducive to interdisciplinary interactions. Mukamel expressed his view that a program in single molecule methods would be a natural choice for a Biological Physics position at the UR.

Institute of Optics

The institute of Optics has made two recent appointments in areas relevant to Biological Physics. Novotny is building a laboratory to do near-field microscopy of nanoscale materials, including biomolecules. Berger (PhD in physics) is building a laboratory to use Raman spectroscopy as a method for analyzing the content of tissue, blood samples, and living subjects. Novotny was very enthusiastic about potential collaboration should a position in Biological Physics be in the area of single molecule methods. Both Berger and Novotny are examples of the sort of small scale single-investigator type programs that a position in Biological Physics is likely to be; both seem to have gotten off to very promising starts at the University, receiving federal funding and easily finding contacts for potential interdisciplinary collaborations. The new director of the Institute of Optics, Wayne Knox, is reportedly interested in expanding the number of appointments in biomedical optics within the Institute.

Center for Visual Sciences

Committee members met with David Williams, Director of the Center for Visual Science and Prof. of Brain and Cognitive Sciences, and Allyn Chair of Medical Optics. The center is a broad interdisciplinary effort involving the departments of Brain and Cognitive Sciences and Computer Science on the River Campus, and the departments of Neurobiology and Anatomy, Neurology and Ophthalmology in the Medical Center. Roughly half of its 26 members are in River Campus departments, and half are at the Medical Center. The center serves as a good example of effective collaboration across Elmwood avenue. The center has umbrella training and core grants from NIH which help to support seven support staff members. Research at the center ranges from development of the visual system to the interaction between visual perception and memory. Williams own area of research involves optical techniques to study the structure of the eye and the optical and neural limits of human vision. Williams was enthusiastic about interactions with the Department of Physics and Astronomy, and mentioned as possible areas of overlap the general field of neuroscience, the physics of NMR applications in biological tissue, and adaptive optics.

Other Departments

The committee also met with **Biology** chair Angerer. While generally positive, Angerer did not mention any specific areas of interaction that seemed promising to him. However Orr and Huelsenbeck's work in evolutionary biology has potential overlap with the area of bioinformatics. In **Computer Science**, Ogihara's work on biological computing similarly has overlap with bioinformatics. The **Brain and Cognitive Science** department, and the newly created **Biomedical Engineering** department both have strong overlap with the field of neuroscience (see more below). Biomedical engineering also has McGrath, who studies cell mechanics and motility, and Waugh, who studies mechanical properties of cell membranes and other subcellular components.

B - Medical Center

The presence of our expanding Medical Center has the potential to be a truly major advantage that Rochester has over many other Universities, when it comes to trying to recruit in Biological Physics. It is not just the presence of first rate research activities that is a draw, but specifically it is their *close* proximity to campus. A recent candidate for a position in bioinformatics at the Medical Center particularly stressed what a great asset it was if a researcher could conveniently walk from his academic base on campus, where he teaches and holds office hours, to the medical center which may serve as a base for some of his research activities. He pointed to his present situation at Washington University, where parking issues alone (the Wash U Medical Center is about 2 miles from campus) set up substantial obstacles to smooth collaborations between the Medical Center and academic departments.

Our committee held several meetings with faculty in the Medical Center, including members of the new research centers housed in the Aab Institute of Biomedical Sciences [25]. We have been impressed with the many current and emerging opportunities for collaborations with physicists, and with the enthusiasm with which our inquires were greeted. Three areas in the medical center were identified as being particularly promising.

Structural Biology and Biophysics

The field of structural biology uses physical tools to determine the structure of biological macromolecules (proteins, RNA, DNA) and macromolecular complexes. X-ray crystallography and NMR spectroscopy are the principal tools used in this research. Optical methods are often used to probe fluctuations in macromolecular structure. Rochester has an active and fairly large effort in this area that includes faculty from the Department of Biochemistry and Biophysics in the Medical Center and from the Department of Chemistry (Bren, Krugh, Miller, Turner). These faculty are formally linked through the Medical School's "GEBS" (Graduate Education in the Biological Sciences) cluster in Biophysics and Structural

Biology [26]. This particular cluster is responsible for the PhD degree program in Biophysics. Our committee met with Bill Bernhard, director of the cluster and a Biochemistry and Biophysics faculty member. Bernhard enthusiastically stated that hiring a physicist working on biological problems at the molecular level would be a significant asset to the biophysics cluster, and stated that he would be happy to promote interactions, including possible membership for such a person in the cluster. He thought that recruiting one person in this area made sense because of the many possible collaborators and the existing infrastructure. He mentioned techniques such as optical tweezers, atomic force microscopy, and spectroscopy of protein dynamics, that he thought would be promising. He cautioned, however, against someone whose primary concern was too specifically on instrumentation. He expressed his view that NIH was very supportive of interdisciplinary research, and recognized the importance of bringing in physics.

Neuroscience

Neuroscience research at Rochester is strong, broad and highly collaborative [27]. It is represented in both the Medical Center (Department of Neurobiology and Anatomy, Center for Aging and Developmental Biology) and on the River Campus (Department of Brain and Cognitive Sciences, Center for Visual Sciences). Based on this strength, an initiative in "Perceptual and Neural Systems" is one of three main programs within the new Department of Biomedical Engineering. Nationally and internationally, problems in the neurosciences have emerged as an important area of fundamental and applied biological physics. The committee met with Howard Federoff, who directs the Aab Institutes Center for Aging and Developmental Biology, and with Gary Paige, Chair of Neurobiology and Anatomy. Both were very interested in the possibility of collaboration with Physics. Federoff mentioned existing collaborations his group has with Miller and Rothberg in Chemistry, and with Ogihara in Computer Science. Paige was particularly enthusiastic. He pointed out to us that a recent search in his department had produced three applicants with deep training in physics, and it was his perception that a joint appointment and perhaps even some shared research space was not out of the question for a new appointment in Biological Physics. Both Federoff and Paige offered to help review candidates if we have a search that proceeds in this direction

Bioinformatics and Computational Biology

This is the least developed and the most poorly defined of the three areas, but it deserves mention because of its potential significance for Biological Physics. While there currently is no formal bioinformatics group in the Medical Center, it has been recognized that the formation of such a group is vital to the mission of the new research centers. A search committee has been formed that includes Dr. Richard Insel, director of the Aab Institutes Center on Human Genetics and Molecular Pediatric Disease and Deborah Cory-Slechta, Associate Dean for Research in the Medical School. Recruitment of 5-6 faculty in this area is anticipated, and several applicants have visited campus earlier this year. Of these, two of three had either a current or previous direct background in statistical physics. The medical Center appears to be interested in the participation of River Campus departments in this process, and Teitel has been invited with other River Campus representatives to meet with visiting candidates.

IV - Funding Prospects

The prospects for obtaining external funding in support of a program in Biological Physics appear at present to be excellent. Shown in Appendix D is a chart of federal research funding for different disciplines from 1970 to 2000, compiled by American Association for the Advance of Science. It shows that while funding for physical sciences or engineering remains almost constant (~$5 billion) throughout the three decades, funding for life sciences during the same period has tripled, from ~ $5 billion to $17 billion in constant FY 2001 dollars. In Appendix E we list recent federal funding obtained by some of the prominent groups discussed in section II. NSF funding for these groups appears quite high, and one is impressed by the broad scope of the NSF programs through which funding has been obtained.

As indicated in the quotation from Harold Varmus at the beginning of section II, and as supported by the conversations we had with faculty at the Medical Center, NIH is also a major, and presumably increasing source of funding for physics based Biological Physics research. Six of the nine experimentalists listed in Appendix E have NIH funding. An example of NIH movement to fund in this area is a recent new initiative on "Single Molecule Detection And Manipulation" [28].

Most of the investigators listed in Appendix E are senior. Some however, such as Quake and Kas, are more junior. As further evidence of the ability of young investigators in this field to get funding, we list in Appendix F the NSF funding obtained by both the recent biologically oriented appointments in the Institute of Optics. Berger has been at the UR only about 8 months. Novotny has been at the UR about a year and a half. Both succeeded in getting NSF funding on their first tries.

In addition to funding sources targeting specifically Biological Physics, the molecular scale of the systems of interest make such research programs natural competitors for funding under new nanoscience initiatives that have been launched by both NSF and DOE.

Finally, the field of Biological Physics is also supported by private foundations such as the Whitaker Foundation [29] and the Keck Foundation [30] which offer grants to young investigators. Kas from Texas-Austin, for example, has grants from both the Witaker and Keck Foundations.

V - Recommendations

In its 1997 report, the Faculty Recruiting Strategy Committee listed a set of "golden rules" that it felt should guide recruitments into the department. These rules included: (1) "Respond to scientific urgency"; (2) "Make timely investments in new fields"; (3) "Preserve funding stability of our groups"; (4) "Maintain critical mass and replace key personnel"; (5) "Preserve both the quality and supply of superior graduate students".

We believe that all the above rules unequivocally argue that an appointment in Biological Physics should be made as soon as possible.

Biological/biomedical research is clearly a field in scientific ascendance. Along with the growth in scientific interest there has been, and will continue, a corresponding growth in the availability of external research funding. One needs only to look at the expansion of research at our Medical Center and the creation of the new Biomedical Engineering Department here at the UR to see the reality of this. As outlined in section II, the tools and ideas of physics now place our field on the threshold of being able to make important new contributions in the biological/biomedical area. That Biological Physics is an exciting and rapidly growing field has attracted the attention and the investment of virtually all the top physics departments in the country. We believe that an appointment in Biological Physics thus satisfies golden rules (1), (2) and (3).

The Department of Physics and Astronomy at the UR has had for many years an active program in Biological Physics, through the presence of Bob Knox (a recent winner of the APS prize in Biological Physics) and the joint appointment of Tom Foster. Both have had successful and visible single investigator programs. Knox, though still an active presence in the department, officially retired in 1997 and has since worked only with undergraduate students. Although the department is now considering making additional joint appointments in the area of biological/medical physics, the committee feels that for the department maintain a distinguished program in Biological Physics, a full time faculty appointment is imperative. We believe that an appointment in Biological Physics thus satisfies golden rules (4) and (5). Appendix G lists the major subfields of first-year graduate students in 1997-98 from AIP 1998 Graduate Student Report: First Year Students. By the end of their first year of graduate study, 4% of domestic students and 2% of foreign students have chosen biophysics as their research specialty.

In section III we outlined the environment of existing research at the UR into which a new faculty in Biological Physics would arrive. We believe this environment, spread across the College and the Medical Center, is broad based, is highly conducive to establishing interdisciplinary interactions, and will be attractive to potential candidates (see more below). The presence of Foster, who has appointments in the Medical School, Optics, and Physics, will facilitate such interactions. In section IV we presented evidence of a bright funding outlook for support of new single investigator programs in Biological Physics. We therefore believe that all the ingredients exist to establish a new, successful, program in Biological Physics here at the UR.

Finally, we address the question of whether the establishment of such a successful program in Biological Physics would have a significant positive impact upon the department. One might argue that since Biological Physics is to be relegated to a single FTE in our department, that even a successful program could not make a dramatic impact on the national visibility and ranking of the department. In this respect, we believe that an appointment in Biological Physics represents an investment in the long range future of the department. Not to make such an appointment will leave the department without a presence in one of the major new emerging areas of physics. A successful appointment in this area, on the other hand, may lead to growth and recognition at the national level. The time for such an appointment is now, when the field is still relatively young and growing, rather than later when one will be forced to "catch up" with more established groups elsewhere. The committee believes that the following three specific areas represent the likely best targets for recruitment in Biological Physics:

1. Single molecule techniques: An appointment in this area appears to be a natural choice for Rochester, building upon the department's and the University's reputation and strength in optics. An appointment in this area may also allow for branching out into optical investigations of nanostructures more generally, another hot and growing field. For an appointment to be successful in this area of Biological Physics, however, we believe it is important to find someone who demonstrates a good understanding of the biological questions worth pursuing with such methods, rather than someone whose interests are focused on the technique itself.

2. Neuroscience: We believe that the strong multidisciplinary activity in this area at the University makes it an attractive one. The topics and speakers at the forth coming ITP workshop "Dynamics of Neural Networks" [17] represent good examples of the sort of ways physics can contribute to this field. The presence of physics in this field is perhaps less advanced than it is for single molecule techniques, but this may also be an opportunity for us to get into the field early.

3. Bioinformatics: The mapping of the human genome makes this subject clearly one of the major scientific initiatives of the future. A successful appointment in this area could therefore bring the department into this high impact area. This was the area specifically recommended by Albert Libchaber when he visited UR to advise the committee two years ago. Proceeding in this direction however would be premature until it becomes clear what concrete steps the Medical Center takes to establish a group in this area.

Although the above seem at present to be the best targets, we believe that a recruitment should be broadly advertised for any field of Biological Physics, specifying the above three fields only as potential areas of interest. The goal of attracting an individual of the highest quality should outweigh programmatic concerns. It should however be recognized that a recruitment in Biological Physics can easily extend over more than one year, due to the highly competitive nature of the current market.

The committee therefore recommends that the field of Biological Physics be given high priority for the next available faculty recruitment.

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[27] http://broca.bcs.rochester.edu/neuroscience/

[28] http://grants.nih.gov/grants/guide/pa-files/PA-01-049.html

[29] http://www.whitaker.org

[30] http://www.wmkeck.org

Appendix A
Charge of the Committee

Overall Charge:

Should the department plan to have a program in Experimental Biological Physics with only one single Physics faculty appointment and with one or more joint appointments in other departments.

Items for consideration:

1. In the short term, coordinate Biological Physics colloquia(*) with the aim of educating the department about the sub fields of Biological Physics that may be appropriate for our department.

2. Is it required that a Biological Physics program in our department be connected with programs and facilities in other departments, and what should be the nature of that connection?

3. Compile a list of faculty and investigators at the UR and local area institutions are doing Biological Physics related work.

4. What are the funding sources for such a position?

5. What kind of facilities, startup funds etc. are needed?

6. Can a single investigator in the department of Physics and Astronomy make a major impact in the field? Can a single appointment in Biological Physics have an impact on our future national rating? On our future graduate recruiting?

7. Can a small department such as ours plan on a program which relies only on more joint appointments (e.g. the new Chair in medical imaging in Optics) similar to the present plasma physics program in ME and the Laser Lab.?

Verbal interim report to the faculty to be made in September 99. Final report to faculty (written) May 99.

(*) Foster agreed that current budget for seminars in Biological Physics be used instead to help bring colloquium speakers in this field.

Charge as revised by the committee
Overall Charge:

Should the department actively pursue an appointment in the field of Biological Physics as one of the next highest recruitment priorities?

For Consideration:

(1) What is the rational for such an appointment in the Physics & Astronomy Department?

(2) What interactions with other segments of the University Community are necessary for such an appointment to be successful?

(i) What resources/facilities at the University are available/necessary?
(ii) What are the possibilities for collaboration with other researchers at the University? at nearby institutions?

(3) Can the Department have a successful program, that makes an impact in the field, given the limited opportunities for growth of any new subfield as implied by our Department's fixed size?

(4) Can the Department hope to attract an outstanding person in this field? What type of startup funds/resources are needed?

(5) What are the prospects for research funding for such a position?

(6) What would be the overall impact of such an appointment upon the Department? Would it boost our visibility? Would it foster larger interdisciplinary activities? Would it help graduate recruitment?....

Appendix B
Invited Colloquium Speakers in Biological Physics

April 22, 1998
Robert Austin, Department of Physics, Princeton University
Adventures in Flatland
(http://PUPGG.PRINCETON.EDU:80/%7Erha/)

April 28,1999
Albert J. Libchaber, Rockefeller University
DNA Mode d'Emploi
(http://www.rockefeller.edu/labheads/libchaber/libchaber.html)

April 12, 2000
Prof. Watt W. Webb, Dept. of Applied Physics, Cornell University
Biophysics with Multiphoton Microscopy and Correlation Spectroscopy Fluorescence
(http://www.aep.cornell.edu/FFR/Faculty/Webb.html)

April 18, 2001
Prof. Sol Michael Gruner, Dept. of Physics, Cornell University
The Bicontinuous Mesophase Materials: Lessons From Biology
(http://bigbro.biophys.cornell.edu/)

Note: The visit of Austin preceded the official consitution of our committee.

Appendix C
UR Faculty from Other Departments Interviewed by the Committee

Douglas H. Turner, Professor of Chemistry

Thomas R. Krugh, Professor of Chemistry

Kara L. Bren, Assistant Professor of Chemistry

Shaul Mukamel, Professor of Chemistry

Christoph Dellago, Assistant Professor of Chemistry

Todd D. Krauss, Assistant Professor of Chemistry

Robert C. Angerer, Professor and Chair of Biology

Andrew Berger, Assistant Professor of Optics

Lukas Novotny, Assistant Professor of Optics

David Williams, Professor of Brain and Cognitive Sciences, Allyn Chair of Medical Optics, and Director of the Center for Visual Sciences.

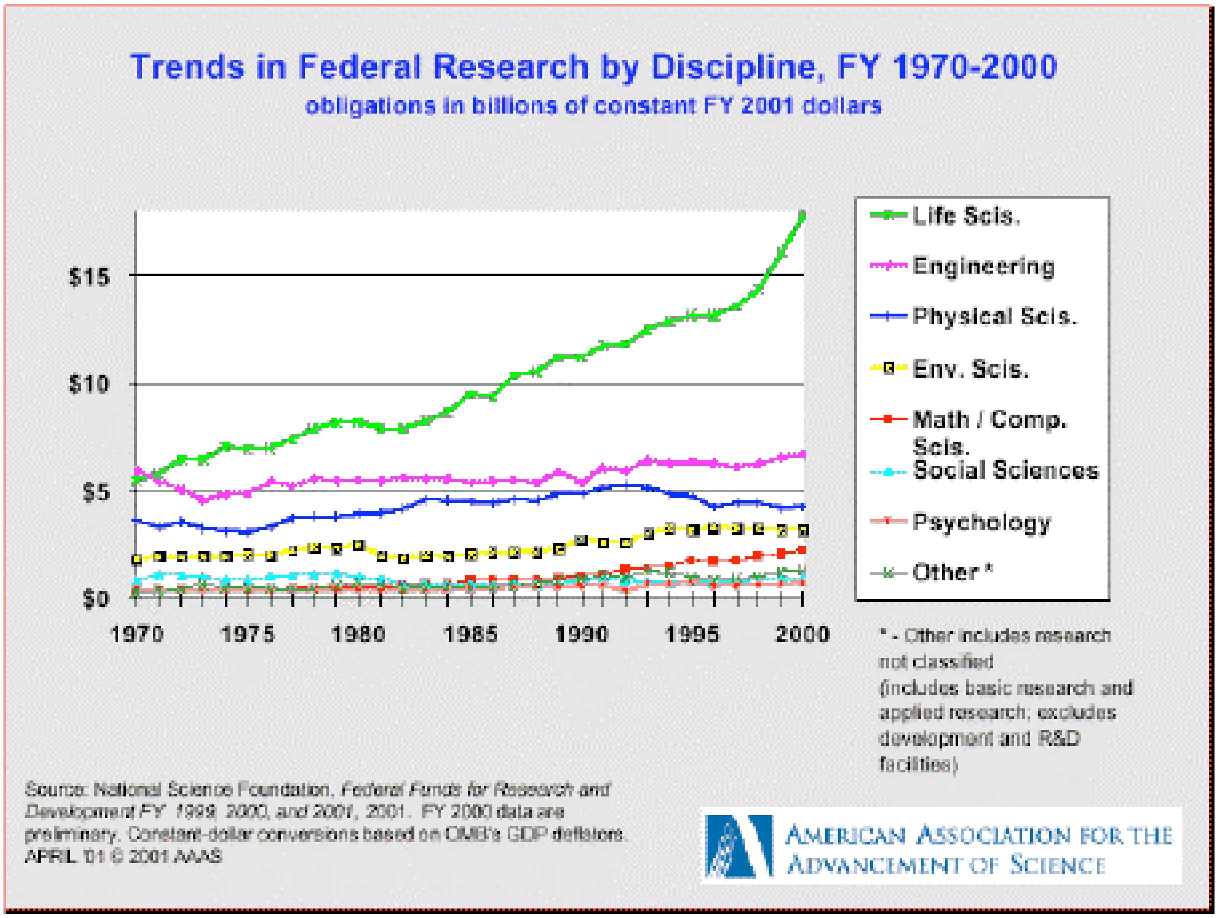
Mitsunori Ogihara, Associate Professor and Chair of Computer Science

William A. Bernhard, Professor of Biochemistry & Biophysics and Director of Biophysics and Structural Biology

Howard J. Federoff, Professor of Neurology, Molecular Medicine and Gene Therapy; Chief, Molecular Medicine and Gene Therapy; Director, Center for Aging and Developmental Biology

Gary D. Paige, Professor of Neurology, Ophthalmology, Neurobiology and Anatomy, Surgery (Otolaryngology) and Brain & Cognitive Sciences; Unit Chief, Sensory Motor Neurology Unit; Chair, Department of Neurobiology and Anatomy

Appendix D
Trends in Federal Research by Discipline



Appendix E
Sources of Funding of Established Groups in Biological Physics

Below is listed the agency, grant title, grant amount, and agency program for recent bioligically related research grants of the listed individuals (note: NIH website did not provide funding levels of grants).

Steven Chu, Stanford
NSF - Polymer Dynamics and Biophysics with Single Molecules
$1,300,000 (1248 Physics-Other)

Steven Block, Stanford
NIH - Transcription Studied at the Molecular Level
(National Institute of General Medical Sciences)

W.E. Moerner, Stanford
NSF - Single-Molecule Optical Probes of Protein Biophysics
$300,000 (1164 Molecular Biophysics)

Stephen Quake, CalTech
NSF - XYZ on a Chip: Integrated Microfluidic Analysis System
$510,000 (1406 Thermal Transport & Therm Proc)
NSF - A Microfabricated Cell Sorter for Molecular Evolution
$109,060 (1402 Biochemical & Biomass Eng)
NSF - CAREER: Polymer Physics with DNA
$407,398 (9134 EDucation & Interdiscip Resear)
NIH - FLuorescent Photobleaching Method For Sequencing Dna
(National Center For Human Genome Research)

Shimon Weiss, LBL
NIH - Development Of Q-Dots As Biological Probes
(National Center For Research Resources)

Stan Leibler, Princeton
NSF - Physical Aspects of Self-Correcting Assembly and Force Generation in Cytoskeleton Proteins (Libchaber is co-PI)
$1,273,073 (9134 Education & Interdiscip Resear)
NIH - Robustness And Individuality In Bacterial Chemotaxis
(National Institute Of General Medical Sciences)

Robert Austin, Princeton

NSF - XYZ on a Chip: Engineering of Innovative Molecular Sieves on a Chip by Nanoprint Lithography
$459,931 (1519 Integrative Systems)
NSF - NANOSCALE: Nanoscale Magnetics in Biology
$100,000 (1467 Materials Processing & Manufct)
NSF - Microlithographic Manipulation of Macromolecules
$425,000 (1164 Molecular Biophysics)
NSF - Mechanical Rigidity of DNA and its Relation to DNA-Protein Interactions
$298,300 (1144 Biomolec Struct & Funct)

Josef Kas, Texas-Austin
NSF - Microscopic Origin of the Viscoelasticity of the Cytoskeletal Rim and the Impact on Shape and Mechanical Resistance of Cells
$270,000 (1132 Cellular Organization)
NIH - Control Of Cell Elasticity By The Actin Cortex
(Nat Inst Of Arthritis And Musculoskeletal And Skin Diseases)

David Kleinfeld, UCSD
NSF - Imaging Study of Single Neuron Computation in Leech
$300,000 (1162 Computational Neuroscience)
NSF - IGERT Full Proposal: Computational Neurobiology Graduate Program
$2,700,000 (1335 IGERT Full Proposals)
NSF - Third Harmonic Microscopy: Dynamic, High-Resolution, Three-Dimensional Imaging Without Bleaching
$344,773 (1108 Instrumentat & Instrument Devp)
NSF - Role of Propogating Oscillations in Reptilian Visual Cortical Processing
$165,000 (1162 Computational Neuroscience)
NSF - Modern Biophysical Principles and Instrumentation
$259,749 (9134 Education & Interdiscip Resear)
NSF - Two-Photon Laser Scanning Microscope for Developmental/Cell Biologists
$231,544 (1108 Instrumentat & Instrument Devp)
NIH - Optical Imager For Electrical Dynamics In Cortex
(National Center For Research Resources)
NIH - Deep Multi-Photon Imaging Of Brain Structure & Function
(National Inst Of Neurological Disorders And Stroke)
NIH - Motor Modulation Of Sensory Input In Rat Vibrissa Cortex
(National Institute Of Mental Health)

Eugene Shakhnovich, Harvard
NSF - Thermo-mechanical Processes in Chemically Disordered Gels and Networks: Toward Molecular Design of Responsive Materials
$288,000 (1765 Materials Theory)

Jose Onuchic, UCSD

NSF - Computational Laboratory For The Development Of New Approaches To Complex Biological Phenomena
$100,000 (1108 Instrumentat & Instrument Devp)
NSF - Biocomplexity: From Gene Expression To Morphology And ulticellular Organization In Dictyostelium
$2,999,982 (1154 Biochemistry Of Gene Expressio)
NSF - Understanding Protein Folding: Quantitative Connections Between Energy Landscape Theory And Experiments
$750,000 (1164 Molecular Biophysics)
NSF - Understanding Protein Folding: From Lattice Models Towards Real Proteins
$543,000 (1164 Molecular Biophysics)
NSF - Theoretical Methods For Dissecting Electron Tunneling Interactions In Proteins
$285,000 (1164 Molecular Biophysics)
NSF - Electron Tunneling Pathways In Modified And Native Proteins
$253,000 (1164 Molecular Biophysics)

Terence Hwa, UCSD
NSF - Statistical Mechanics of Sequence Matching
$225,000 (1765 Materials Theory)

Eric Siggia, Rockerfeller
NSF - Theoretical Condensed Matter Physics
$411,000 (1765 Materials Theory)

Appendix F
Sources of Funding of Recent Biologically Related Faculty at the Institute of Optics

Andrew Berger
NSF - Biophotonics: Frequency-modulated Raman Spectroscopy of Biological Specimens
$222,295 (5345 Biomedical Engineering)

Lucas Novotny
NSF - Development of a Near-Field Optical Instrument for the Study of Semiconductor Nanostructures and Student Training
$300,000 (1189 Major Research Instrumentation)
NSF - Biophotonics: Near-field Raman Microscopy of Biological Membranes
$269,239 (5345 Biomedical Engineering)

Appendix G
Major Subfields of First-Year Graduate Students

Table 7. Major subfields of first-year students enrolled in a physics or astronomy program who have plans to receive a PhD, 1997-98.

	US Citizens	Foreign Citizens
Undecided	22	24
Astronomy / Astrophysics	18	8
Particles and Fields	13	13
Condensed Matter	12	25
Atomic and Molecular	6	3
Nuclear	4	5
Optics/ Photonics	4	4
Biophysics	4	2
Materials Science	3	3

Source: AIP Statistics Division, 1998 Graduate Student Report.