FIRST DRAFT OF
DEPARTMENT OF PHYSICS PLAN

March 15, 1999

1. A Vision for Physics

The aim of Physics is to discover the underlying principles governing all natural phenomena, particularly those relating to matter, energy, and their interactions.

By its outstanding success throughout the 20th century, physics has transformed our vision of the universe in which we live and has led to a tremendous flowering of technological advances on all societal fronts — many of which we now take for granted. This impact has arisen because, in addition to its role in elucidating the basic rules controlling all natural phenomena, physics is the "measurement science" – showing how mathematical and computational precision may be applied to understand the behaviour of complex systems. Furthermore, physics is the discipline that has pioneered new methods of observation that extend our ability to comprehend our world.

For these reasons, physics is a core discipline for prospective scientists in all fields, and physicists themselves often become generalists who apply their unique skills in observation, analysis and modelling to areas that extend beyond physics and beyond science.

The aim of the Department of Physics at the University of Toronto is to be at the forefront of research, emerging as the strongest physics department in Canada, in research, in graduate level training, and in specialist and general undergraduate instruction, and to be fully competitive with the very best physics departments in the leading public research universities in the U.S. and the world. Situated in Canada's largest research-oriented university with students of the highest calibre recruited widely from the whole country, we view our goal as a national obligation for the department and the University.

Our plan is driven by four broad initiatives: Subatomic Physics and Astrophysics, Complex Systems and Materials, Planetary Science, and Computational Physics. This categorization does not reflect the strong cross-linkages that exist between all these initiatives. In the case of Computational Physics the cross-linkages are so complete — indeed, physicists have led the development of scientific computation, which underpins nearly all of physics — that this initiative permeates the other three. In all four initiatives, we have undertaken undergraduate and graduate program development that involves new directions and closer links with cognate disciplines within the University.

Our goals can only be met if we remain a vital and active member of the Faculty of Arts and Science. This requires us to continue to enhance our undergraduate course offerings, to maintain the excellence of our graduate program, and to reinforce the strong linkages with departments such as Astronomy, Chemistry, Geology, and Mathematics and the Faculty of Applied Science and Engineering. Together with closer collaborations with graduate organizations such as the Canadian Institute for Theoretical Astrophysics (CITA), the Institute for Biomaterials and Biomedical Engineering (IBBME) and the Isotrace Laboratory, we believe our plan properly capitalizes on the interdisciplinary aspect of the University.

a) The Focus of Physics for the Next Decade

The Department of Physics is approaching the year 2000 with an excellent faculty, a strong research base and the opportunity to enhance our undergraduate and graduate programs. Through a year-long process of consultation, discussion and study, we have identified four key initiatives that we believe our department must pursue.

1. Subatomic Physics and Astrophysics — the area in which the most fundamental formulations of the general laws of nature are developed through theoretical insight and experiments that

probe our universe at both subatomic and astrophysical scales. The goal of this synthesis is an understanding of the fundamental structure and evolution of our universe.

2. Complex Systems and Materials — the broadest area of physics, with the greatest impact on other sciences and society. It involves research on matter at all levels of complexity, from atoms to molecules, to solids, to biological systems. The systems we find most interesting range from atomic gases at extremely low temperatures, to crystals that are superconductors at unusually high temperatures, to biological structures whose basic physics principles remain to be uncovered. This initiative presents enormous opportunities for the development of new materials and technologies.

3. Planetary Science — the area of physics where we apply fundamental principles to comprehend one of the most complex systems — the planet we live on. Observations of planetary phenomena using remote sounding of our atmosphere, geophysical exploration and theoretical modelling remain central to our study of earth. The development of more sophisticated techniques to observe and model our planet is key to understanding the human impact on our ecosystem.

4. Computational Physics — Physics has been at the forefront in applying computational techniques to understand the behaviour of complex systems and to perform large scale data analysis. This imbues virtually all of our activities, ranging from data acquisition and analysis in our undergraduate laboratories to the use of the highest performance computing systems in the University to model the earth's atmosphere.

These four intiatives focus our resources on the most effective ways to train the next generation of physical scientists, and at the same time they support a physics graduate research program at the forefront in those fields of research that are our priorities. We believe this will move the University of Toronto forward as one of the leading institutions in education and research in the physical sciences.

The department spans the three campuses of University of Toronto. Our goal is to provide undergraduate programs in an integrated manner across the three campuses, with most graduate teaching and research performed on the St. George campus. In this planning document, we address the undergraduate and graduate curricula at the St. George campus and graduate research across all three campuses in order to develop a coherent complement plan.

2. The Department of Physics in the Next Decade

a) Our Undergraduate Program

We offer a wide variety of undergraduate programs in physics, ranging from the specialist programs that target those who intend to become professionals in physics and related fields, to courses and programs designed for students in areas such as engineering and life sciences who need a solid grounding in experimental physical science. In all of our offerings, we provide students with both an understanding of how our world works, and the skills necessary to apply quantitative reasoning, experimentation, and model-building to solve a wide variety of problems.

The majority of our first year students take "Physics for the Life Sciences I", a course designed to teach physics in a manner relevant to the life sciences. We devote significant effort to this task: a wide collection of lecture demonstrations, tutorial sections with ~25 students each, a drop-in-centre and a first year laboratory that is one of the most intensive in the Faculty. A significant commitment is also devoted to Engineering Science students in the first two years of their program.

The heart of our undergraduate teaching effort is the set of specialist programs we offer individually and jointly with Astronomy, Chemistry, Computer Science, Geology, and Mathematics. Along with a program in Applied Physics introduced in 1997, these comprise the baseline of our current efforts. The Physics Major program stresses breadth rather than depth, and has been an important avenue for educating students about the role that physics plays in other areas.

Over the last ten years, we have made several innovations in our undergraduate programs. As just one example, we have introduced a successful set of courses in scientific computation, presenting students with hands-on examples of how current scientific problems are tackled computationally. These courses are unique to the Faculty and are made possible by the existence and continued support of UPSCALE, our undergraduate computing facility.

However, due to complement reductions over the last 10 years (33.5 FTE in 1999 compared with 38 FTE in 1990 on the St. George campus), we had to reduce the number of offered courses. To preserve the specialist programs, we eliminated courses specific to the Physics Major program, which now relies on a subset of courses aimed principally at Physics Specialist students. This has discouraged enrolment in our Physics Major program and limited the curricula of some of our specialist courses. We have also been forced to offer more fourth year courses cross-listed as first year graduate courses. We have not had the teaching resources to offer new courses specifically aimed at evolving programs. The Applied Physics, Biophysics and Planetary Sciences programs (the latter two just introduced in 1999) have been developed using existing course offerings. Finally, the reductions in the department's base budget have limited our ability to maintain and rejuvenate our laboratory courses.

Undergraduate Program Initiatives

Our priorities in the next planning cycle are to strengthen our existing program offerings, to support the University of Toronto at Scarborough (UTAS) Early Teacher Project on the St. George campus, to enhance our new interdisciplinary programs, and to develop a new limited-entry program that will attract some of the very brightest students to our Faculty. We discuss the impact these initiatives will have on our undergraduate teaching activity in Appendix C.

i) A Distinct Physics Major Program

We propose to reinstitute a first year and two third year courses (2.0 FCE) designed for the Physics Major program. These courses will enable us to introduce to the students in the Physics Major a broader range of topics in physics, and at the same time continue to give specialist students more in-depth treatment of topics such as quantum mechanics, electrodynamics and subatomic physics.

ii) The Early Teacher Project

There is a desperate need in Ontario for well-trained teachers of the physical sciences and mathematics. The Early Teacher Project (ETP) at UTAS has long been a unique avenue for the training of such people, providing students with an enhanced undergraduate science education and direct entry into OISE/UT (admission is limited to 30 students/year). However, resources at UTAS can no longer provide support for all the science specialist programs.

Planning with UTAS have led us to an arrangement where we continue offering ETP to UTAS students in astronomy and physics by having them take their first two years at UTAS and their last two years on the St. George campus. At the same time, Astronomy and Physics Specialist students on the St. George campus will be able to enrol in ETP. UTAS will continue to administer ETP, and has already approved the program changes. We will need to mount two half-courses: "Physical Sciences in Contemporary Society" and "Current Questions in Mathematics and Science," which we believe will also be of interest to students in the revived Major program. We expect ETP at St. George to continue to evolve to include other programs in the Faculty.

iii) Biological Physics

Biological systems will form the basis of a great deal of science and technology in the coming few decades. Some of the strongest student interest in physics is in this area, and we have identified biological physics as a priority for graduate research and training. We recognized in 1997 that the Biology and Physics Specialist program was not meeting this interest, and developed with the Department of Physiology a new Biophysics Specialist program. As with other program initiatives, we introduced the Biophysics Specialist without adding additional courses. We now propose to enhance this program by offering a new half-course in biological physics and reinforcing our linkages with the Departments of Botany, Physiology and Biochemistry. We also need to introduce new biological physics experiments in our undergraduate laboratory.

The replacement of the Human Biology Program with a Life Sciences Major Program offers another opportunity to enhance our interdisciplinary approach to physics and the life sciences. Students in the Life Science Major program will now be able to choose a Physics Major to enhance their analytical background.

As part of our complement renewal, we propose the development of a strong research program in biological physics to support this teaching initiative.

iv) Planetary Sciences Program

With the Departments of Astronomy, Chemistry, and Geology, we have developed a new Specialist program in Planetary Science. This will require collaboration in at least two new half-courses, and leads us to propose two additional half-courses designed for students in this program.

Reflecting the department's initiative in Astrophysics in conjunction with Astronomy and CITA, we also propose to augment our Physics Specialist program's fourth year options with an option in this area. We will make use of existing courses in Physics and Astronomy and will mount a new course on Big Bang Cosmology.

We also propose to develop an undergraduate program in Exploration Geophysics, led in part by the endowed Teck Chair in Exploration Geophysics. This program will be mounted mainly by Physics with the cooperation of the Department of Geology and the Division of Mineral Engineering in FASE, and is reflected in a complement request in our plan.

v) Applied Physics and UPSCALE

To strengthen our recently introduced Applied Physics specialist program, we plan to offer a course composed of modules focusing on various real-world applications of physics. We also need to upgrade our third and fourth year laboratory to include more experiments reflecting the current state of applied physics techniques (see Appendix G).

We have been a University leader in the development of scientific computation within the undergraduate program. Our effort is centred around UPSCALE, which supports computation in the undergraduate laboratory, computational assignments in lecture courses, and a third and fourth year computational laboratory course. UPSCALE must continue to evolve to keep pace with the rapidly changing computational technology. Our requests specific to UPSCALE are found below in Section 5.

vi) The "New" MPC Program

Many of our most successful alumni were attracted to the University because of a demanding program, "Mathematics, Physics and Chemistry," which was discontined over 20 years ago. This program attracted a core group of students who set the standard for excellence in the physical sciences in North America.

We propose, in collaboration with other physical and mathematical science departments, the creation of a new limited-entry program that we tentatively call "Mathematics, Physical Sciences and Computation," or MPC for short. A discussion document that describes the rationale for MPC and a possible implementation is found in Appendix D. This proposal and its resource implications are currently being refined.

b) Our Graduate Program

Our graduate program in physics remains the largest in Canada. We effectively recruit the very best Canadian and international students (as evidenced by the number of external scholarships held by our students), and our graduates move quickly into leadership roles in academia, research and other applied fields (see Appendix E).

There are currently 108 graduate students in the department. Over the past seven years, we have reduced our enrolment from about 170 students to numbers that have been slightly over 110 for the past few years. One positive factor in this decline has been our successful effort to reduce the length of our Ph.D. program, through the introduction of the one-year M.Sc. and annual supervisory committee meetings. This decline has also been driven by a reduction in our supervisory capacity due to retirements, and of a reduction in graduate funding.

These factors have made it increasingly difficult for us to offer a full suite of graduate courses. We have responded by offering introductory graduate courses as cross-listed advanced undergraduate courses, and by offering some graduate courses in alternate years. The quality of our graduate program has been adversely affected by these developments, especially when coupled with the shortened target time for the Ph.D. degree, giving students fewer opportunities to take courses in alternate years.

Graduate Program Initiatives

Our highest priority graduate initiative in the next planning period will be to reverse the trend to more cross-listed courses (Objective 2.10 of the White Paper) by converting several cross-listed courses into a graduate-only format. We are also developing a more efficient delivery of our graduate courses through the introduction of a core course format. In a department as heterogeneous as ours, the effective design and delivery of such a format is a challenging problem, but one on which discussions are in progress. In almost all scenarios, we will be required to introduce an additional 5.0 FCE in our graduate course offerings.

According to the White Paper, “doctoral-stream enrolment should be limited only by supervisory capacity.” Using this as a guide, we have set a preliminary graduate enrolment target for 2004-2005 of 160-170 students (see Appendix F). While aggressive recruitment will be necessary to increase our enrolment, this effort is already well underway. In addition to the department's visible presence at events such as the Canadian Undergraduate Physics Conference, we use the NSERC Summer Research Awards to bring potential graduate students to Toronto while they are undergraduates, we have developed new publicity material, and we have redesigned and expanded our web pages. The International Recruitment Awards has allowed us to undertake a major initiative in increasing the number of students we can welcome from abroad.

One achievement of the past planning cycle has been the introduction of a collaborative Astrophysics M.Sc. Program mounted jointly by the Departments of Astronomy and Physics. We have supported this program with two faculty appointments (one jointly with Astronomy). As this program becomes established, we plan to offer two new graduate courses in this area. We are also considering offering a professional M.Sc. program in Exploration Geophysics, which would be offered jointly with the Department of Geology and the Division of Mineral Engineering in FASE. Complement to support this program would come from the Teck Chair and an additional appointment in exploration geophysics.

The University of Toronto has a wide array of strong programs in the planetary sciences, spread among Physics, Chemistry, Geology, Astronomy, and CITA. We intend to continue working towards stronger collaboration between these units. The development of a collaborative M.Sc. program in Planetary Science, along the lines of the one in Astronomy and Physics, is one possible future initiative that we are actively exploring.

Complement Implications

We are proposing to maintain a strong set of Physics Specialist programs, to strengthen the Physics Major program (2.0 FCE), support ETP (1.0 FCE), and develop the Applied Physics, Biophysics and Planetary Sciences Specialist programs (3.0 FCE) during the current planning period. Our move to a more distinct M.Sc. graduate program will require the introduction of 5.0 FCE. Together, these initiatives result in an increase in teaching load of 11.0 FCE, which will require 7.0 FTE additional complement to deliver. Taking into consideration the five retirements on the St. George campus, we will require a minimum of 12.0 FTE new appointments on the St. George campus in the next planning period.

c) Research Initiatives

Our plan has identified four over-arching initiatives for the department, and these have set the priorities for each of our three research groups during the next cycle. Our specific research-related proposals grow out of these initiatives. Within each broad thrust, we have identified requests for faculty positions by two priority levels: (1) Positions that are essential to support our initiatives, providing the teaching and research resources at the minimal level outlined in this plan; and (2) positions that will allow the department to implement most effectively the proposals outlined in this plan.

We describe in Appendix B the current complement positions that have been bridged to allocations from the APF in the next planning period. These positions constitute our very highest priority complement requests.

i) Subatomic Physics and Astrophysics

Subatomic physics involves the study of nuclear matter and its constituents. The particle physics group focuses on studying the very highest energy interactions and the fundamental constituents of matter. These topics are intimately tied to the origin and the fate of the universe, as researchers try to understand the conditions in the aftermath of the Big Bang. Theories of elementary particles are now heavily constrained by astrophysical and cosmological considerations. At the same time research in subatomic physics, for example in the measurement of nuclear reactions of astrophysical interest, places important constraints on the parameters governing stellar evolution and even on the nature of the universe. Within this initiative, our goal is to strengthen our experimental particle physics research effort, and to establish Toronto firmly as one of the leading centres for astrophysics research in North America.

Our experimental particle physics group is involved in two experiments currently collecting data, ZEUS and CDF, and are involved in one new project, the ATLAS experiment at the Large Hadron Collider under construction at CERN, Geneva. This group is one of the strongest in Canada, providing the Canadian leadership for three major international collaborations, including ATLAS. The principal goal of ATLAS, the highest priority particle physics project in Canada, is to discover the Higgs boson, the central missing piece in our understanding of the origin of mass. As this experiment prepares to come online around 2005, we plan to shift our focus increasingly to it.

The group is currently involved in detector upgrades and collection of data for the two ongoing experiments, and instrumentation development for ATLAS. It is understaffed given its leadership role, the number of students and postdoctoral fellows and the resources at its disposal. We therefore request an additional complement position in **experimental particle physics**, as we consider this essential for the group to maintain its current level of activity. This position presents an opportunity to make a joint appointment with the TRIUMF laboratory. We request a second complement position in **experimental particle physics** later in the planning period in order that our particle physics group begin to develop the next generation of experiments that would follow ATLAS. Although our theoretical particle physics group is relatively young, we will have one retirement in this area by 2004 and a complement position in **theoretical particle physics** late in the next planning cycle in order to maintain our ability to continue offering advanced undergraduate and graduate courses in particle theory.

A recent joint appointment with the Department of Astronomy has strengthened ties between the Departments of Physics and Astronomy and CITA. Recognizing the growing importance of astrophysics and its connection to particle physics, we have identified as a high priority the development of an experimental astrophysics group. The next decade will see new data coming in at an unprecedented rate from both orbiting and ground-based instruments, and this group would be well-placed to participate in a vital way in this burgeoning field. We are presently pursuing an opportunity appointment in **experimental astrophysics** in this area, bridged to an APF position (see Appendix B). We propose an additional **experimental astrophysics** position, joint with Astronomy. With these appointments, we will have created perhaps the strongest group in experimental astrophysics in Canada. Future appointments in **experimental or theoretical astrophysics** and **experimental particle physics** are requested late in the next planning period to further strengthen these groups.

An early retirement has left the department unable to support mathematical physics, particularly in the traditional areas of group theory, gravitation, and formal field theory. At the same time, the Departments of Mathematics and Physics, together with CITA, have identified an appointment in **mathematical physics** with interests in string theory as a high priority. We are currently pursuing a joint appointment in this area, with bridging funds from CIAR, the Canadian Institute for Advanced Research (see Appendix B).

ii) Complex Systems and Materials

Research into complex systems and materials is performed in our department by the quantum optics and condensed matter group. The uniqueness of this group in North America is that we have been able to establish strength in both condensed matter physics and quantum optics, rather than in just one or the other. The group's research topics range from the role of quantum fluctuations in novel magnetic properties of exotic materials to the design and application of new ultrafast lasers for cutting-edge research in biophysics, astrophysics, and micromachining. Within this initiative, our goal is to complete the rebuilding of our condensed matter physics group, build on our strength in quantum optics and establish a collaborative biological and nonlinear physics research and teaching program.

The major new thrust in our condensed matter group is research on materials that display novel magnetic and electrical properties such as superconductivity at high temperatures. These materials, collectively known as correlated electron systems, can only be studied using sophisticated instruments, low temperature facilities and high-field magnets. Our department is poised to become one of the leading groups in this area, with two young faculty, strong leadership from a recent recruitment (Prof. Louis Taillefer, a Steacie Fellow and head of the CIAR Superconductivity Program), a current Tier II search underway, and some of the most modern facilities in Canada. We therefore request one appointment in **experimental condensed matter physics** in the next planning period, as it will give this research effort the necessary breadth to be competitive with the very best university groups in North America. The theoretical side of the condensed matter group is at a critical juncture, with four retirements in 2004. It is imperative that we plan carefully for the healthy evolution of this group, with the view to fostering synergy with the experimental efforts. We therefore request **two** positions in **theoretical condensed matter physics**. Without these two positions, we will not be able to offer a viable graduate program in this area of physics.

Our quantum optics group is unquestionably the strongest in Canada, and the driving force behind Photonics Research Ontario (PRO), an Ontario Centre of Excellence located in McLennan Physical Laboratories. Our researchers focus on topics such as the development of ultra-intense lasers, optical studies of biophysical systems and laser-cooling of atoms. Our theoretical group is spearheaded by two faculty (Profs. John and Sipe) who are among the pioneers in the area of novel optical materials, studying topics such as photonic bandgap materials and Bose condensation. Over the next five years, we believe the group has an excellent opportunity to take up a leadership role in North America, provided we are able to maintain a strong base in core areas such atomic and molecular interactions, and move aggressively in new fields such as laser cooling and photonic bandgap materials. We therefore request in our plan two new experimental positions, one in **experimental atomic, molecular and optical physics** and the other in **novel optical materials**, and one position in **theoretical quantum optics**. Faculty in these positions will integrate well with our proposed undergraduate and graduate programs.

The object of biological physics is the study of fundamental processes occurring in living systems, and the field has undergone rapid expansion because of the availability of new precision optical probes and micromechanical techniques developed by physicists. We have identified this area as a high priority for our undergraduate program and have a long-range goal of developing a strong graduate research effort in this area, in collaboration with medical biophysicists within the University. At present, the department has only a small effort in this area, with two members of the quantum optics group devoting part of their research effort to studies of biophysical systems and with one appointment currently being searched for as part of our current plan.[1] Several cross-appointed faculty in other units (IBBME and the Institute of Medical Science) are also involved in graduate research in this area, and contribute to our undergraduate Biophysics program.

In order to support this initiative in biological physics, we request **three** complement positions in the next planning period in **biological physics**. We believe this will create a core group of experimental physcists that will be able to lead biological and nonlinear physics in Canada. It would also provide the academic leadership to make our new Biophysics program into one of the most exciting interdisciplinary areas we offer our students.

iii) Planetary Physics Research

Our department is unique in North America for having a substantial fraction of its faculty devoted to the study of our planet. We have developed geophysics and atmospheric physics groups that are well-known for their research focus on the fundamental physics processes that govern planetary phenomena. Over the coming decades, global environmental science is expected to be an area of strong growth in both research and teaching, and the University of Toronto must maintain and expand on its leadership position. Our role in this collaborative effort is to focus on the more quantitative aspects of research in this area, producing core-science-based graduates who drive many areas of this field. In partnership with cognate academic units, we intend to strengthen our role in fundamental atmospheric physics and geophysics research within the University.

The geophysics group has experimental and theoretical strengths in geochronology, rock magnetism, geodynamics, crustal evolution and marine geophysics. The impact of a retirement in the area of seismology and one retirement in the next planning period is such that complement renewal in this research discipline is one of our highest priorities. Applied geophysics has traditionally represented the largest fraction of graduate student activity within geophysics, so the new Teck Chair in Exploration Geophysics is a cornerstone of the group's plans. The Chair is expected to have strong connections with industry, and we anticipate she will be cross-appointed to Geology and the Lassonde Institute. In order to establish a group that can support this applied geophysics effort, we propose a complement position in **exploration geophysics** that would be a joint appointment with the Department of Geology and perhaps the Division of Mineral Engineering in FASE. Our geophysics group also maintains a world-class effort in geochronology research, an important area of inter-disciplinary research with the Departments of Geology and Anthropology and the

[1] The more general area of nonlinear physics is concerned with the dynamics of open, driven processes. Such processes typically undergo instabilities leading to new organized structures and possibly to chaotic motion. Similar nonlinear processes are common in the formation and dynamics of biological structures, particularly at the cellular scale and larger. Thus, there is considerable overlap between biological and nonlinear physics. We have supported a successful experimental effort on physical problems in this area and currently have a search underway for an additional experimentalist in the general area of biological and nonlinear physics. We therefore consider our biological physics effort one part of our nonlinear physics research and will continue to build on this overlap in future appointments. Nonlinear physics processes are also responsible for many phenomena at the planetary scale, creating a strong overlap between this area and our planetary physics research.

Royal Ontario Museum. Physicists continue to develop the tools of geochronology — accelerator mass spectrometry, ion ablation methods, plasma ionisation techniques — that have opened new frontiers in earth science and human evolution studies. An appointment in **geochronology** in the next planning period is a high priority for our department, given the retirement of the faculty member who has led this field.

Our experimental geophysics effort is supported by active research in geodynamics and crustal evolution, or more broadly speaking solid earth geophysics. This is an important part of our planetary sciences effort and we will need to maintain its strength with at least one appointment in **solid earth geophysics** late in the next planning period.

Our Atmospheric Physics group has experimental strengths in remote sounding and theoretical strengths in atmospheric dynamics and climate modelling. It is one of the very best groups in North America, as evidenced by the large number of graduate students, the group's research output and its funding. However, our experimental effort is understaffed given the range of activities underway and the research opportunities available to the group with strong support from the Canadian Space Agency. We also believe a complementary theoretical position in data analysis and interpretation will strongly enhance these experimental activities. We therefore request one position in **experimental atmospheric physics** and a second position in **theoretical atmospheric physics**. Among our theorists can be found the leadership for three major Canadian inter-disciplinary collaborations in climate science and the leadership for the CFI PSCINET initiative. The University can enhance its role in this area, particularly in areas related to ocean-climate studies and computation. We therefore propose two complement positions in this area, with one being a joint appointment with the Department of Chemistry in **atmospheric chemistry** and the second being a **theoretical atmospheric physicist** specializing in ocean and climate modelling.

3. Involvement in Faculty Priorities

There are a number of Faculty infrastructure needs that will have a significant benefit to our department.

The previous conversion (jointly funded by the department and the Faculty) of MP134, a medium sized classroom, to a Smart Classroom two years ago has demonstrated the added value of the technology in teaching physics and other subjects. We request that the Faculty continue this initiative and upgrade the five remaining classrooms in McLennan Physical Laboratories, providing this technology to all undergraduate instruction in our building.

We have a need for one or two 300-350 seat lecture halls that will be exacerbated by growing student numbers. This type of new teaching space would better promote the quality of physics instruction compared with an amphitheatre such as Convocation Hall. We expect this resource to be valuable throughout the physical sciences.

The Physics Library represents a major departmental resource. Despite careful space utilization and the fact that physicists have taken a leadership role in the use of electronic publication, the growth of the paper collection will exceed our space capacity in a few years. This is also the case in the department libraries of Astronomy and Chemistry. This led to an initiative by the three departments to create a "Physical Sciences Complex," which would house a joint library and meet the need for quality student space. While development efforts to fund this facility have not been successful, the concept remains for us a high infrastructure priority.

4. Resource Requests

a) Complement Requests

In the previous two sections, we have outlined how our teaching and research initiatives come together into a single plan for the department across the three campuses. To maintain our teaching and research effort, we require an increase in complement on the St. George campus of 7.0 FTE, which together with five retirements during this period, bring a total St. George complement request for the next planning period of 12.0 FTE. We also note that we have requested 3.0 FTE positions from UTAS to support ETP during a period when we have three retirements.

Our research priorities represent an integrated view of our research effort across all three campuses. Our first priority complement requests total 15.0 FTE. This is well matched to our proposed complement needs for teaching on the three campuses. Three of the positions proposed in the plan below would therefore be made at UTAS, with the likely areas of those appointments in theory or planetary physics, and the balance would be appointed on the St. George campus.

We have divided our requests into three classes of priority, the first being the positions already bridged (described in Appendix B), the second being our first priority new requests, and the third being second priority new requests that set a longer range view of the evolution of our complement. Four of these are joint positions.

Our First Priority Complement Requests

1. Biological Physics Experiment: This appointment is required to support our initiative in biological and nonlinear physics research and teaching (this position will allow a transfer from UTM in nonlinear physics and a corresponding new UTM appointment in biological physics).

2. Experimental Astrophysics: A joint position with Astronomy to build up strength in this new area of research with close collaboration with Astronomy and CITA.

3. Experimental Particle Physics: A joint appointment with the TRIUMF laboratory, this position supports the department's active role in the ATLAS experiment at CERN, the highest priority particle physics project in the department.

4. Experimental Particle Physics: This second appointment would be directed toward research in an area that will complement the department's focus on ATLAS.

5. Condensed Matter Theory: This position, one of two for a theoretical physicist with interests in correlated electron systems, is required to maintain a vital graduate research program in theoretical condensed matter physics.

6. Quantum Optics Theory: This appointment will enhance the current strength of the optics group, allowing the department to maintain its leadership role in the development of theories describing the interactions of matter and light.

7. Biological Physics (experiment or theory): This appointment is required to bring our effort in this area to the level where we can support our biophysics teaching initiatives and create a viable research program.

8. Condensed Matter Experiment: An experimentalist in correlated electron systems will complete the development of this research group. The proposed combination of experimentalists, theorists, and materials and cryogenic infrastructure will make Toronto a leading force in this field.

9. Experimental Atomic, Molecular, and Optical Physics: This is required to maintain sufficient strength in core areas and to build on a growing experimental and theoretical program in novel phenomena in atomic physics.

10. Experimentalist in Novel Optical Materials: This position will expand the experimental quantum optics research effort into areas such as photonic bandgap materials, nanostructures and biological materials, where we have significant theoretical strength.

11. Condensed Matter Theory: This position is required to maintain a graduate program in condensed matter physics, and support the experimental effort in correlated electron systems.

12. Applied Geophysics (joint appointment with Geology or with the Division of Mineral Engineering): Along with the Teck Chair, this position allows us to support a collaborative undergraduate program and retain a strong research effort in applied geophysics.

13. Atmospheric Chemistry (joint position with the Department of Chemistry): This position will support the new B.Sc. in Planetary Science, and will support the collaboration between Physics and Chemistry in environmental science.

14. Planetary Physics Experiment: This is required to support the new Planetary Science program. The focus would be on extraterrestrial classical planetary science (planetary evolution, planetary atmospheres, and space missions) and would complement proposed Astronomy positions in star and planet formation.

15. Geochronology: This is required to maintain our established research program of international stature in advanced geochronological methodologies. The appointment contributes to a Faculty-wide initiative including ISOTRACE, Geology, Anthropology and the ROM.

16. Solid Earth Geophysics: This is required to complement the strong research effort and graduate program in theoretical geodynamics and crustal evolution.

17. Atmospheric Physics Theory: This appointment would support the experimental atmospheric research effort, with particular interest in analysis and interpretation of space-based measurements.

Priority 2 Complement Positions

1. Theoretical Particle Physics: This appointment will maintain the strength of our research and teaching efforts in theoretical particle physics.

2. Experimental or Theoretical Astrophysics: This appointment will strengthen our astrophysics effort, at a time when several new satellites will be coming online.

3. Experimental Particle Physics: This appointment will strengthen our experimental effort in this area as we anticipate future faculty renewal.

4. Nanostructures (Condensed Matter Experiment): A position that will bring nanoscience expertise into our condensed matter research effort, and take advantage of the growing Nanotechnology Programme of the CIAR.

5. Biological Physics (Theory or Experiment): This is required to support the growth of the department's expansion into studies of modern problems in nonlinear and biological physics.

6. Ocean Dynamics and Climate: This theoretical atmospheric physics appointment is required to fill a notable gap within the Planetary Physics group.

b) Non-academic Staff Requests

i) Administrative Staff Requests

Our administrative staff have had to assume increasing workloads as decentralization of administrative services continues, in particular from the School of Graduate Studies. At the same time, we have had to provide support for increased undergraduate student enrolments and increased levels of research and contract activity. In addition, the department has taken a more pro-active role in regard to alumni, high school and public liaison, placing further demands on these resources.

In recognition of these changes, we undertook an extensive administrative review of all administrative staff functions in 1998. This led us to reallocate staff resources to new activities associated with outreach activities, public liaison and web page support. We identify the need for an additional 0.8 FTE of administrative support, with 0.6 FTE allocated to support our graduate program and 0.2 FTE allocated to support our research administration effort.

ii) Technical Staff Requests

As part of the CFI PSCINET proposal, we have identified the need for one computing professional (1.0 FTE) that would provide technical support for this high performance computing system. This additional staff is the minimum necessary in order to allow the department to continue to provide computational support for our teaching and research activities.

iii) Training of Teaching Assistants

We recognize that the ability of our teaching assistants and laboratory demonstrators is highly uneven; from course evaluations, it is clear that improving this aspect of the undergraduate program would have an enormous impact on the quality of the educational experience — perhaps a greater impact relative to cost than anything else. The amount of training that we provide at the beginning of the academic year, which presently ranges from one to three hours, needs to be expanded to 25 hours per student. We therefore request a total of 1900 hours in additional TA support in the first year, reducing to 950 hours in subsequent years.

c) Modernizing the Infrastructure in Physics

For the next planning period, our infrastructure initiatives are summarized below in order of priority:

- We will need ~ 575 m^2 for undergraduate study space and graduate student offices.

- We will need ~ 1200 m^2 for research laboratory space.

- We request \$100,000 for new undergraduate laboratory equipment, and \$75,000 per annum for modernization and renewal of existing apparatus.
- We request \$50,000 for an upgrade of our UPSCALE computer facility, and \$62,000 for completion of the Nortel Applied Physics Laboratory.
- We request \$100,000 to complete the purchase of a computer controlled vertical mill in our mechanical workshop and \$50,000 per annum for small capital equipment renewal.
- We request \$140,000 to update the design, fabrication and testing equipment in the Physics Electronics Resource Centre.

We provide details on these requests in Appendix G.

5. The Legacy of "Strengthening the Core"

We have already discussed in some detail the impact of the last planning period on our undergraduate and graduate programs. The research groups in our department have also faced unique challenges in coping with the budget cuts of the last planning period, but our researchers have continued to make significant scientific advances. This success has been recognized by increases in research funding (\$6.94M per annum during 1995-98 compared with \$5.70M per annum during 1991-94) and by many of our scholars receiving prestigious fellowships or awards (see Appendix H).

Our subatomic physics group has seen the most extensive evolution over the last ten year period. Toronto has played a leading role in nuclear physics studies, with our researchers being key collaborators in such initiatives as the Isotrace Laboratory, the radioactive beam facility at the TRIUMF laboratory in Vancouver, and the nuclear structure studies performed at the AECL Chalk River Laboratories. Toronto has also been one of the leading institutions in experimental and theoretical particle physics. The nuclear physics effort has already suffered significant attrition. The difficult decision to allocate new complement positions to higher priority areas will mean that by 2002, when our last nuclear physicist retires, active nuclear physics research will be limited to the Isotrace Laboratory and professors emeritus.

By July 1, 2000, this group will number 13.5 FTE, with two additional nuclear physicists retiring between 2000-2004.

Our quantum optics and condensed matter physics group focuses on the study of complex systems and materials. During the last planning period, we were able to attract to our quantum optics group the NSERC-Lumonics Industrial Chair in Quantum Optics (joint with Chemistry) bridged to a position in the next planning period. The quantum optics group has attracted three CFI awards in the last year and has associated with it both of our current Killam Fellows.

Our research in complex materials using low temperature techniques has focused on the study of novel materials that display, among other things, superconductivity at unusually high temperatures. We have been rebuilding this experimental research effort and in 1998 we recruited an outstanding experimentalist, Prof. Louis Taillefer. This rebuilding effort continues with one appointment scheduled for July 1, 1999. We are also solidifying our effort in the study of complex systems with the transfer from UTM in 2000 of an established experimentalist studying systems that display complex, nonlinear behaviour such as pattern formation in granular flows. This area forms with biological physics a new initiative for the department, and is supported by an APF position in the current planning period.

Complement in this area of research will number 16.5 FTE by July 1, 2000 (13.5, 1.0 and 3.0 FTE at St. George, UTM and UTAS, respectively).

Our experimental atmospheric physics research effort was significantly augmented in 1995 when we secured an NSERC Industrial Chair in Remote Sounding (held by Prof. Jim Drummond). This allowed us to make a junior appointment bridged to an APF position in the next planning cycle, which has significantly enhanced the impact and strength of this group. The new hire, Prof. Kim Strong, is principal investigator on a balloon-based atmospheric sounding experiment and received a CFI New Opportunities award to construct an atmospheric observatory on the top of the Burton Tower. Prof. Drummond's research has involved the development of a multi-million dollar satellite instrument (called MOPITT) that is due to launch on a NASA platform this summer. The result is a concentration of experimental atmospheric physics research efforts on remote sounding of the atmosphere. Our theoretical atmospheric physics group, consisting of four researchers, remains one of the largest atmospheric modelling efforts in Canada, with the group providing the leadership for three major Canadian inter-disciplinary collaborations in climate studies.

Our geophysics group continues to be the focus of geophysics research at the University. During the last planning period, we raised private funding to create the J. Tuzo Wilson Professorship in Geophysics. With a donation from the Teck Corporation and a junior position that had been unfilled prior to 1995, we were able to create the Teck Chair in Exploration Geophysics.

Our planetary physics group will number 11.5 FTE by July 1, 2000 (9.5 and 2.0 FTE at St. George and UTM, respectively).

At the same stage in the previous planning exercise the Department of Physics had 45.5 FTE between all three campuses. This will be 43.5 FTE by July 1, 2000. In this respect we have been able to mitigate the effects of overall reduction in complement positions since 1995. However, this has only been achieved by making appointments outside of Plan 2000, and we presently have 3.5 FTE whose positions are "bridged" to complement positions from the APF in the next planning period.

6. Planning Process Used

A Department Planning Committee was established early in the planning process. It consisted of the Chair, the two Associate Chairs, and eight other professors representing the research groups in the department as well as physicists appointed at UTM and UTAS. Subsequently, the department Administrative Officer and a representative of CITA were added to the committee. Between the Spring and Autumn of 1998 the three major research groups held planning meetings during which their priorities were discussed. Joint meetings with the Astronomy Planning Committee were also held. Progress reports to department staff meetings were made, and staff meetings were convened in February and March 1999 to discuss the initial drafts of the planning document.

Student input was obtained through a number of channels. The department maintains standing Undergraduate and Graduate Curriculum Committees with student representation. Various issues involving the curriculum and teaching are brought before these committees, including initiatives referred to in this plan. In addition, the department held two open meetings on February 2 and March 2, 1999 to which undergraduate and graduate students were invited. A wide spectrum of student experience, from first year undergraduate to senior graduate, was present at this meeting.

7. Tri-Campus Issues

We have traditionally maintained undergraduate programs on all three campuses, but have more recently focused our graduate research on the St. George campus. The budget restrictions within Plan 2000 forced UTM and UTAS to reduce significantly physics complement by 2000 to 5.0 FTE and 4.0 FTE at UTM and UTAS, respectively, with a further reduction at UTM to 4.0 FTE physicists in 2002. Differences in support for the laboratory-based undergraduate courses have also created disparities in the course content and innovation in the undergraduate laboratories across the three campuses. In order to enhance the delivery of physics across the three campuses, we have adopted an aggressive tri-campus planning model that involves close interaction between the Physical Sciences Division at UTAS, the Science Division at UTM and the faculty at St. George at both the undergraduate and graduate research level.

Perhaps the most notable initiative has been the establishment of a new "framework" agreement involving the department and UTM, where we have agreed to take responsibility for planning and delivery of the undergraduate physics program at UTM and St. George, using resources from both campuses. This has allowed us to better integrate the physics offerings across the two campuses, to begin enhancing the undergraduate laboratory courses at UTM and move toward a model where students at UTM and St. George will receive the same, high quality physics instruction. It also normalizes the staff relationships across the two campuses, as faculty appointed at both campuses now enjoy access to teach all levels of undergraduate physics. Over the next four years, we are phasing out the Physics Specialist program at UTM, are revitalizing the Physics Major program and are involved in the creation of two new minor programs, Biological and Environmental Physics and Philosophy of Science. We expect these program offerings to be well-matched to the needs of UTM students, who tend to favour joint major programs over the more focused Specialist offerings, and the research priorities of the UTM campus.

The Division of Physical Sciences at UTAS and the department have also been actively involved in planning, with the primary goal of knitting the undergraduate physics programs across the two campuses. This will allow the two campuses to offer jointly ETP to students in a new UTAS program, Physics and its Applications, and to students in the existing St. George specialist program, Astronomy and Physics. To support this initiative, UTAS will maintain a complement of 4.0 FTE physicists (which will require the hiring of 3 faculty during the next planning period). The Department of Physics will offer the two ETP half-courses described earlier.

Almost all the graduate physics research is performed on the St. George campus, where the University has located the technical, administrative and computational resources necessary to support this specialized activity. Our research infrastructure requests on the St. George campus therefore support over 40 FTE research faculty. The department and UTM Sciences Division are proposing, however, the establishment of a biophysics-related research initiative at UTM, made possible by the exchange of one of the current Physics appointments at UTM with our highest priority APF allocation. This is an exciting proposal, as it directly supports one of our initiatives in this plan and is well-integrated with the proposed research initiatives at UTM.

Appendix A : Summary of Requests

a) Complement Positions

Priority 0 Complement Requests

1. Experimental Atmospheric Physics (Kim Strong) — bridged by NSERC Industrial Chair to 2002.
2. Experimental Astrophysics (search in progress) — bridged to retirement in 2002.
3. Mathematical Physics (joint appointment with the Department of Mathematics) — bridged by CIAR to July 2002.
4. Experimental Quantum Optics (Dwayne Miller) — bridged with NSERC Industrial Chair to 2002.

Priority 1 Complement Requests

1. Experimental Astrophysics (joint appointment with the Department of Astronomy)
2. Experimental Particle Physics (joint appointment with TRIUMF)
3. Experimental Particle Physics
4. Condensed Matter Theory
5. Biological Physics Experiment (related to UTM transfer)
6. Quantum Optics Theory
7. Biological or Nonlinear Physics (Experiment or Theory)
8. Condensed Matter Experiment
9. Experimental Atomic, Molecular, and Optical Physics
10. Experimentalist in Novel Optical Materials
11. Condensed Matter Theory
12. Applied Geophysics (joint appointment with the Geology or the Division of Mineral Engineering)
13. Atmospheric Chemistry Experiment (joint appointment with the Department of Chemistry)
14. Planetary Physics Experiment
15. Geochronology
16. Solid Earth Geophysics

17. Atmospheric Physics Theory

Priority 2 Complement Requests

1. Theoretical Particle Physics
2. Experimental or Theoretical Astrophysics
3. Experimental Particle Physics
4. Nanostructures (Condensed Matter Experiment)
5. Biological Physics (Theory or Experiment)
6. Ocean Dynamics and Climate

b) Non-Academic Staff Requests

1. 0.8 FTE of academic support (secretary II)
2. 1.0 FTE computing professional for PSCINET
3. 1900 hours of TA support for training (950 per annum after first year)

c) Infrastructure Requests

1. About 575 m^2 for undergraduate study space and graduate student offices.
2. About 1200 m^2 for research laboratory space.
3. $100,000 for new undergraduate laboratory equipment, and $75,000 per annum for modernization and renewal of existing apparatus.
4. $50,000 for an upgrade of our UPSCALE computer facility, and $62,000 for completion of the Nortel Applied Physics Laboratory.
5. $100,000 to complete the purchase of a computer controlled vertical mill in our mechanical workshop and $50,000 per annum for small capital equipment renewal.
6. $140,000 to update the design, fabrication and testing equipment in the Physics Electronics Resource Centre.

Appendix B : Summary of Bridged Positions

The Department of Physics has been successful in receiving support from a number of sources to bridge new positions to the next planning period. Our highest priority request from the APF is funding for these positions when the bridging arrangements expire. These positions are:

- Astrophysics: An opportunity appointment has been approved in this area as part of our initiative to strengthen our experimental astrophysics initiative and to support our collaborations with Astronomy and CITA. This appointment is being bridged to a retirement in June, 2001.
- Mathematical Physics: A joint appointment with the Department of Mathematics that restores an essential graduate teaching and research area in the department and supports an initiative of CITA, Mathematics and Physics to introduce the study of String Theory to the University. This position is bridged by CIAR to July 2002.
- Experimental Quantum Optics (joint with Chemistry): This position is currently the NSERC-Lumonics Chair in Quantum Optics, and is bridged by NSERC to July 2002.
- Experimental Atmospheric Physics: an excellent appointment has already been made, building on the existing strength of this group and allowing us to extend our efforts on climate studies and atmospheric chemistry. This appointment has been bridged by funding from an NSERC Industrial Chair.

Appendix C : Undergraduate Teaching Activity

We summarize the undergraduate teaching activity of the Department of Physics in Table 1, where we provide the most recent information (1998-99) and the data from five years ago (1993-94) for comparison. The bulk of our FCE count originates from first year students in the life sciences (about 960 FCE) and students in the Engineering Science program (about 350 FCE). Most of our first year offerings include the First Year Laboratory, serving about 1650 students this year.

Year	UG Enrolment (FCE)	Faculty (FTE)	CLTA/Tutors (FTE)	Stipend (FTE)
1998-99	2223	28.0	5.0	2.0
1993-94	2007	36.5	7.0	1.0

Table 1: Undergraduate teaching activity. Enrolment figures and complement strength come from Faculty data.

All of our undergraduate program initiatives will increase enrolment, with the effects being most pronounced in our specialist and major programs. The largest impact is likely to occur in the Majors program with an expected increase of 100 students, conservatively based on the losses incurred in recent years. We expect the specialist program initiatives will add another 70 students. This will increase our undergraduate teaching effort by about 250 FCE, which is significant in a relative sense when one notes that we associate about 700 FCE currently to this effort.

These estimates do not take into account increases in enrolment in other programs that will affect class sizes in our large first year physics courses, the impact of the double cohort, or the consequences of the proposed MPC program.

Appendix D : A New Limited-Entry Program

a) Introduction

The Faculty of Arts and Science has a comprehensive structure of programs in the mathematical sciences, physical sciences and computation. However, for most incoming students, these programs do not identify themselves as ones where students will be given a challenging and academically rigorous four years of study, from which they will emerge as some of the best prepared math and science students in North America. In particular, the fact that computation is an essential element of most of these programs is not evident.

The education of such students has nonetheless been our goal, and we have been quietly succcessful about it. In this proposal, we describe a new program with the following key features:

1. It should create for our best mathematically-oriented students the most optimal environment for intellectual growth. This environment would be one where a strong background in mathematics would form the basis for study in one or more related fields in physical sciences and computation.

2. The program would have sufficient resources to allow us to focus special attention on these students and enhance their educational experience through the use of common seminars, mentoring and guidance, and summer employment within or outside the university in a position relevant to their studies.

3. The program would create a cohort of students that learn and advance together through their years in the Faculty, developing the intellectual interests and bonds that will make them the most successful in future endeavours.

4. The students who enter this program should be targetting careers in academic research in mathematical or physical science, or in related fields in industry or commerce where priority is given to the ability to conceptualize problems at an abstract level, and solve them analytically or computationally.

i) The Mathematics, Physical Sciences and Computation Program

The goals of this new "program" would be:

1. To provide an intellectually exciting set of programs tailored to give students an advanced education in the mathematical sciences, physical sciences and computation,

2. To create a single cohort of students that will study and learn together. These students would take common first and second year courses (in common sections in multi-section courses and labs), but remain connected through all four years.

3. To allow our faculty to set aside limited resources to focus on this small cohort of students. These resources would include:

   - 1-on-1 faculty mentorship (meeting monthly)
   - joint MPCn99Y seminar courses (one in each year) discussing the most important problems facing MPC today. Current examples are:

  - quantum computing
  - limits of internet information transfer
  - nanostructures
  - risk analysis and statistics
  - high temperature superconductors
  - problems with a theory of everything
  - is there a cosmological constant?
  - the science of global warming
- a set of ROP299Y courses that will enhance the 1-on-1 student-researcher interactions and allow students to pursue specific interests.
- summer research projects within the laboratories or research groups of sponsoring faculty.
- a fourth year thesis course similar to what is required in the Engineering Science program.

Students would be required to follow one of our existing specialist programs in the mathematical and/or physical sciences. The admissable programs should be ones where there already is some requirement for strong mathematical skills and where scientific or applied computation are natural elements, and where the program would be able to include the additional requirements of the MPC. A possible list of programs that satisfy these requirements would be:

1. Astronomy and Physics
2. Chemical Physics
3. Computer Science and Mathematics
4. Computer Science and Physics
5. Computer Science and Statistics
6. Mathematics and Physics
7. Mathematics and Statistics
8. Mathematics
9. Physics
10. Statistics

Each student would be required to satisfy the following additional requirements:

1. Take MAT157Y, MAT240/247H AND PHY140Y (in most programs, this is already required or optional)
2. Take common MPCn99Y seminar course in each year.

3. Take introduction to Computer Science (CSC148Y)
4. Take Introduction to Computational Physics (PHY307F)
5. Take one ROP299 course

All of the students in the MPC program would be taking the following common courses:

- In 1st year: CHM151Y, MAT157Y, PHY140Y, CSC148Y, SCI199Y
- In 2nd year: MAT257Y, MAT267H, ROP299Y
- In 3rd year: PHY307F (or equivalent scientific computation course)

This program would be limited-entry, where recruitment and selection is performed between March and April. A suggested framework is:

1. Enrolment is limited to 60 students, selected by a committee using transcripts, recommendations and a phone interview.
2. Entrance scholarships would be offered to all students as well as in-course scholarships
3. Identify common section that all students would be enrolled in mandated common courses. Have to check for any possible timetable conflicts.
4. Have beginning, mid-term and end-of-term meeting following by pizza/dinner.
5. Provide students with either placement in summer research programs coordinated by collaborating departments or by appropriate summer employment outside the University environment.
6. Introduce the PEY as an option in higher years.
7. The program could be taken optionally in a 25 credit format, over five years, with automatic enrolment into the appropriate 1-year M.Sc. program of a sponsoring department.
8. We would track the progress of ALL students after graduation, to form an almuni database and to be able to measure how effective the program is.
9. An advisory committee would be responsible for implementation and management of MPC. This committee would have course reps from each cohort of students (5), and a representative from each sponsoring department.

Appendix E : Physics Graduate Employment

We admit most graduate students into the M.Sc. program, after they have completed their undergraduate work at the specialist level in physics with a B+ or higher average. Students with M.Sc. degrees from North American universities are normally accepted directly into the Ph.D. program. However, it is often suggested to students who have higher degrees from other educational systems that they spend at least the first two terms of their graduate career in Toronto as M.Sc. students. This allows them to adjust to local conditions, investigate fully the research opportunities, and choose an appropriate supervisor. Typically such students transfer directly into the Ph.D. with little or no delay in their progress.

Almost all of our M.Sc. students proceed to the Ph.D. degree. For the past few years, about twenty students have graduated each year from the University of Toronto with a Ph.D. degree in physics. Table 2 summarizes their employment after the Ph.D. After about three or four years we lose touch with some of our graduates, as the number in the third column indicates. Averaging over the past three years, about a third of our graduates go on to positions in academia, some of which are temporary postdoctoral positions. Another third accept research positions in government laboratories or industry. The final third apply the skills they have learned in their years as graduate students to new areas, such as patent law and financial analysis.

Graduating Year	Number of Graduates	Information Current	Academic Positions	Research in Govt/Industry	Other Work
90/91	29	24	13	9	2
91/92	12	8	5	1	2
92/93	18	16	7	4	5
93/94	17	16	6	8	2
94/95	21	18	8	7	3
95/96	23	22	9	4	9
96/97	16	16	5	7	4
97/98	22	22	6	10	6

Table 2: Employment of graduates of the Department of Physics.

Appendix F : Graduate Enrolment Planning

We show in Table 3 our current, projected, and targeted enrolment from 1995 to 2005. The numbers given for academic years 95-96 to 98-99 are "actuals." By "1st year" we mean both incoming M.Sc. students and students entering the Ph.D. directly, i.e., the "year" indicates the year of enrolment in graduate studies in the department. Almost all of our M.Sc. students now complete that degree in one year.

Over the past seven years our graduate enrolment has dropped considerably, from about 170 students to the current 108. There are two main reasons for this. The first is that over this period the number of full time core faculty members dropped 20%. With fewer faculty members available to supervise and support graduate students, our enrolment suffered a natural drop. In addition, however, we have been successful in shortening the average time it takes for a student to finish the Ph.D. program. Since the "1st year" enrolment includes both M.Sc. students and some beginning Ph.D. students, we should not have any students in the "> 5 years" category if all our students were to achieve the University's goal of a 4 year Ph.D. program. We expect that we will always have some students in this category, however, because of the occasional unavoidable delay in research progress. We believe it is reasonable to expect that about a third to a fourth of our students will inevitably experience some such delay. This would lead to a steady-state percentage of 5-10% of our enrolment in this category as a realistic target. Clearly we are still well above this target, with nearly 20% of our enrolment in this category. Yet the numbers indicate we have made significant progress towards this target over the past few years.

As measured by the number of "1st year" students in the past few years, our graduate enrolment is already increasing, reflecting the growth of the research programs of the new faculty members have joined us in the past few years. Numbers in (parentheses) are projections based on current enrolment. Here we continue to assume a typical 20% drop in a class size from 1st to 2nd year, as some students leave after completing the M.Sc. or beginning the Ph.D., and a following small drop the following year. We also assume we will continue to be successful in getting more and more students to complete within the canonical 5 year period.

	1st year	2nd year	3rd year	4th year	5th year	> 5 years	Total
95-96	19	17	13	15	22	30	116
96-97	23	15	16	12	15	29	110
97-98	26	18	12	16	12	24	108
98-99	26	19	17	12	15	19	108
99-00	34	(19)	(18)	(17)	(11)	(15)	114
00-01	36	27	(17)	(18)	(16)	(8)	122
01-02	40	29	25	(17)	(17)	(10)	136
02-03	38	32	27	25	(16)	(8)	146
03-04	38	31	30	27	22	(8)	156
04-05	38	31	31	30	24	10	164

Table 3: Graduate student enrolment plan.

The totals in the table above are our enrolment targets. They are based on the ability of our faculty to supervise graduate research, taking into account the natural growth in research groups of young faculty members, and the declining number of students supervised as faculty members approach retirement. The numbers in parentheses are extrapolated enrolment based on our current student population, taking into account attrition.

In our department the usual practice is for faculty members to stop taking on new graduate students three years before their retirement date. Of our present faculty, two cross this "retirement minus 3 mark" in 1999-2000, and six cross this mark in 2001-02. At present, these 8 faculty members are supervising only 5 students in all. Hence we expect little overall effect on our enrolment as these faculty members approach retirement.

On the other hand, we now expact an increased demand for graduate students. In the current academic year we welcomed Kofman (cross-appointed from CITA), Taillefer, and Pen (cross-appointed from CITA) to the department. Their research groups are all in a growth mode. In 1999-2000 we will welcome three new faculty (one jointly appointed in Physics and Astronomy), and two others for whom searches are now underway. Typically young faculty members in the department build their research groups very quickly. Professor Steinberg, for example, joined the department in 1996 and now supervises 5 graduate students. While different researchers build their groups to different sizes at different rates, we expect the ability of our department to supervise graduate students to increase significantly over the period 1999-2005.

We plan to take advantage of the SGS International Recruitment Awards to significantly build our enrolment in the 1999-2000 academic year, increasing our number of entering students on visas from 8 to 14. We feel these Awards represent a dramatic and welcome commitment of the University to help us build our graduate enrolment. If new awards are available each academic year, we will certainly take advantage of them. The "build" of our first year class to 34 in 1999-2000 should allow us to fill the needs of our new faculty members, as well as new cross-appointed faculty such as Dyer (Astronomy), and Norwich and Joy (IBBME).

We plan a continued increase in our first year class to take advantage of new faculty members we expect to be appointed as a result of the Complement Planning for 2000-2004. We expect a peak in the size of this class in 2001-2002 associated with the arrival of the Teck Chair. After that we are aiming at a first year class of about 38 each year to the end of the 2000-2004 period, which will yield a total graduate student enrolment of 160-170 students at that time.

Recruitment

To build and sustain these increased numbers we need to improve our recruiting efforts. Currently about 50% of the Canadian students who apply are academically admissible, and about 50% of the students we accept actually come here. We need to make efforts both in attracting a greater number of applications and in getting the students we accept — especially the best ones — to join us.

With respect to foreign applicants, the International Recruitment Awards should make a significant difference. The department only admits students for whom it can provide adequate financial aid, often in a "package" of scholarship funding and supervisor support. In the past we have actually discouraged many potential applicants from abroad from applying; with the high differential fee, the burden on research grants of providing competitive financial support to foreign students was prohibitive. We can now be much more aggressive in attracting foreign applications.

We have already begun a recruitment effort aimed at attracting more excellent Canadian applications, involving attendance at meetings such as the Canadian Undergraduate Physics Conference, and the use of the reinstated NSERC Summer Research Award program to attract potential graduate students to spend some time Toronto in their undergraduate years. New publicity material was assembled this year, and with improvements and expansions in our web page we can now be much more aggressive in encouraging Canadian undergraduates to apply.

Our Admissions Committee has been freed from other responsibilities to concentrate on encouraging the students we accept to choose to do their graduate work here. A member of that committee is assigned as a "first contact" with each accepted applicant, who is telephoned and put in touch with potential supervisors. Various research groups have begun efforts to bring accepted candidates to the University for special events, or just to visit and talk in detail with potential supervisors.

An important component of attracting accepted candidates is the financial package we can offer them. In each of the past two years we have increased the funding we expect supervisors to contribute, and we provide generous "top-ups" to students with prestige scholarships. Nonetheless, continued support from the University is essential here. It is important to note that in attracting students here we are competing not with other departments in this University, but with other departments of physics across the world.

Demographics

About a quarter of the department's graduate students are members of "visible minority" groups. This will likely increase as we welcome more graduate students from abroad. About a quarter of the department's doctoral students are female, a proportion significantly larger than the average female physics doctoral enrolment in U.S. private universities (15%) or U.S. public universities (12%) in the fall of 1996, the last year for which we have data.

Appendix G : Modernizing Infrastructure in Physics

The Department of Physics is located in a building complex, constructed in 1966, comprising a sixteen story tower attached to a three story wing, providing a contiguous basement. The top three floors accommodate Astronomy and the twelfth floor houses CITA. This configuration is not conducive to communication and inhibits the essential collegial environment. Additionally space is constrained and the allocation of laboratory space for teaching and experimental research is limited to the North Wing or the basement. The latter also accommodates our support services. The lack of investment in both new capital items and in the maintenance of existing infrastructure over several decades has significantly eroded its value and is now a constraint on the initiatives undertaken by the department.

Despite these difficulties, we have made a number of significant infrastructure improvements during the last planning period. We recently installed a numerically-controlled vertical machining centre in our mechanical workshop to replace milling machines that exceeded twenty years in age. In our cryogenics facility essential to low temperature researchers, we replaced the thirty year old helium liquefier by a new, fully automated system. With a contribution from Nortel, we created a new undergraduate laboratory and computing facility. In collaboration with Photonics Research Ontario, Materials and Manufacturing Ontario (MMO), McMaster University and private sector partners, and relying on CFI, ORDCF and NSERC funding, we have completed construction of and are now operating an advanced laser micromachining facility. We have underway an upgrade to the department's central computing and networking that includes the purchase of a new server. We installed a security/central check-out system in the department's library. We upgraded our laser laboratories, providing our scientists with the highly controlled environments needed to perform precision optical experiments. We created a sophisticated Space Test Facility, with support from the Canadian Space Agency. We installed a new clean room laboratory to allow the experimental particle physics group to construct instrumentation for the next-generation ATLAS project. We are constructing an Atmospheric Observatory on the roof of the Burton Tower, supported in part by CFI. We have spearheaded the CFI PSCINET Scientific Computing initiative.

The department's physical infrastructure requirements address two broad issues: the quality of the student's experience and the support for research activities. These initiatives are enumerated below, in order of priority.

1. Senior undergraduates lack useful space for study in McLennan Physical Laboratories. Additional space and a number of study carrels are required to accommodate growth to 2004. We also must provide additional space for first-year students to study, socialize and to give them greater access to department computing facilities. We require additional space of 300 m^2.

2. In order to support the new faculty hires envisioned in this plan, we will require eight new research laboratories, of which the space for two will be recovered from faculty retirement and the reallocation of existing laboratory space. The total space requirement, including 14 new faculty offices, is 1200 m^2.

3. Increased graduate numbers including our plan to redesign the graduate program with about 38 in-coming M.Sc. students, will require an estimated 275 m^2 of additional space.

4. We now have a high priority need to update the experiments available in the undergraduate laboratory to include new experiments in biological physics, to support our program developments in those areas and to satisfy the expanding interests of students. We estimate the cost

of adding new experiments to be \$100,000. Longer term capital reinvestment is required to modernize and replace the existing \$750,000 currently invested in laboratory equipment. We estimate that an investment of at least $\sim 10\%$ per annum would be minimal, and therefore request \$75,000 per annum for this item.

5. We need to make a major upgrade of the undergraduate computing facility, UPSCALE: We have to replace the current X-terminals as they reach the end of their useful life with PC's, and expand our central computing capabilities over the next 5 years. We estimate that \$50,000 will be needed to fund these additional seats. We continue to rely on ITCDF for funds for software development, as we move more of our offerings to the web.

6. The Nortel Computational Laboratory has not yet been completed, and demand for the existing stations is very high. We propose to complete the Nortel Undergraduate laboratory, adding 6 instrumentation stations at a cost of \$62,000.

7. Physics Technical Services, recently acquired a new numerically controlled Vertical Machining Centre under a four year lease agreement but will require an on-going investment in new machinery within the plan, and a significant budget for maintenance/up-grade of smaller capital equipment. We request \$100,000 to complete the lease payment and \$50,000 per year for capital equipment renewal.

8. The Electronic Resource Centre (PERC) is a critical element in the department's ability to provide advanced instrumentation to its members. Major users include the Space-based Atmospheric group, and with the recent Federal commitment to The Canadian Space agency, we can anticipate enhanced needs for sophisticated instrumentation. In order to keep the capabilities abreast of current electronic technology PERC will require a significant investment in design and assembly equipment estimated at a cost of \$140,000.

Appendix H : Faculty Awards and Distinctions

The excellence of our faculty and staff is reflected in the awards and honours that they receive. During the last seven years, our faculty and staff have received the following research recognitions:

- Alfred P. Sloan Fellowship, Sloan Foundation – Prof. Michael Luke
- Alfred P. Sloan Fellowship, Sloan Foundation – Prof. Thom Mason
- Alfred P. Sloan Fellowship, Sloan Foundation – Prof. Louis Taillefer
- Fellow of the Royal Society of Canada – Prof. Henry van Driel
- Herzberg Medal, Canadian Association of Physicists – Prof. Louis Taillefer
- Herzberg Medal, Canadian Association of Physicists – Prof. Sajeev John
- J. Tuzo Wilson Professorship – Prof. Derek York
- J. C. Polanyi Prize – Prof. Aephraim Steinberg
- Killam Fellowship, Killam Foundation – Prof. Henry van Driel
- Killam Fellowship, Killam Foundation – Prof. John Sipe
- Killam Fellowship, Killam Foundation – Prof. Sajeev John
- McLean Fellowship, University of Toronto – Prof. Sajeev John
- Louis Neel Medal, European Geophysical Society – Prof. David Dunlop
- Rutherford Memorial Medal, Royal Society of Canada – Prof. Pekka Sinervo
- Rutherford Memorial Medal, Royal Society of Canada – Prof. Dwayne Miller
- Sandford Fleming Medal, RCI – Prof. Derek York
- Steacie Fellow, NSERC – Prof. Ted Shepherd
- Steacie Fellow, NSERC – Prof. Louis Taillefer
- Steacie Prize, NSERC – Prof. Sajeev John

During the last seven years, our staff have also been honoured with the following teaching awards:

- CAP Teaching Award, Canadian Association of Physics – Dr. John Petrie
- Outstanding Teaching Award, Faculty of Arts and Science – Prof. John Sipe
- Outstanding Teaching Award, Faculty of Arts and Science – Prof. Jerry Mitrovica
- Outstanding Teaching Award, Faculty of Arts and Science – Prof. Pekka Sinervo