Stepping Up to the Cosmos

1. Executive Summary

Astronomy and Astrophysics deals with profound questions, basically how did the universe evolve, how do stars and planetary systems form, and what is the human role in the cosmos. It is an accessible science with broad appeal. Research and teaching are closely interwined. Canada is a major player, next in impact to the US and UK. Within Canada, UofT is in a unique and enviable (with some nuance!) position of leadership, traced largely to the establishment of the Department's David Dunlap Observatory (DDO, 1935) and the Canadian Institute for Theoretical Astrophysics (CITA, 1984), and the stewardship, with national and international outlook, in making the most of these opportunities. We have developed a national Long Range Plan for the discipline through which many hundreds of millions of dollars are being invested for the university community through NRC, CFI, NSERC, and the Canadian Space Agency (CSA), most in international ventures. The priorities of the Department of Astronomy and Astrophysics (DAA) are in synergy with this national and international effort. Our discipline advances through observation, theory, instrumentation, and computational simulations.[1] At UofT we have great strength in the first two, give top priority to renewing instrumentation, and lead in the emergent pillar of computation. Our Plan priorities both embody the principles by which we advance and enable, by addressing the environment required for continued success at the very highest level.

1. creation of the Dunlap Institute for Astronomy and Astrophysics (Dunlap Institute) as a renewal of the memorial that founded the David Dunlap Observatory (DDO)
2. an overarching *sine qua non*: bring together the very best personnel – faculty, postdoctoral fellows, students, and staff – develop each to full potential and unite their talents so as to grapple most effectively with these profound questions
3. as the top Department in Canada, continue to lead the development of Canadian astronomy by example, by creating networks, and by specific initiatives
4. as *one of the most important centers of astronomy in North America*,[2] provide leadership within international partnerships in attacking key astronomical problems
5. in support of the above, and looking to the future, form partnerships to design and build the major observing facilities required; the 30-m optical telescope our immediate focus
6. train expert personnel in designing instrumentation, executing observational campaigns, performing large-scale simulations, scientific analysis of the large data sets, and theory; maximize impact by providing top research opportunities and access to top facilities
7. renew guaranteed access to a major optical telescope, Magellan being crucial
8. establish laboratories for instrumentation and experimental astrophysics
9. establish top-tier facilities for computational astrophysics and capitalize on strength in analysis of huge data sets
10. consolidate space for astronomy and astrophysics activities on the St. George campus
11. develop and maintain effective links with cognate departments and faculties
12. communicate widely the stunning results of our astronomical research, through our popular and accessible science literacy courses, and multi-faceted public outreach.

Ours is a living Plan that we expect to realize through specific initiatives articulated below. Exemplary support throughout the University for these exciting pursuits is gratefully acknowledged. We are enthusiastically committed to working together to achieve these dreams.

---

[1] Realistic simulations now provide a "laboratory" for a discipline largely constrained by remote sensing.
[2] According to the most recent international review (May 1999)

2. Vision and Priorities

Providing Answers to Profound Questions. How did our Universe come into being? What produced the structures seen extending over billions of light years? How did our planetary system evolve? Are we alone? Recent technological developments have given us new capabilities for observing the Universe, both as it is now and as it was long ago, allowing our ideas of the Universe to be based to a hitherto unimaginable extent on observable facts. Together with the application of astrophysics and superb computational simulations, such progress has been made that, amazingly, many answers seem within reach, fueling tremendous exhilaration among professionals, students, and the public alike.

Through "precision cosmology" **fundamental parameters of the Universe** (age, rate of expansion, overall geometry, etc.) are being tightly constrained by comparison of the results of large scale simulations with observations of such diverse phenomena as the cosmic microwave background, the recession of distant supernovae, gravitational lensing, clusters of galaxies, and the ashes of big bang nucleosynthesis. A humbling result is that baryonic material (of which stars, planets, and we are made) constitutes only a few percent of the total mass-energy density of the universe, the dominant forms being dark matter and even more mysterious dark energy.

The discovery of hundreds of extrasolar planets is offering new observational insight into theories (and related computational simulations) of the **origin and evolution of planetary systems**, including our own. It is becoming possible to characterize extrasolar planets physically through fairly direct observation and it is the goal of next-generation international facilities, on the ground and in space, to search for signs of life on extrasolar terrestrial planets. Signs of life are being sought elsewhere in our solar system.

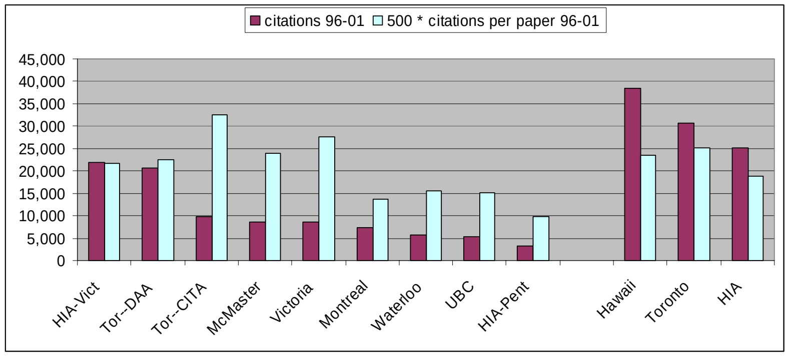
Understanding **how stars form** from parent clouds of diffuse gas and dust is critical. On the largest scales, stars, in their billions, make up galaxies, and so to interpret the observed evolution of galaxies we need an *ab initio* prescription of star formation to light up the simulated structures in our computations. On a more "intimate" scale, the star formation process gives rise to planetary systems. From cosmic nucleosynthesis (the realm of **astrophysics**), through interstellar chemistry (**astrochemistry**), to processes in planetary atmospheres/surfaces, there is a trail of increasing complexity leading to life (**astrobiology**).

We have a talented faculty of international stature and a competitive engaged student body. Our vision knits tightly to the eleven goals enunciated in the White Paper. In Stepping Up, we will enhance our pre-eminent position in both research and teaching by focusing on the **Priorities** highlighted in Section 1. Specific **Initiatives** to ensure that these goals are achieved are highlighted in Section 4, with the same numbering for ease of cross-reference.

3. Self-Study

International Recognition. The Association of Universities for Research in Astronomy – which runs the Space Telescope Science Institute (Hubble and the successor James Webb Space Telescope (JWST)), three leading national suites of ground-based telescopes for the US national community, and the US Gemini effort, all under contract with NSF – recently invited DAA to apply for International Affiliate status. Our application, supported by the Dean and President, was endorsed "unanimously and enthusiastically" at the recent (April 2004) AURA meeting. International Affiliates are a select few, DAA being the only one from Canada. From Europe are Cambridge and Leiden.

Citations. The summary chart[3] (impact: citations per paper multiplied by 500 for common vertical scale) shows strong performances for both DAA and CITA. U Hawaii, a partner institution in CFHT and many other major world observatories, was also tracked; this provides a broader calibration, Hawaii being rated number three in the US by "in-cites." The DAA publication rate has continued to rise over 2000-4, averaging over 90 per year and we are optimistic that this will be blossom further given the newly-hired faculty, the growing number of postdoctoral fellows, and the expanding graduate program. DAA papers are in top journals, e.g., the Astrophysical Journal and Nature.



Placements. Of the 100 most recent PhD graduates, 37 (18 in Canada) hold faculty positions in universities, 31 (20) hold professional astronomer staff positions in government laboratories, observatories, universities, 17 are postdocs, 5 are in industry, 4 in colleges and secondary education (6 unknown). Of 30 recent postdocs, 14 (7 in Canada) hold faculty positions, 12 (3) hold professional positions in government laboratories, 1 is in industry and 1 in secondary education (2 unknown). Faculty of DAA and former students are frequently chosen for major leadership positions, e.g., CFHT Executive Director (Racine, McLaren, Fahlman), HIA Director General (van den Berg, Lilly, Fahlman), Observatories of the Carnegie Institution of Washington Director (Searle, Freedman). In fact, personnel from DAA have founded and developed most astronomy programs in Canada: McMaster (4 faculty members), Queen's (4), St. Mary's (3), Waterloo (3), York (3), Calgary (2), Montreal (2), UWO (2), Victoria (2), and Alberta, Brandon, and Laval.

Awards, Grants. Prestigious research awards to DAA faculty include Killam, Sloan, CIAR Fellows, PREA, Beals (Canadian Astronomical Society), and CRCs. NSERC discovery grants are held by most faculty ($700K total per annum), averaging more than 50% more than the typical grant in GSC 17. In the past few years, about three times this per annum ($5,300,000 total) has been granted through OIT, CFI, NSERC CRO, CSA, PREA, Connaught, and Sloan. Major recognition for teaching includes the Northrop Frye Award, the Faculty of Arts and Science teaching award, and the Award for Exceptional Commitment and Achievement in Adult Learning (Continuing Studies). Our librarian has been honoured by the Physics-Astronomy-Math Special Libraries Association, and our graduate students have won the Gordon Cressy Award and the Plaskett Medal (best thesis; Canadian Astronomical Society (CASCA)).

Leadership. As well as participation in many international review committees, telescope time assignment committees, advisory and publication boards, etc., our faculty have undertaken major leadership roles, heading recently, e.g., Board of the James Clerk Maxwell Telescope, Mid-Term Review of the Canadian Long Range Plan (LRP) for astronomy, CASCA, Joint Committee for Space Astronomy (CSA and CASCA), Board of Trustees of the Ontario Science Centre (vice-chair), Royal Astronomical Society of Canada, Commission on Variable Stars of the International Astronomical Union, and American Association of Variable Star Observers. With the strong and active support of the Dean and President, DAA members have recently spearheaded the formation

[3] Data compiled by Dr. D. Crabtree of the Herzberg Institute of Astrophysics, most recently for 1996-2001.

of the Association of Canadian Universities for Research in Astronomy (ACURA), which is now undertaking a major role in implementing the LRP (see flagship project TMT in Section 4 – 5).

(a) Teaching with a Broad Reach. Our teaching program – for specialists, science students in other disciplines, non-scientists, and the public – is informed directly by our engagement at the forefront in research. Every aspect of the curriculum is continually updated. DAA has a major focus on graduate and postdoctoral training on the one hand, and science literacy courses on the other, for within a liberal arts curriculum there is a central role for an appreciation of the cosmos. Ours is a highly accessible science, with a large amateur base as well, and we demonstrate in practice that our mission includes bringing our quality research to the public and providing expert views and credible sources to the media. Teaching is a priority for all faculty, with a mentoring program and Education Discussion Group (involving graduate students as well). Our high-flying researchers teach the *large* first and second year courses with enthusiasm.

(i) Undergraduate. Our undergraduate **specialists** are in demand at the top graduate schools (including private). They receive hands-on training in excellent laboratories. The 40-cm reflector with a spectrograph on the roof of the McLennan Labs and the 30-cm telescope with a wide-field camera at UTSC have been upgraded for automated, remote, and scripted robotic operation, allowing students to observe both from "warm rooms" and from home over the Internet. DAA has a 2-m radio telescope for undergraduates, also atop the McLennan Labs (receiver tuned to the 21-cm line of neutral hydrogen). This telescope can be operated remotely too. Additional research opportunities are given through ROP, summer employment, and the senior research project. A computer lab, well equipped in hardware and astronomical software packages, is used in conjunction with research work and upper-level practical astronomy. Our outreach to **non-scientists** is particularly worthy of note, being our area of contact with the greatest number of FCEs and the general public (see iv). As well as engendering an appreciation of the development of ideas, scientific methods, reasoning, and a capacity to stay abreast of future developments and above all to be skeptical and critical (initiating life-long learning), it is our mission to contribute to "common knowledge" on the great intellectual issues raised by considering the cosmos. The origin and evolution of the Universe provides a "big picture" perspective on the human place and role in the cosmos and the "large and critical questions that face us in the world and that define the broader intellectual landscape."

(ii) Graduate. The international reviews have confirmed the Department's very high standard of graduate training. Students' PhD theses regularly rank alongside those from the best departments worldwide. Most graduate students now opt for our new direct entry PhD, which emphasizes immediate engagement in research and sets its sights clearly on providing the strong preparation required to move on to top research and teaching positions, while still finishing within five years.

(iii) Postdoctoral. Postdoctoral training, in theoretical astrophysics, is the mainstay of CITA where there are ~20 postdoctoral fellows. Such advanced training has taken place over the years in DAA as well, with high quality (research accomplished) and success (subsequent placement). This program is now receiving even higher priority with 10 postdoctoral fellows on campus.

(iv) Outreach. DAA and DDO have a long-standing commitment to outreach in an extensive public tour and public lecture program at the campus observatories and at DDO. We also work closely with the Royal Astronomical Society of Canada and other local astronomy clubs, and through the Education and Public Outreach Committee (chaired by Percy) of the Canadian Astronomical Society. We participate in judging science fairs, visit high schools, lecture to senior alumni, and mount major public lectures of our own and with the student Astronomy and Space Exploration Society (ASX).

(b) Research. We are addressing nothing less than the fundamental structure of the Universe and our place within it. The UofT has been participating vigorously in these revolutionary advances through DAA, hosting CITA, leadership in the Cosmology and Gravitation Program of the Canadian Institute for Advanced Research (CIAR), and creation of an astrophysics cluster under the Canada Research Chair (CRC) program. We are thus already positioned well among the publicly-funded research-intensive universities. In practice we also compete for faculty, postdoctoral fellows and graduate students, and, in the accompanying research, with the best private universities (e.g., Caltech, Harvard, Princeton, MIT). Thus in developing our priorities, our sights are set high. The Department is actively engaged in a wide range of observational and theoretical research on the cosmic microwave background, large scale structure, the early universe, galaxy formation and galactic structure, the evolution and formation of stars and planets, and high energy astrophysics. Through large surveys in progress, we are presently searching for extrasolar planetary systems (EXPLORE and its relatives) and the most distant galaxy clusters identified optically (RCS 2). We have established the new Canadian Megaprime Science Centre for the Canada-France-Hawaii Legacy Survey (CFHLS). The MOST satellite is being exploited to probe stellar structure (asteroseismology) and to characterize extrasolar planets. Graduate students work with the best facilities on forefront problems.

(c) Faculty and Staff. The entire graduate complement is about 21 (depending on the snapshot), including tri-campus and CITA; (about) 13 are in DAA, 5 new over the past planning period (one more bridged). We carefully recruit top faculty on the basis of strong teaching and research. The “trajectories” of our past five hires illustrate their rich international background: Yale, Harvard, Berkeley, Michigan (F); UST Beijing, Caltech, QMC, CITA; Amsterdam, Caltech, Utrecht (F); Harvard, Berkeley, CITA; UBC, Oxford, HIA, Cambridge; Bethel, Princeton, Caltech. These new recruits together with remaining mid-career strength constitute an invigorated, ambitious, and vibrant department. CITA is just adding a CRC position. In addition, the graduate complement should benefit from a complement replacement at UTM and at least two at UTSC in the present plan. Given the research opportunities and demand for courses this not really enough. Our long-time solo faculty librarian is being replaced. A small (4) but skilled and dedicated staff supports our teaching and research activities on campus and there are 6 in support of DDO.

(d) (i) Dispersed Space. DAA and the graduate program are centred in the McLennan Labs. We have residual research activities and all of our shops at DDO in Richmond Hill. Carlberg and the entire CFHLS team are housed temporarily in the Greenhouse Tower and we are looking for offices for our newest recruit and his postdocs. A unique Stratospheric Telescope Integration Facility (STIF) has been opened next to the Greenhouse Tower. UTM and UTSC faculty are of course not at St. George every day. This dispersion is particularly disadvantageous to a small department engaged in collaborative work and trying to maintain critical mass. We do benefit from having CITA on adjacent floors.

(d) (ii) Research Infrastructure. DAA researchers presently enjoy access to the Magellan 6.5-m telescopes and the Dupont 2.5-m at Las Campanas under a limited-term instrumentation-development collaboration with the Carnegie Observatories. We have an active experimental program using telescopes on long-duration stratospheric balloons for cosmological and Galactic research and for this have just opened STIF. The DDO 1.88-m telescope is equipped with an efficient CCD grating spectrograph. DDO also provides shops for electronic and mechanical work. We also use the major optical, radio, and satellite observing facilities of the world, including the Hubble Space Telescope, the Spitzer Space Telescope, and the national facilities CFHT, JCMT, and the Gemini telescopes.

DAA and CITA are recognized centres in the computational study of dynamical systems – ranging from comets in the solar system to the large-scale clustering of galaxies – developing some of the most powerful numerical techniques in use today. We have installed a series of competitive machines, most recently a novel parallel computer (over 500 processors), at the time (a year ago) the fastest computer in Canada (38^{th} in the world). This facility has been used to carry out some of the largest, most accurate N-body and MHD simulations ever. Aggressive computation is also required for analysing the enormous amounts of data acquired in modern observing campaigns, and so other major computing systems support CFHLS and EXPLORE.

A long-standing national treasure is the Departmental and Observatory library, undergoing renewal in an increasingly electronic era. It houses the largest astronomy and astrophysics library in Canada, having extensive holdings ranging from the old publications of small European observatories to computer-readable star and galaxy catalogs and digitized sky surveys.

(e) Governance, Climate, Culture. DAA is among the smaller Departments, which offers advantages with respect to "transparency, openness, and consultation" in departmental decision making and general feelings of collegiality and inclusiveness. Monthly faculty meetings offer a regular opportunity for dissemination of information, consideration of committee recommendations, and collective brainstorming on strategic, structural, and cultural issues. The Graduate Astronomy Students Association (GASA) sends two representatives to faculty meetings and has over the years initiated many positive changes in policy and practice. There are diverse opportunities for interaction: morning coffee, twice-weekly gatherings after the Department seminar and colloquium, bi-weekly education discussion group, dim-sum lunch discussions, admin staff meetings, DDO shop meetings, etc. Collegiality and inclusiveness are also engendered by Department social events: Chair's reception (fall), celebration of awards (spring), GASA parties (equinoxes), receptions related to public lectures, the AstroGradNetwork dinner. The Department has a supportive relationship with undergraduates through the Physics and Astronomy Student Union (PASU) and the Astronomy and Space Exploration Society (ASX).

4. Specific Initiatives: Targeting Priorities

The initiatives are all important as parts of a continuum of activities required for DAA to perform to its potential on the international stage, in teaching and research. All of these initiatives demand focused effort; some cost little money, others as much as $250,000,000 capitalization.

1. Dunlap Institute. This requires major attention in this Stepping Up period. Ultimately the resources available through the Dunlap Institute could elevate Astronomy and Astrophysics activities in the University to a level matched only by the top centres internationally, allowing us to reach otherwise elusive heights as we seek to realize many other priorities. The multi-faceted Institute would assume a prominent leadership position in research, teaching and advanced training, and public outreach. Specific objectives well aligned with those of DAA and highly complementary to those of CITA (also established with DAA leadership) are to:

- create an international centre of research excellence in astronomy and astrophysics
- participate in the development of scientific instrumentation for world-class observatories
- promote interaction and provide leadership to create major national and international research collaborations
- engage in grand computational astrophysics problems
- promote advanced training opportunities for graduate students, postdoctoral fellows, and research associates

- organize and host international workshops and meetings
- provide a primary means for channeling information on astronomy and astrophysics to the general public.

2. Personnel. This requires wide proactive advertising, individual initiative, and uncompromising dedication to excellence. This is demonstrably our "culture" already. A major focus during this period will be in graduate recruitment to ensure that quality is maintained as the program expands by 50%. However, since we already attract a large pool and are presently turning away well-qualified students, this does seem tractable. Nevertheless, we will be revamping both our printed materials and web site as well as developing more personal contacts. Having made top recruits, developing full potential is essential. Mentoring programs for faculty and proactive "nurturing" PhD committees are key tools, which with heightened awareness, vigorous attention, and continual renewal will promote optimal results. Other major drives will be the postdoctoral program and staffing the Dunlap Institute and related initiatives.

3. Developing Canadian Networks. Here there is deep experience through CITA, CIAR Cosmology, Canadian Network for Observational Cosmology, Canadian Galactic Plane Survey. The most significant currently active network is CFHLS which is using 500 nights of CFHT time over the next few years to tackle problems from cosmology to solar system debris.[4] We are now laying the groundwork for a complementary **Canadian Network for Computational Astrophysics (CNCA)** whose aim is to acquire a tier 1 facility for modeling, simulations, and data analysis, funded by CFI and sited at UofT, while coordinating competitive use in concert with existing tier 2 facilities across the country. As shown with our existing powerful cluster, this new facility will be embraced by high-end users in other disciplines, thus serving broader needs. Such a facility will be support the research goals of I-AIM researchers in scientific computation and so we expect to coordinate closely, both re architecture and personnel. Sustainability through leveraging via the Dunlap Institute is among long-term possibilities.

4. **International research partnerships.** For DAA, this is a natural extension of 3. CFHLS is spawning new activity in which the largest telescopes on the world are used to follow up newly discovered distant supernovae. EXPLORE (planet search) and RCS2 (distant galaxy clusters) are both using telescopes in both hemispheres. A new initiative is the Gemini Deep Deep Survey, which for the first time is measuring spectra of high redshift (1 – 2) galaxies. Much new activity is devoted to exploitation of new facilities in space. The BOOMERANG 2K mission, dramatically successful in its own right, flew the prototype detectors for the Planck Surveyor satellite (precision cosmology, Galactic star-formation science). Similarly BLAST (being assembled now in STIF) uses SPIRE submillimetre-camera technology, a precursor to our involvement in the Herschel Space Observatory (HSO; launch 2007, but for which we are already finalizing the key programs). Success with the microsatellite MOST is leading to new possibilities with nanosatellites (see 11). Our active research partnerships using the new Spitzer Space Telescope, in the infrared, will also lead to key programs with JWST.

Planck and Herschel will be launched in 2007, but already our researchers are playing leadership roles as Co- and Associate Investigators within three international instrument collaborations to develop the technology, control and analysis software, and the best scientific use of the missions. Even JWST (launch 2011) is demanding a lot of attention by our Science Team members for the Near Infrared Camera and the Fine Guidance System (a unique instrument in its own right).

---

[4] It is of paramount importance that this expensive facility (costing $22K per night) be used with utmost efficiency. It is a major accomplishment to have acquired the large blocks of time; we place high priority on devising the best proposals and, through peer review, obtaining time well beyond our "statistical share."

5. Design and build *major* observing facilities – TMT. We are leading an initiative in Canada toward a "second-to-none" partnership in the next-generation 30-m optical telescope (TMT). TMT will enable detection of distant galaxies as they first form, and also characterization of extrasolar planets. In the recent CFI competition this "big science" proposal (total facility cost $1,000,000,000) has received top grades from the expert committee and MAC and Board – *"we can't afford not to do it."* We are presently engaged in figuring out (non-trivial!) financial, organizational, and management plans to work effectively both across Canada and with our partners (Caltech, UC system, AURA). This exciting project also brings major responsibility, and so we are delighted to have the strong support of the Dean and President and, beyond UofT, of the ACURA organization.

An emergent priority is to provide leadership within Canada to ensure that we develop and have access to next-generation facilities in space (to overcome the effects of the atmosphere: the blurring in the optical, and, more basically, the blocking of major parts of the electromagnetic spectrum, e.g. x-ray, infrared and submillimetre).[5] Because each of these advanced facilities is so expensive, and there is such challenging lead time,[6] forging international collaborations is essential (see 4). This is most readily accomplished on the basis of the high value that our researchers bring intellectually to each initiative.

6. High impact training. Our graduate enrolment and postdoc program will be expanded significantly to match the new supervisory capacity and exploit the new research opportunities that we have generated. Research and teaching go hand in hand and so access to advanced facilities for our graduate students and postdocs is a must. Computational facilities, already addressed in 3, will include those for data analysis of large data sets, through TPAC (see 9). Undergraduate research, through senior research courses and formal summer training, is also a high priority. With new consolidated space available, we will plan office assignments to keep graduate-postdoc-faculty research groups together as closely knit units and to provide undergraduates with dedicated space where they too can benefit first-hand from the ferment of ongoing research, optimizing their student experience. For our large undergraduate classes in Convocation Hall, [7] we will continue to work with central planning to upgrade the AV facilities (e.g., larger side screens, interactivity) beyond what has already been accomplished.

7. Guaranteed access to a major optical telescope. Access to Magellan has been transformative (and a factor in recent recruitment of three faculty members). "Gravity-T" is a DAA-wide research program probing the nature of dark matter halos[8] in nearby galaxies using globular clusters as test particles. Gravity-T couples the unique IMACS spectrograph on Magellan with the unique strengths of five different research groups in the DAA – automated high-precision faint-object photometry of tens of thousands of objects; rapid-fire and specialized reduction and calibration of thousands of "nod & shuffled" spectra; precision radial velocities; spectral synthesis; dynamical modeling – making DAA one of the few in the world capable of going 'end-to-end' on such an ambitious program. An extension or replacement of the Magellan agreement will need to be advanced, possibly in conjunction with the Dunlap Institute.

---

[5] Through the Canadian Space Agency and CFI, Canada is investing more than ten million dollars per annum in these facilities over the current decade.

[6] Re development of a 10-30 m UV/Optical Space Telescope (another replacement for Hubble), the community received the following call: "With a possible time-frame 20 years in the future, *the time is right* [emphasis added] to define the scientific goals that will determine the basic structure of such a mission."

[7] Despite new format, our energized professors have maintained both enrolment and high student approval.

[8] Arguably these are most fundamental, yet even basic properties are poorly known.

8. Laboratories for instrumentation and experimental astrophysics. Activity in development of instrumentation and in experimental astrophysics is both unifying and enabling. It broadens and deepens student experience. New leadership opportunities are opened up internationally and nationally. Developing expertise in instrumentation is a top priority of the Canadian LRP, through establishing advanced university laboratories. In DAA this will build out of missions in STIF, through activities and programs of the Dunlap Institute (e.g., instrumentation for access to existing large optical telescopes; development of nanosatellites), and work toward the TMT and next-generation facilities in space. New faculty are required.

9. Toronto Processing and Analysis Centre: TPAC (for top-tier facilities for computational astrophysics see 3). Modern telescopes and space missions generate enormous data sets, hitherto unimaginable. With CITA, DAA has developed expertise in processing such data, whether it be extraction of point sources, weak lensing signals, cosmological parameters, smooth images, etc. (for the record CFHLS, RCS, EXPLORE; Boomerang, CBI, Boom2k, Planck; BLAST, Herschel/SPIRE, Scuba2; IRAS, ISO, MSX, Spitzer; MIGA, VGPS, IGPS). This has required new algorithms and significant computing power and disk space and has produced end products of interest to a wider community (not an archival service, though T-space could be very useful and is being investigated). TPAC will recognize this on-going effort, broaden experience for students, refine expertise and infrastructure to support all the telescopes and observatories that are being put in place through the LRP, and focus on problem-solving common across areas.[9] It will need to be an attractor of new resources (= people, expertise, skills, hardware), from CSA, NSERC, CFI, possibly leveraged through the Dunlap Institute.

10. Consolidate space. Dispersed space is already the major structural problem affecting our teaching and research activities, and with the TMT and proposed Dunlap Institute the pressure is really severe. There is some hope of consolidating space in the Nursing building as the DDO makes a transition to the Dunlap Institute on campus (housing advanced shops and labs) and later still in a much-anticipated redevelopment on the nursing site. The latter will require our effort in both advancement and in preparing a major grant application for CFI.

11. Effective links across campus. Progress in our field is achieved through a continuum of interwoven approaches, encompassing theory, computer simulations, observations, and instrumentation. The name "astrophysics" reflects the long-standing strong two-way connections with fundamental physics. Similar intellectual connections have now inspired "astrochemistry" and most recently the burgeoning field of "astrobiology." Planetary science interacts with geophysics, geochemistry, and atmospheric physics. In general, the profound questions of the cosmos demand equally imaginative solutions. Applied mathematics is certainly in evidence, as is signal processing, statistics using large data bases, archival research through virtual observatories, etc. Engineering is essential to the design of large telescope structures, control systems for adaptive optics, detector development and fabrication, etc. Based on current experience, we see much of this linking being accomplished on a project basis through individual or team interactions. Nimble as our researchers are, such is the sweep of the field that it is unlikely that a single individual would be regarded as "interdisciplinary." Instead, each brings specialized strengths, and appropriate connections are fostered to form multidisciplinary teams. The rigour achieved through disciplinary knowledge within a multidisciplinary team is a culture that we continue to champion; these teams become incubators for ideas well beyond the initial

---

[9] Indeed, much of the high-level mathematics underpinning the analysis is applicable more broadly, and so it is expected that TPAC will resonate strongly with I-AIM.

stimulus. Our goal is to have in place the links that make our research most effective. Here are some essential collaborations for which we have high expectations.

- Wide-ranging stimulating interactions with CITA: theorists, modelers, observers, experimentalists, and instrumentalists all engaged. TPAC and CNCA.
- Extrasolar planets: DPES/UTSC Centre for Extrasolar and Solar-system Planets, strongly supported by DAA (2 recent complementary hires), CITA, and Physics.
- Computation – simulation and analysis: CNCA, TPAC, I-AIM, and related interests in Physics and Chemistry (manifested in PSciNet), and DCS.
- Early Solar system: geochemistry experiments on interplanetary and cometary-return (including interstellar!) dust particles, with Geology.
- TMT: UTIAS and engineering (structural, control, fluid dynamics), Physics (optics, IOS initiative), industry.
- Advanced shops and fabrication facilities: STIF; development in Dunlap Institute; overlapping technical interests/needs with Physics, Chemistry; Nortel Institute.
- Nanosatellite (stabilized) for asteroseismology of the 300 brightest stars: jointly with UTIAS and Dynacon, as with MOST.

12. Outreach. Building on a wide range of positive activity will be new initiatives to optimize our image, presence, and resource provision on the Internet and also locally on campus (e.g., electronic interactive display in place of present old static version). There is no shortage of new material, every day, from our own research activities and from the wider international community. This will tie into tour activities, recruitment activities, new K-12 materials (often mission based), and technological advances in the Department library.

5. Request for Faculty Positions

Instrumentation is top priority. An important measure of the resolve of the Department is that a search for a bridged position is being held over, despite seeing highly-qualified applicants that we could have recruited readily in other key sub-disciplines, like observational cosmology, go off to competitor universities. One additional position is urgently needed to strengthen this pillar (also to develop the Dunlap Institute). A computational astrophysicist is essential for both teaching and research programs (see TPAC, CNCA, I-AIM). These identified needs in instrumentation and computation are consistent long-held priorities, and indeed our request is simply to fill these highly-ranked positions for which ROS funding was in the end not sufficient.

6. Measures of Success and Contingency Plans

Indicators should include: ability to recruit and retain top personnel (faculty, students, staff); the measures presented and quantified at the beginning of Section 3 (international recognition, citations, placements, awards and grants, leadership); student participation and ratings; media coverage and public appreciation; effective policy and organization. The initiatives in Section 4 are sufficiently explicit that it should be possible to measure progress and/or achievement quite readily. The main potential obstacle is sheer lack of time and human resources to exploit the many attractive opportunities available. A source of relief would be a more robust layer of postdoctoral and technical help within the research pyramid (another leveraging role for the Dunlap Institute), along with professional assistance with promoting and managing large research projects like TMT (the required aggressive, entrepreneurial approach to funding, leveraging, and partnering with government and industrial and private sectors takes an enormous amount of energy, effort, and time). It will be an interesting six years.

Appendix: Proposed Graduate Enrolment Targets, 2005-2010

Department of Astronomy and Astrophysics

Although each priority and initiative in our Plan does not say "graduate program" explicitly, the graduate program is so tightly interwoven in everything we do, and why we do it, and what our impact is, that it is fair to say that the graduate program is central to the Department's existence.

We do attract good students and then train (by which we mean educate!) them well, so that most go on to postdoctoral positions and then to faculty or professional positions in the discipline. To repeat a line from the DAA Plan (section 3), "Of the 100 most recent PhD graduates, 37 (18 in Canada) hold faculty positions in universities, 31 (20) hold professional astronomer staff positions in government laboratories, observatories, universities, 17 are postdocs, 5 are in industry, 4 in colleges and secondary education (6 unknown)." Department reviews and OCGS reviews have also commented favorably on the program and the quality of the theses, which compare well with our competitors (Cambridge, Caltech, Princeton, etc.). This has been recognized in "best thesis" awards from the Canadian Astronomical Society too.

We want to sustain this high quality. The proposed plan would require admitting 9 students on average per year (a larger cohort also has program advantages). We already attract a large pool of applicants and are presently turning away well-qualified students. This year we admitted 7 (possibly 8). Thus maintaining quality seems tractable. Independently of growth, our energetic faculty are keen on raising the quality further, which will be addressed by revamping both our printed recruitment materials and the entire DAA web site, as well as by using personal contacts and initiatives even more effectively (the discipline is small enough even internationally that we know the recommenders personally).

Target	*2005-06*	*2006-07*	*2007-08*	*2008-09*	*2009-10*
PhD – Funded	32	35	38	41	45
PhD – Total	35	37	39	42	46
Total	35	37	39	42	46

Here is the proposal. This a pretty simply table, because since the time that DAA introduced the option of a direct entry Ph.D. program, with immediate engagement in research along with courses, all but a very few students have opted for it. We still have a M.Sc. program on offer and a joint M.Sc. progam (with CITA and Physics) which is a potential (though apparently not preferred) entry route especially in theoretical astrophysics. We still offer the courses needed for the M.Sc. programs, since these are also needed in the direct entry Ph.D. program. The direct entry Ph.D., given nuturing proactive Ph.D. committees, ought to be flexible enough to meet most student's requirements.

The present funded cohort stands at 29 for 2004-05. Thus what the first line in the table projects is steady growth over the Plan period, totaling 50%. The second line includes steady improvement in "time to completion", as we come into alignment with the five year funding program, aided by the direct entry Ph.D. program.

The growth is demand driven and would still not saturate supervisory capacity. Capacity has increased with five young active faculty members joining DAA in the last planning period, one bridged position under active search, and one faculty member being added to CITA this year (and one early in the last planning period). The faculty renewal anticipated in ROS has thus materialized and it is time to increase the size of the graduate cohort to match.

Since we have a tightly unified graduate department in astronomy and astrophysics, the DAA graduate cohort must anticipate the added supervisory capacity coming from UTM and UTSC as well. This is no longer a matter of speculation. There will be a complement replacement at UTM in the present Plan (perhaps even growth). There is a new Centre for Extrasolar and Solar-system Planets being established in DPES at UTSC, with a guarantee of five positions (possibly eight including growth). For graduate astronomy and astrophysics, these are all net new additions to graduate supervisory capacity.

The argument above is presented differentially. It could be presented in absolute terms: 45 graduate students means about 2 graduate students per faculty supervisor. Given that our most active supervisors have had as many as 4 or 5 students, and that all of the new and remaining faculty are supervising, this plan is, if anything, too conservative for a very active discipline with international prominence.

DAA uses faculty research grants and some department endowments to support the graduate funding packages. Total research grants have grown with faculty renewal and the faculty growth will be accompanied by more. With advance planning, the department endowments could sustain more graduate funding too. Equally importantly, we presently have too many TA requirements to be filled by our present graduate students. We meet the needs by hiring five people from outside the graduate department each carrying a heavier than normal load, and by permitting some of our own students to carry higher than desirable loads. Thus, expansion of the graduate cohort will actually help our TA situation.

At the present time, we would have difficulty housing the increased number of graduate students, even at the minimal COU standard. However, with the anticipated development of the Dunlap Institute on campus and consolidation of astronomy and astrophysics space at the Nursing building/site there is some hope.

Measures of success would continue to be time to degree, student satisfaction, awards, and placement.