# Reflections on the Growth of Astronomy at the University of Massachusetts and the Five College Astronomy Department

by

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## I. Introduction

As Astronomy at the University of Massachusetts has developed within my memory from virtual non-existence to a program of international repute, it seems appropriate to try to collect some of this history in one document. The present paper was begun in 2003 and was supplanted and revised over the following three years. To those readers interested solely in the growth of the Astronomy Program, I apologize for including some reflections on my personal scientific career in Sections IV and VIII. A digital version of this text and the accompanying figures is available in the Archives at each of the Five Colleges and on an attached CD-R.

In addition to drawing on my own memory of events, this paper is also based on material from the offices of Five Colleges, Inc.; from the Archives of Amherst College, Smith College, Mount Holyoke College, Hampshire College, and the University of Massachusetts; from records kept by the Astronomy office at the University of Massachusetts; and from the annual reports of the Amherst College Observatory and the Four/Five College Observatories published between 1960 and 1992 in, first, the *Astronomical Journal*, and, subsequently, in the *Bulletin of the American Astronomical Society.* I am grateful for comments and assistance from Albert Linnell, Thomas Arny, Rae Steining, Allen Langord, Linda Slakey, Butch Cardiasmenos, and the Archivists Peter Nelson at Amherst College, Patricia Albright at Mount Holyoke, Susan Dayall at Hampshire, Mike Milewski at UMass, and Nanci Young at Smith; and to Neal Katz for suggesting that this history be written. Of course, none of the above are responsible for whatever errors or omissions are present.

## II. Early History of Astronomy in the Pioneer Valley

Astronomy has had a long and distinguished history in the Pioneer Valley of Massachusetts. A liberal arts education in nineteenth century America was still based on the classical/medieval trivium (grammar, logic, and rhetoric, in Greek and Latin as well as English) and quadrivium (arithmetic = the science of numbers, geometry, music, and astronomy), which date back to Plato and earlier to Pythagoras. It is thus not surprising that astronomy has been part of the curriculum of Amherst College, Smith College, and the Mount Holyoke Female Seminary (subsequently Mount Holyoke College) essentially since their founding.

The subject has been taught regularly at Amherst College since 1825 (Todd, 1903), just four years after the College was founded, at a time when tuition and room cost $10-$11 per semester, and the charge for board was $1.25 per week! Amherst is said to have been just the second institution of higher learning in the United States to acquire astronomical instruments, including in 1831 a transit telescope and astronomical clock. The great comet of 1843 and the discovery of Neptune in 1846 led in Amherst, as elsewhere, to an increased interest in astronomy, and in 1853 the first equatorially mounted telescope completely built by the famous American firm of Alvan Clark and Sons was installed in Amherst's new Lawrence Observatory (popularly known from its shape as "the Octagon"). The 7 1/4-inch refractor cost $2000 and was one of the 50 "most considerable achromatic telescopes of the world" (*Amherst Student*, 1895).

In the late nineteenth and early twentieth centuries Amherst College professor David Todd led some 13 solar eclipse expeditions to all parts of the world, partly under the sponsorship of the National Academy of Sciences (Hudson, 1939). Todd invented techniques for the automatic photography of the solar corona during eclipses. His activities in promoting western education in Japan during an eclipse expedition led to his being awarded the Imperial Sake Cup by the Emperor in 1896. Todd was selected to direct observations of the transit of Venus in 1882 from the Lick Observatory (some of the photographs are reproduced in Sheehan and Misch, 2004).

A second observatory building was constructed at Amherst in 1905 to house the new 18-inch Clark refractor, at that time one of the larger telescopes in the United States. Lowell Observatory founder Percival Lowell convinced Todd to take charge of an expedition to South America in 1907 to observe a favorable opposition of Mars, and the 18-inch telescope was dismantled and shipped to Chile. Todd later noted the difficulties of observing at 14,000 feet elevation and cautioned against observing at even higher altitudes (current LMT observers be warned! see Chapter X below), but the expedition succeeded in obtaining more than 12,000 photographs of Mars. Todd was also interested in aeronautics, which at his time meant primarily balloon flights. To reduce deleterious atmospheric effects on observations, he made astronomical measurements of Comet Halley from a balloon in 1910. He seems to have been convinced by Lowell's interpretation of the "canals" of Mars as the works of an intelligent civilization, and he later took radio equipment on a balloon flight to try to detect signals from the putative Martians.

In twenty-first century Amherst, Todd is better known for scandal than for astronomy --- his wife, Mabel Loomis Todd, had a well-known and long-lasting love affair with Emily Dickinson's brother, Austin, a local attorney. It seems likely that David Todd was not blameless himself, as his wife is reported to have said, “I do not think David is what might be called a monogamous animal” (Sheehan and Misch, 2004; Longsworth, 1999).

Smith College graduated its first class in 1879, and astronomy is listed in the very first published course list, being required of all students in the junior year, with “Advanced Studies in Astronomy” required in the senior year for students choosing the “Scientific Course [major]” (Smith College, 1876). In an early example of four college cooperation the courses were initially taught by Amherst College astronomers William Esty and then David Todd, who were listed in the Smith catalogs among the “Lecturers and Non-resident Teachers”. Todd in fact supervised the construction of the first Smith College Observatory and arranged in 1886 for the purchase of an 11-inch refracting telescope with an Alvan Clark lens and an equatorial mount built by the Warner and Swasey Company (Astronomy, 1887).

In 1887 Smith hired its own astronomer, Mary E. Byrd, appointed as “Teacher of Astronomy and Director of the Observatory”; she was eventually promoted to Professor of Astronomy in 1898. Byrd’s reports of the demands on her time and her pleas for an adequate budget will sound familiar to many experimental scientists today, particularly those in small college environments. “This report, however, gives but little idea of the large demands upon an instructor’s time. During nearly all the hours spent by students in the Observatory there has been need of constant assistance so that the young observers might work without detriment to the delicate instruments and with advantage to themselves.... In spite of ... the remarkable number of cloudy nights this year, the observing books show since September 23 ninety-six evenings of observing” (Smith College Observatory, 1888; cf. Also 1989, 1891, 1892, 1893).

Apparently there was no budget for the Astronomy Department, apart from Byrd’s salary of about $1000, since her first departmental report requests “a small working library and some funds for reducing observations”. Showing a dedication that would be hard to match today, Byrd pledged to match herself up to $100 (10% of her salary!) any funds provided by the College. This offer seems to have been accepted, as the Observatory Report for 1889 gives computing expenses of $91.87, and a separate list of book purchases totaling $100 (among them “Newton’s Principles” for $3 and “The Sun” for $0.40). In 1892 Byrd still pleaded “Voluntary contributions from the students and financial aid from the Cambridge Observatory [Harvard? where Byrd did graduate work] are very gratefully received, but in my judgment the astronomical department of Smith College stands in sore need of a regular, annual appropriation.” The number of students was considerable, totaling 125 over the fall, winter and summer terms in 1892-93, and President Seelye did provide an assistant in

1894. Moreover, the 1891 report of the Smith College Observatory notes that two graduate students worked in the Observatory that year, with a Masters degree being awarded to Harriet Cobb --- to my knowledge, the first graduate degree in astronomy awarded by any of the current Five Colleges.

The heavy teaching load over the years, coupled with some bad astronomical luck ("The research work in which I am particularly interested has been hindered by the dearth of even fairly bright telescopic comets", Smith College Observatory, 1899), seems to have prevented Byrd from publishing astronomical research, but she did publish articles and books on teaching astronomy (e.g., Byrd, 1899). In fact, she considered Smith to be a national leader in astronomy education. As part of a plea for a new telescope (Byrd, 1903), she told President Seelye "at least till recently we have held our own fairly well with the best of the college observatories. In one respect we have been leaders. Here as nowhere else has been worked out a definite scheme to meet the complex requirements for teaching astronomy as a laboratory science".

Training in astronomy was required of all students at the Mount Holyoke Female Seminary from its founding in 1837 until the institution was granted collegiate status in 1888 (when it became the Mount Holyoke Female Seminary and College, and subsequently, in 1893, simply Mount Holyoke College). Some of the questions asked in the first textbook used (Wilkins, 1833) would be familiar to introductory astronomy students today, although the answers might be surprising (e.g., the answer to "How many ... planets are there?" was given as 11, since Neptune and Pluto had not yet been discovered, but the four asteroids then known were included). The course was not simply descriptive, however, with problems given on Newton's laws and the law of gravitation (Olmsted, 1848), leading the College's second professor of astronomy, Anne Sewell Young, to lament, in words that surely resonate with today's teachers of physical science, "... one wonders whether the students of seminary days were less fearful of mathematics than is the college student of today" (Young, 1919). The first observatory was a small structure built in 1853 to house a 6-inch refracting telescope donated to Mount Holyoke. A later donation enabled the construction in 1881 of the John Payson Williston Observatory, which remains in use today and which is the oldest building on the Mount Holyoke campus. Interestingly, the old 6-inch telescope was donated to Huguenot College in South Africa, where it was used by the American expedition to observe the 1882 transit of Venus, at the same time that David Todd was directing northern hemisphere observations from the Lick Observatory (cf. Sessions, 1919; Llamarada, 1911).

The principal instrument at the new Williston Observatory was an 8-inch Alvan Clark refractor and the first Observatory Director was Elisabeth Bardwell, who had been teaching at Mount Holyoke since her graduation in 1866. Regular observations of sunspots (reported to an international center for this purpose in Zurich, Switzerland), lunar occultations, and variable stars were carried out through most of the twentieth century from the Williston Observatory.

## III. The Origin of the Four College Astronomy Department

The visionary who first proposed a joint astronomy department linking Amherst, Mount Holyoke, and Smith Colleges and the University of Massachusetts was then Assistant Professor of Astronomy at Amherst College, Albert P. Linnell (1953). At that time there were separate one or two person astronomy departments at each of the three colleges and no astronomer at the University. In October 1953 Linnell wrote to Amherst College President C. W. Cole with a proposal which he states he had been considering for some time and "which, at first, appears to be little more than a dream, but the more thought is given to it, the more reasonable and logical it becomes." He pointed out that enrollments in astronomy courses were small at the three liberal arts colleges, while the University offered no such courses at all. Moreover, he emphasized, "Good teaching and active research go together". This created a dilemma: to attract students a logical sequence of astronomy courses was required, but such a sequence presented by a single teacher would require so much preparation time that no opportunity would be left for research. Even if a course sequence were offered, instruction in at least part of the advanced curriculum would "breed acquiescence in a kind of teaching which ignores new developments", since one astronomer "cannot be a specialist in all branches of astronomy." Moreover, the distribution of observational instruments, journal subscriptions, and astronomical slides among the four institutions was very unequal and inefficient, and there was no planetarium available for teaching purposes.

Linnell pointed out that some cooperation among the four institutions already existed, as astronomy students from Mount Holyoke and Smith had recently undertaken honors work at Amherst, and the Hampshire Interlibrary Center was a joint venture providing the institutions with material that was too unusual or expensive to be duplicated. He therefore proposed the creation of "a joint department of astronomy", which would eliminate duplicate course offerings and pool facilities and library holdings. A larger department, with more extensive facilities than each college then possessed, would "provide an incentive for good men to join". From the research point of view, "proper scheduling of courses would permit one or more of the departmental members to be away part of the college year engaging in research at one of the large western observatories."

Specifically, Linnell proposed that there be four full time astronomers and a department secretary, and he suggested that (apart from faculty salaries and building overhead) an annual budget of $18,000, divided roughly equally between instruction and research, would be adequate. He explained that the department secretary's proposed salary of $3,000 "is higher than is customary at the colleges ... [because she/he would] help in some computational work, and would do most of the typing of technical papers." Among the courses that might be offered by the joint department were Introductory Astronomy, Navigation, Practical Astronomy, Galactic Analysis, Binary Stars, Astronomical Instruments, Astrophysics, and Special Problems and Honors. The major new expense in the proposal was for a central building for the department with faculty offices, classrooms, library, electronics and optics laboratories, a room suitable for installation of a planetarium, and bedrooms for night observers (this last item leads in to Linnell's suggestion that the new building actually be incorporated as part of the Amherst College Observatory).

In his cover letter to President Cole, Linnell recognizes the difficulties that would face a joint department, including transportation among the colleges, differences in class schedules and academic calendars, and particularly the initial cost of his proposed building. He notes, however, that the timing might be "particularly propitious", since the present senior astronomers at Amherst (Warren Green) and Mount Holyoke (Alice Farnsworth) were approaching retirement, and the single astronomer at Smith was on a temporary one-year appointment. President Cole, in a cover memorandum forwarding the proposal to the other three presidents (at this time the President of the University of Massachusetts was the chief officer of the Amherst campus), describes the joint department as "an interesting and exciting idea", although he thinks that "the building would be a grandiose plan unless foundation support could be secured", which he considers unlikely.

Subsequent progress towards a joint department was slow. The four presidents did instruct the valley astronomers to form a "Committee for Interdepartmental Cooperation in Astronomy", but it began to meet only in early 1956 (with the University represented by physicist William Ross). Linnell (1956) lamented "considerable resistance to the whole idea of cooperation from the present members of the astronomy department at Mount Holyoke", particularly from Professor and Williston Observatory Director Alice Farnsworth. He suspects that his initial suggestions about centralizing such a joint department at Amherst led "the Mount Holyoke astronomy department [to] feel that Amherst may be trying to corral the advanced courses in astronomy". Mount Holyoke's Committee member recommended suspension of any discussions of cooperation schemes beyond occasional social affairs or astronomical colloquia, taking the view that there was no room in advanced courses at Mount Holyoke for students from the other institutions, that "girls from Mount Holyoke probably would not be interested in coming to Amherst to take courses because of the time and transportation problems, ... [and] that the advanced courses at Amherst are probably beyond the capabilities of the girls, and so presumably would not be useful to them." It seemed, according to Linnell, that "there will be little willingness to cooperate if it means losing a shred of departmental autonomy." He did note that both the University and Smith College were apparently interested in cooperation, and that Miss Farnsworth was presumably close to retirement. The Progress Report of the Committee consequently temporized (Cooperation in Astronomy, 1956), informing the Presidents about efforts to achieve greater cooperation in the use of libraries, listing both advantages and disadvantages of jointly taught advanced astronomy courses, supporting (with no specifics) a Master's program in astronomy, and discouraging "any effort among the four colleges to develop a Ph.D. program in the near future".

The thread was next taken up in March 1957 by the Four College Coordinator, Sidney R. Packard at Smith College (the office of Coordinator of joint activities was held on a part-time basis by a faculty member from one of the institutions until 1967, when North Burn was hired as the first full time Five College Coordinator). Packard wrote to all the members of the Committee on Cooperation in Astronomy to ask whether progress had been made on library facilities or other matters. Linnell (1957) quickly replied, reporting little progress even in the matter of sharing information on library subscriptions, although a joint Astronomy Club had been established for students and seemed to be quite successful. He hoped, however, that new appointments in astronomy at Mount Holyoke might improve the atmosphere for joint astronomy courses.

In fact the atmosphere must have improved considerably over the following year, when Linnell (1958a) wrote to the four presidents that "the formation of a joint department of astronomy [is] apparently at hand". He reported the likelihood that Amherst, Mount Holyoke, and Smith would participate immediately, providing an initial staff of four astronomers, with the University joining the next year. The memo proposed an "Astronomy Council", consisting of all the astronomers at the four institutions, which would make decisions on such academic matters as teaching assignments, course offerings, and submission of proposals for external funding. Each astronomer would have one vote, with the chairman (normally the senior faculty member) having a second vote if needed to break a tie. This memo also recommended a series of procedures which subsequently became standard for the joint department: there would normally be at least one astronomer at each institution; beginning courses would be given at each institution, normally by that institution's astronomer; each astronomer would be hired by and paid by a single institution, although the presidents might wish to devise some scheme for sharing departmental salaries; all the astronomers would be considered to be part of the faculties at each institution and would be so listed in the individual catalogs; recommendations for promotion or salary increases would be made to a faculty member's home institution by the joint department (with only those members senior to the individual in question participating in the decision); and all joint (i.e., advanced) courses would be listed in the catalogs of all four institutions.

A month later Linnell (1958b) wrote to President Cole at Amherst requesting formalization of the agreement to form a joint department, stressing that the astronomers at the four institutions would be considered "for academic purposes" to be members of a single department, although individually they would be associated with a particular college or with the University. Perhaps having been asked to list both the advantages and disadvantages of such a joint department, he found none of the latter that were not shared by other joint efforts (transportation among the schools, differing academic schedules, etc.). Among the advantages he stressed the attractiveness to students, to potential new faculty members ("only the dregs of the graduate crop should be relegated to the fate of being the lone astronomer on some college staff"), and to foundations (on all of these issues, time certainly proved Linnell to be correct). At this point it would seem that the separate colleges asserted their individual "sovereignty", since Linnell (1959) felt constrained to clarify some points concerning the actual operation of a joint department in a memorandum to Four College Coordinator Packard the following spring: each college would continue to be responsible for their own observatory; each course proposed for inclusion in the catalog of a given college must first be approved by the faculty of that college in its normal manner; and each institution would maintain its own requirements for astronomy majors and honors students. Linnell did assert the necessity of the joint department playing the key role in the "hiring or firing", as well as promotion and tenure, of astronomy faculty members at all four colleges, since it would be responsible for astronomy teaching at all the institutions. The final decision on personnel matters would, however, rest with each college. He made a strategic retreat on financial matters, stating, "There is no intention to have a joint department budget [over and above the individual institutional budgets for astronomy]".

The requested formalization of an agreement took place, and a press release was drafted in August 1959, reporting that Amherst, Mount Holyoke, Smith and UMass had authorized the formation of "an association of teachers of Astronomy ... which is virtually equivalent to a joint department of Astronomy". This "cooperative arrangement" would allow students at all four institutions to plan a single astronomy program, would provide an increased diversity of course offerings, and would permit (through the sharing of teaching duties) faculty members to be away from campus during parts of the academic year to carry out astronomical observations or other research. The last advantage, it was emphasized, was usually available only to faculty at large universities and would allow the four institutions "to attract more competent teachers". Perhaps some effect of this kind was already at work, as the same press release announced the appointment of four new astronomers, Robert Koch at Amherst, Edward Olson at Smith, Kenneth Yoss at Mount Holyoke, and Robert Howard at the University.

At a meeting on November 18, 1959, the Four Presidents agreed that the "Joint Astronomy Department" would begin on February 1, 1960, and that the costs (including faculty salaries) would be divided equally among the four institutions. Albert Linnell must have been chosen as Department Chairman, as he is requested to ensure that "proper statements of the joint department" be inserted in all four catalogs, hopefully including a uniform course numbering system. Students registering for any of these courses offered <u>not</u> on their home campus would <u>not</u> need to apply through the existing procedure for interchange students, but would register in the same way as they would for courses at their home institution. A joint astronomy budget of $600 was authorized, to be allocated at the discretion of the Department Chairman. Astronomy faculty were to be reimbursed for transportation among the colleges at the rate of 8 cents per mile, apparently to be drawn from the joint budget. In addition, each institution would be responsible for minor equipment costs on their own campus, and the issue of purchasing major new equipment for astronomy was postponed.

An academic year budget for the "Joint Astronomy Department" for 1960-61 was presented to the four colleges by Linnell (1960a). Excluding faculty salaries, the proposed budget included $690 in joint support for clerical assistance, $9140 for local expenses at Amherst, $1305 at Mount Holyoke, $1750 at Smith, and $3300 at the University, for a department total of $16,185. It appears that the four presidents agreed to share equally the total cost of the astronomy department, including salaries, at least through academic year 1961-62 (Four Presidents, 1960). This procedure was modified for later years, with faculty salaries divided among the institutions "on the basis of current enrollments and department opinion about the division of labor between elementary and advanced courses" (Presidents, Treasurers, and Deputies, 1962).

Formation of the joint department was announced to the astronomical community in the "Reports of Observatories: Amherst College Observatory" published in the *Astronomical Journal* (Linnell, 1960b). The research programs of four of the five department astronomers were supported by grants from the National Science Foundation --- Howard on solar magnetic fields, Koch on photometry of binary stars, Yoss on the space velocities of giant stars with either weak or strong CN absorption, and Linnell on binary stars. Olson's research was on model solar atmospheres.

Over the next six years the joint department received more than $250,000 in research grants, and 15 astronomy majors went on to graduate study in astronomy. The astronomers took advantage of the possibility of sharing teaching during the academic year to carry out several-week observing runs at, for example, the Mt. Wilson Observatory, the Kitt Peak National Observatory, and the Steward Observatory. Smith College purchased a 180-acre tract of land in West Whately as the site for a new observatory and 16-inch telescope.

Nonetheless, conflicts developed over the support requested by the department and the resources supplied by the four institutions. The desired funding included, at various points, a $200,000 addition to the Amherst College Observatory to serve as a central focal point for the Department and a 48-inch optical telescope costing several hundred thousand dollars. Moreover, the astronomers strongly desired the development of a graduate (Masters) program, both to provide teaching assistants for the introductory courses and (presumably) to increase the visibility of the joint department and to promote research. The Presidents responded that they wished to see a larger number of majors and increased enrollments in advanced courses before endorsing a graduate program, and they specifically rejected the proposal for a joint Four College Astronomy Masters degree, taking the view that such degrees should remain the province of individual institutions. As the University was willing to begin graduate work in astronomy, the astronomers requested in January, 1964, that the "Joint Department of Astronomy ... be transferred completely to the University of Massachusetts as its 'Home' institution", while retaining the title of Joint Department and continuing the commitment to teach an introductory course on each campus. As part of such reorganization, the astronomers requested that the University initiate a doctoral program within three years.

The request for transfer of the department was not accepted, but in March 1964 the University agreed to offer MS and PhD degrees in astronomy if a proposal from what was now called the Four College Astronomy Department were approved in the usual manner by the University's Graduate Council and Trustees. The four Presidents planned (meeting of March 10, 1964) to continue the Joint Department, with Amherst, Smith and Mount Holyoke maintaining at least one resident astronomer each, and the University committed to two additional faculty positions (for a total of 3) by September 1966. The graduate program would be solely under the aegis of the University, although the Chairman of the Four College department would be responsible for both the undergraduate and graduate phases of the astronomy program. Any Department faculty member could be assigned by the Chairman to teach graduate courses and/or supervise thesis research. Personnel actions for individual faculty members were to be the responsibility of the individual institutions, but should be made in consultation with the Department Chairman. In August 1964 Linnell (1964), styling himself "Chairman, Astronomy Department, University of Massachusetts" indeed submitted a proposal for M.S. and Ph.D. programs to the University's Graduate Council.

Professor Linnell's appointment remained under this plan at Amherst College, however, and the College was not anxious to host the chairman of a Department that offered graduate degrees. Moreover, President Calvin Plimpton decided that one astronomer at Amherst College was sufficient, and refused to reappoint Robert Koch. In response to this situation, Linnell stepped down as Chairman in 1965, and he, Koch, and UMass astronomer Stanley Sobieski all resigned from their respective institutions at the close of the 1965-66 academic year.

## IV. Beginning the Graduate Program in Astronomy

The early nineteen-sixties was a period of dramatic growth for the University of Massachusetts, with annual increments of about 1500 students and 100 faculty (essentially growing by "one Amherst College" each year!). Overseeing much of this development were Provost Oswald Tippo (from 1964) and Dean of Arts and Sciences (then united in one college) I. Moyer Hunsberger. In 1964 Hunsberger hired Robert Gluckstern to chair and build a modern Physics Department. Gluckstern supported the development of a graduate program in astronomy at the University, and, following Linnell's resignation, he was appointed as Acting Chairman of the Four College Astronomy Department for 1965-66. He proposed that astronomy and physics at the University be joined "for administrative purposes, under the title of the Department of Physics and Astronomy", with the University's astronomy faculty continuing to be also members of the Four

College Astronomy Department. Within the University's administrative structure a unit that offered degrees but that was not a separate department was called a "program", so the position of Chairman of the University's Astronomy Program was created.

Gluckstern recruited me to be both Chairman of the Four College Astronomy Department and Chairman of the UMass Astronomy Program, beginning at the start of the 1966-67 academic year. I imagine I was one of only a few faculty candidates at the four institutions who were interviewed by the Four College Coordinator as well as by administrators from the separate institutions. At a meeting on May 10, 1966, the four Presidents agreed with this appointment, stating that as Four College Chair I would have responsibility for initiating astronomy personnel actions (including new appointments) at each of the four institutions, subject to review and approval by each institution. They recommended that the Astronomy Program at the University have a separate budget and that the Chairman of the Astronomy Program participate in University department head meetings and receive separate allocations of faculty positions and teaching assistantships. They further recognized that, to avoid "second class citizenship", all members of the Four College Astronomy Department must have the opportunity to participate in the graduate program. A separate budget for Astronomy at the University was not achieved until 34 years later, but I did participate in meetings of College of Arts and Sciences department heads/chairs. Separate allocation of faculty positions was never a divisive issue during the period of rapid University growth, and I assumed effective responsibility for astronomy faculty recruiting at all four institutions.

For the beginning of the 1966-67 academic year Thomas Arny, a postdoctoral research associate at Amherst College for the previous two years, and Stephen Adler, an Instructor at Mount Holyoke, were promoted to Assistant Professor at the University and at Mount Holyoke, respectively. The only other returning astronomer at the colleges was Frank Stienon at Smith College, who resigned at the end of the 1967-68 academic year. Since Adler did not receive tenure in 1969, the re-organized Four College Astronomy Department thus began with virtually an entirely new cast of faculty members.

After my appointment but before the beginning of the fall semester, Gluckstern and I recruited Edward R. (Ted) Harrison, an astrophysicist from the Rutherford High Energy Laboratory in England. Harrison had an interesting background. The Second World War interrupted his education, and he had not received a PhD. Nonetheless, he had achieved an international reputation for his work in cosmology and the formation of structure in the early universe. He was appointed as Full Professor without tenure, although tenure followed rather quickly. In addition to his research work, Harrison has subsequently published outstanding books on cosmology for the literate layperson (for example, Harrison, 1985 and 2000).

### *IVa. Personal Digression*

*Harrison had expected to collaborate on research with me, since my PhD thesis was in the same area of research, the initial formation of galaxies as the universe expanded. A principal outcome of this work was the "Layzer-Irvine equation", an energy conservation relation for density fluctuations in an expanding universe (Irvine, 1965; Peebles, 1980; Davis et al., 1997). I, however, had felt stymied by the lack of observational data in cosmology at the time my thesis was completed in 1961 and had completely changed the direction of my research. During a NATO Postdoctoral Fellowship at Leiden Observatory, I worked with H. C. van de Hulst on problems of light scattering relevant to planetary atmospheres and interstellar/interplanetary dust. Digital computers at that time were just becoming available for astronomical research, allowing progress to be made on problems that had previously been too computationally complex. In the fall of 1961 the Leiden Sterrewacht (Observatory) still employed a room-full of assistants with mechanical calculators; an astronomer could submit a complex computation to the head of this group, who broke it up into pieces that were assigned to individual operators (e.g., calculation of the Mie functions which describe the scattering of electromagnetic radiation by spherical particles). Within a year Leiden University's new Computer Center (directed, as I recall, by an astronomer) was accepting programs on paper tape written in ALGOL, a European alternative to FORTRAN.*

*I began actively to apply the new computing technology to problems suggested by van de Hulst. He and I wrote a review paper on radiative transfer in planetary atmospheres which incorporated some new results and which he was to present at a meeting in Liége, Belgium (van de Hulst and Irvine, 1963). However, the conference organizers decided to change their schedule after the meeting started but before van de Hulst had arrived, with the result that my first ever professional presentation was a major review at an international conference, given without the slides, which were still in Holland --- I made very active use of the blackboard!*

*During this time in Leiden I made what has always seemed to me to be my second real theoretical innovation. This involved showing that the frequency-dependent profile of a spectral line formed during the reflection of sunlight from a cloudy, absorbing planetary atmosphere can be obtained from the reflection* *properties of a non-absorbing ("conservative") atmosphere, if the probability distribution of the path lengths traveled by scattered photons in the conservative case is known. The latter can indeed be found by Laplace transform techniques or various approximations in many cases; the same methods can be used to reduce problems of time-dependent scattering, as of a pulse of light, to the time-independent case (Irvine, 1964, 1967). This "breakthrough", although occasionally cited in the Russian geophysics literature, seems to have passed essentially unnoticed in the rest of the world. Instead, I became much better known for what has seemed to me to be a rather mundane reworking of a nineteenth century German theory for light scattering by a densely packed particulate layer, often cited as the "Hapke-Irvine" law (Irvine, 1966; e.g., Bridges, 2001). The latter did lead, however, to a long collaboration and friendship with Finnish astronomer and planetary scientist Kari Lumme, which included studies of Saturn's rings (e.g., Lumme and Irvine, 1979, 1982).*

*After the NATO Fellowship I returned to Harvard, in order to work with my thesis supervisor, David Layzer, and prepare my PhD thesis for publication. Subsequently, however, Layzer's federal grant support expired, and Professor Donald Menzel hired me to supervise a project to measure the phase curves and albedos of the Moon and planets in an accurate and consistent manner (a planetary phase curve is its brightness as a function of the angle Sun-planet-Earth; the albedo measures the planetary reflectivity). The project, funded by NASA, involved observations from observatories in France and South Africa, where local observers had been hired (e.g., Irvine, Simon, et al., 1968). The observers sent chart paper recordings of the brightness of the planets and standard stars back to Harvard, where they were measured by a technician and the results transferred to punch cards (by this time the preferred means of communication with computers). Although I had never made an astronomical observation in my life, my management of the project apparently established my reputation as a planetary scientist, and I was later elected as the fourth Chair of the young Division for Planetary Sciences of the American Astronomical Society.*

## V. Initial Growth of Astronomy and Transition to a Five College Astronomy Department

The new Astronomy Program at UMass thus began with three theoretical astrophysicists, Irvine, Harrison, and Arny (whose research on star formation included modeling the collapse of interstellar clouds). Clearly an astronomy program needed an observational component, and just as clearly New England was not a good location for traditional optical astronomy. We thus began exploring two possible options: observations from above most of the atmosphere, and radio astronomy, where at most wavelengths the atmosphere is relatively transparent.

To seek advice on high altitude observations, I visited Professor John D. Strong, Director of the Laboratory for Experimental Astrophysics and Physical Meteorology at Johns Hopkins University. Strong had become a pioneer in high altitude astronomy from balloons, after a career that included inventing the technique for aluminizing telescope mirrors, aluminizing (among others) the world's largest telescope mirror at Mt. Palomar, growing the first optical quality halide crystals for infrared spectroscopy, and developing the technique of Fourier transform spectroscopy. Targets of his balloon-borne observations included planetary atmospheres and the Sun. When asked whom he might suggest to develop a program of infrared astronomy at UMass, Strong replied "How about me?" Amazingly, the University managed within a few months to complete a metal building to house most of Strong's equipment (including a 3-ft diameter, 100-ft long absorption cell for measuring infrared spectra of gases) and a good part of his technical staff by the time he arrived on campus in the fall of 1967. This building was officially designated the Astronomy Research Facility. A second faculty position was made available to Strong's former student, William (Bill) Plummer, who began his appointment the following year. Over the next several years the group made a number of balloon flights with a 16-inch telescope, primarily to study the solar chromosphere and zodiacal dust in the vicinity of the Sun. Strong and Plummer also initiated an active program of laboratory astrophysics, which included measuring the infrared spectra of atmospheric gases and the reflectivity of potential planetary surface minerals.

A revised proposal for a Graduate Program in Astronomy was drafted during the 1966-67 academic year and approved by the University in time to admit the first MS/PhD students in 1967. During the 1967-68 academic year the Four College Department reported 37 undergraduate majors, including 3 seniors, 5 graduate students, and total enrollments in introductory and advanced undergraduate courses of 1227 and 56, respectively. The Department hosted 3 Visiting Scientists, including astronomers from Czechoslovakia and Japan, and 26 colloquium speakers. Eighteen research papers and two abstracts were published by Department members that year.

Pursuing also the option of developing a program in radio astronomy, the University became a charter member of the Northeast Radio Observatory Corporation (NEROC) in 1967. NEROC's goal was to build a very large aperture (440-ft) radio telescope that would be operated as a regional facility. Funding for the new telescope was not obtained. Instead, in 1970 NEROC took over from the Air Force the operation of the 37-meter-diameter Haystack radio telescope in Westford, MA, with support from the National Science Foundation, NASA, and the Air Force. Of the original 13 members of NEROC (including Boston University, Brandeis University, Brown University, Dartmouth College, Polytechnic Institute of Brooklyn, SUNY Buffalo, SUNY Stony Brook, the University of New Hampshire, and Yale University) the most active in using the telescope for many years were Harvard University, the Smithsonian Astrophysical Observatory, MIT, and the University of Massachusetts.

A program in radio astronomy naturally involved recruiting radio astronomers, and for the fall of 1968 the University hired G. Richard Huguenin from Harvard and William A. Dent from the University of Michigan. Dent was famous for discovering the time-variable nature of radio emission from quasars, a completely unexpected phenomenon that required the source of emission in these objects to be extremely small (the power source is now generally accepted to be a "super-massive" black hole at the center of a galaxy). He became a major user of the Haystack Observatory, as well as of the National Radio Astronomy Observatory's 36-foot telescope at Kitt Peak, both of which he utilized to study the variations in flux from what would come to be known as Active Galactic Nuclei.

Huguenin had realized from early in his career that new scientific results in radio astronomy flowed from the development of innovative instrumentation. He had built a team for this purpose at the Harvard College Observatory, in order to study rapid time variations in the radio emission from solar flares. This equipment turned out to be perfect for observing pulsars, which had just been discovered at Cambridge University, and Huguenin and his co-workers made the first American discoveries of pulsars (the rapidly rotating remnants of collapsed stars). However, he did not have a faculty position at Harvard University, and I was able to recruit him for the University of Massachusetts.

Another event during this period relevant to astronomy was the founding of Hampshire College, designed by the original Four Colleges to be an avowedly experimental and innovative institution of higher learning. The first Dean of Sciences, Everett M. Hafner, was a physicist who had been an early proponent of gamma ray astronomy (e.g., Fazio and Hafner, 1967) and who also had an interest in what would later be called astrobiology (Hafner, 1969a). His plan that astronomy be a point of emphasis within the physical sciences at Hampshire led to the College joining the joint astronomy program, which thus became the Five College Astronomy Department. "With all of the physical sciences before us, we focus on astronomy as especially attractive for early development at Hampshire" (Hafner, 1969b). He was made a member of the Astronomy Graduate Faculty at the University. Hampshire began its participation in the Five College Department by hiring a married couple, Kurtiss and Courtney Gordon, two radio astronomers who shared a faculty position beginning in 1970. FCAD faculty meetings hosted by Hafner at Hampshire, accompanied by sherry, provided a relaxing setting for academic discussions that was never quite duplicated at the other Valley institutions.

Smith College's participation in the joint Department was revitalized by the appointment of Virginia Trimble as Assistant Professor of Astronomy in 1968. Virginia's recruitment colloquium set a new standard in miniskirts, which certainly never again reached such a high level. When she was hired away by the University of Maryland after only a short term, she was replaced by Waltraut Seitter from the University of Bonn, who had held temporary appointments at Smith in the early 1960's before returning to Germany. Waltraut was truly passionate in her teaching of astronomy as an observational science, regularly bringing Smith students on her observing runs at the Kitt Peak National Observatory in Arizona. When, some years later, she accepted a Chair in Astronomy at the University of Münster, she became, I believe, the only woman in such a position in all of Germany.

The long and productive association of David van Blerkom with the department began in 1969, when he became a Postdoctoral Research Associate working with me on radiative transfer problems in planetary atmospheres. The following year he was promoted to Assistant Professor. David was the epitome of a scientist educated in the liberal arts. He had a love of ancient languages and cultures, and periodically taught a course (for credit!) on Egyptian hieroglyphics. He was fascinated by the Sumerians and studied cuneiform writing, and I believe that he had read everything extant written in Hittite. He was acquainted with leading Egyptologists, and his knowledge was extremely helpful to me in trying to determine the likely validity of a suggestion that comets are mentioned in the so-called pyramid texts, some of the oldest writing on our planet (the meaning of the text in question is obscure, and it seems, surprisingly, that there is no unambiguous reference to observations of comets in the entire hieroglyphic literature; cf. Weeks, 1998; Irvine and Bergin, 2000). David also had a wonderful sense of humor, and the bulletin board outside the Astronomy office at UMass still bears his announcement of a weekly graduate student Journal Club, which managed to work the name of every astronomy faculty member into his adaptation from Lewis Carroll:

'Twas Irvine, and the slithey Schloerb
Did gyre and gimble 'bove the din:
All Denty were the Tademaru's
And Scoville did mesh Hugeunin

“Beware the Journal Club, my son!
The jaws that bite, the claws that catch!
Beware the Arny bird, and shun
The frumious Vanblerkomsnatch!”

He took his vorple chalk in hand;
Long time the blackboard’s safety sought –-
So rested he by the StromYoung tree,
And stood as if in thought.

And as in steady state he stood,
The Harrison with pipe of flame,
Came slashing through the ego wood,
And snorted as he came!

Kwan, too! Kwan, too! And ν and ν
His vorple chalk went Spitzer-snak!
He left him red, his briar dead,
He set him on the track.

“And hast thou slain the Journal Club?
Come have all A’s, my Goldsmith boy!
Oh phased array, O VLA!”
He published in his joy.

‘Twas Irvine, and the slithey Schloerb
Did gyre and gimble ‘bove the din:
All Denty were the Tademaru’s
And Scoville did mesh Hugeunin.

As might be surmised from the above, the graduate students lived in dread of Harrison’s questions (one famous example asked students to calculate the length of “a wild goose chase”, which required estimates of the energy contained in a bird’s meal, the efficiency of extracting that energy for flight, etc.).

David van Blerkom had an apt illustration for every occasion, such as that in Figure V-9, from a 1981 description of the Five College Astronomy Department. He was broad ranging in his research interests, writing about both stellar atmospheres and, for example, the reflection of light from bizarrely shaped planetary cloud layers (such as occur in the real world!). He was also intrigued by unusual and exotic diseases, a tragic irony, since he was ultimately struck down by such an illness at a relatively young age.

In 1970 Tom R. Dennis replaced Stephen Adler at Mount Holyoke College as Assistant Professor and Director of the Williston Observatory. Tom’s principal achievement for the Five College Astronomy Department was obtaining funding for a new 24-inch telescope for the Observatory, which became a workhorse instrument for Department laboratory/observing courses. Over the years he became increasingly estranged from his colleagues, complaining that the FCAD "had essentially been converted into a subsidy [sic] of the state University" (Dennis, 1982). Several years later his argument that Mount Holyoke was not receiving its fair return from the joint astronomy budget led to a crisis for the Five College Astronomy Department, including his threat of secession by Mount Holyoke. Ultimately, his views provided at least part of the stimulus for restructuring the Department's procedures (discussed below).

Amherst College was the site for the first astronomy course that I personally ever taught --- even in graduate school I had never been a teaching assistant, and in fact, as a physics major, I had only taken one semester of astronomy in my entire student career. But, in 1966-67, while the Department was searching for a junior astronomer to fill the Amherst College position, I took on the responsibility for the introductory course there. The class was scheduled for the College's planetarium, on the second floor of a lovely old building. Unfortunately, the planetarium was locked when I arrived, and no one then in the building had any idea where the key might be. Consequently, my very first teaching experience took place on the front lawn!

The astronomer who was subsequently appointed at Amherst did not work out, but in 1971 the College hired George Greenstein, a theoretical astrophysicist whose interest in pulsars nicely complemented the observational work of Huguenin's group. Some years later Greenstein's interests shifted from research to science writing for the general public, for which he received an award from the American Institute of Physics in 1984. He is the author of several non-technical books on astrophysical topics (e.g., Greenstein 1984, 1997) and subsequently was named the Sidney Dillon Professor of Astronomy at Amherst.

The division of astronomy expenses had become somewhat more arcane in the late 1960s. The salaries were apportioned at the end of the academic year by assuming that a full course load for a single astronomer was four courses per year. Each Four/Five College Astronomy course taught (that is, any course beyond the introductory course at each institution) thus corresponded to 25% of that individual's salary, which was shared equally among the institutions. The remainder of his/her salary was considered a local expense, as were equipment, supplies, etc., for introductory courses. The non-salary budget of the joint Department grew to $6500 for 1966-67; primarily, this represented the salary of the Department secretary, but limited funds for travel, colloquia, supplies for joint courses, and the support of research publications were included.

The new formula for sharing salary expenses had the disadvantage, however, that an individual college's share might vary significantly from year to year, depending on which astronomers taught joint courses that year. Consequently, the four Presidents and the Chancellor (now representing the University of Massachusetts Amherst) asked the Department in 1970 to seek a more stable cost-sharing formula. On the basis of the average budgets over the previous few years, I proposed a salary formula in which it was assumed that local activities at each of the private colleges would require 5/8 of the time (and hence salary) of that institutions astronomer(s), while Five College (joint) courses would cost each institution 40% of the salary of an imaginary astronomer earning the average salary of all department members (including the University). If the sum of these two items exceeded the salary paid by a college to its "own" astronomer, the difference was due the University. Typically the University's salaries were higher than those paid at the colleges, partly because the college astronomers were more junior, with the result that the University usually was reimbursed at the end of the accounting year (for example, $8510 for the 1970-71 academic year). Some years later this formula was also replaced, and each institution simply paid their own faculty members. The budget for joint expenses continued to grow over the years, reaching $27,450 in 1975-76, predominantly for the salaries of the department secretary, a technician for the Departments' several optical telescopes, and a teaching assistant to help with advanced laboratory and observational courses.

The astronomy faculty at this point had become quite successful in raising federal support for their research. Thus, the annual value of such grants rose from $233,620 in 1967-68 to more than $500,000 in 1970, with Huguenin, Dent, Arny, Harrison, Irvine, and Strong serving as Principal Investigators on 15 research grants from the National Science Foundation, the National Aeronautics and Space Administration, and the Department of Defense's Advanced Research Projects Agency and Office of Naval Research. Twenty-two scientific papers were published during the 1970-71 academic year (Five College Astronomy Department, 1972), including 4 authored by Harrison and 3 by van Blerkom.

## VI. Development of the Five College Radio Astronomy Observatory

Early in its history the Four/Five College Astronomy Department had one principal obstacle in its path toward becoming one of the leading astronomy programs in the US --- the lack of a major observational facility. Richard Huguenin proposed a solution --- build a radio observatory! Funding the capital costs of a new, powerful radio telescope seemed an almost insurmountable task, but Huguenin had a plan. He had brought from Harvard a staff of 3 outstanding radio engineers, 3 technicians, and a postdoctoral research associate, and he proposed to build the telescope "in house". The largest radio telescope in the world capable of observing pulsars was then (as now) the 1000-foot diameter Arecibo telescope in Puerto Rico. Building another such giant telescope in New England was impossible. But a comparable effective collecting area could, Huguenin reasoned, be duplicated at much less expense by building an array of many smaller telescopes, each designed to be constructed by relatively unskilled labor using inexpensive materials. Huguenin envisioned an array of 32 such "mini-Arecibos", each 120 feet in diameter, linked electronically to act as a single instrument. As a start he proposed building four such dishes, providing a sensitivity comparable to that of the 250-foot Jodrell Bank telescope in the UK, which was then producing important research on pulsars and other astronomical objects.

Each of the proposed antennas would have a fixed reflector (mirror), whose beam on the sky would be pointed by moving the feed element (focal point). The reflector would be constructed by suspending cables from an outside perimeter consisting of a ring girder supported by 26 utility (telephone) poles, covering the cables with inexpensive wire mesh, and then tying down the surface into a spherical shape. Three larger utility poles (70 feet in height) in the center of each antenna would support a rotating truss carrying the antenna feed, itself moveable to cover $\pm 36^{o}$ of sky from the zenith (Huguenin's team had designed a similar moveable feed for the 300-foot transit telescope at the National Radio Astronomy Observatory in West Virginia, increasing by an order of magnitude the amount of time that a radio source could be tracked on a given day). The reflectors would be designed to operate from 50 to 500 MHz, that is, at meter-wavelengths. Various possible sites were evaluated, and a location on the Prescott Peninsula within the Quabbin Reservation was chosen. This site was described as "perhaps unique within Massachusetts", being five miles from such possible sources of radio interference as power lines and highways (electric power was initially generated on site, and was subsequently brought in through a buried cable). Long-term protection of the site seemed assured, since the general public was excluded from this watershed/reservoir area. The land was owned by the state and administered by the Metropolitan District Commission (MDC), which had the responsibility to provide water to eastern Massachusetts. A permit was given to the University of Massachusetts by the MDC in November 1969 for the use of approximately 20 acres for an observatory consisting of approximately 32 antennas, associated electronics, and small laboratory buildings.

As was often the case in latter-twentieth century astronomy, the site selection was not without some controversy. Initial site clearing resulted in the inadvertent demolition of an observational "blind" that had been placed in a tree by a wildlife photographer who had regular access to the Prescott Peninsula (among the "tools" found in the blind were empty liquor bottles, but one imagines that bird watching could at times be a cold and lonely endeavor). The aggrieved photographer subsequently complained to the Commissioner of the MDC, the Governor of the Commonwealth of Massachusetts, and the University. An article in the Boston *Record American* newspaper on August 10, 1971, entitled "Quabbin Waters Endangered" attacked the "massive radio telescope" as a threat to the beauty of the area and the integrity of the watershed. The local state senator proposed a bill which would have excluded the new Observatory from the Quabbin area. Fortunately for astronomy, the University's legislative liaison managed to prevent the passage of the bill. A subsequent inspection of the initial construction at the Observatory's site by the Metropolitan District Commissioners (Sears, 1971) concluded that the observatory was "about as desirable an installation as could be placed within the Prescott Peninsula". In a pleasant example of interdepartmental cooperation, Professor Frederick Greeley of the University's Department of Forestry and Wildlife Management examined the question of whether the observatory would provide any hazard to either nesting or wintering bald eagles --- the latter were a frequent sight on the reservoir. He concluded that it was unlikely that that the telescope would trouble the birds. This conclusion has been borne out by the subsequently successful program of raising young birds at a site near the Observatory and releasing them to re-establish nesting bald eagles in Massachusetts.

However, even an in-house effort certainly needed some funding to build such an observatory, and Huguenin and I set about raising money. The University had no effective development office, but Amherst College's Development Office, in the person of John Callahan, was very helpful. The Five College Coordinator at that time, North Burn (who, I am told, actually had a brother named South Burn), raised the question of whether proposals should be submitted from the University or from Five Colleges, Inc. We argued that the University's bureaucracy made submission and administration of such proposals quite complex; moreover, the Five College consortium might be an attractive element for potential donors. This approach was agreed upon, and proposals were sent to a number of foundations; the first success was a small grant from the Edwin H. Land-Helen M. Land Foundation for $1,500. Callahan suggested approaching the Fleishman Foundation, among whose Board members was Amherst alumnus and astronomer Walter Orr Roberts, and a proposal for $73,000 was submitted. This amount initially seemed too large for that Foundation, but a grant of $20,00 from the Alfred P. Sloan Foundation provided the leverage needed to persuade the Fleishman Foundation to donate $53,000 for the proposed observatory.

Shortly before the relevant deadline, we learned of a new National Science Foundation grant program called the College Science Improvement Program (COSIP), designed to improve science teaching at the undergraduate level. As COSIP was expressly interested in inter-institutional proposals, it seemed a natural for the Five College Astronomy Department. The Department office mobilized over a weekend to gather required student statistics, write the proposal sections, and produce sufficient copies (Irvine, 1970). This proposal was submitted from Amherst College for the Five College Astronomy Department, since there was not sufficient time to gain approval from the other presidents for a Five College, Inc., submission. To deliver the proposal on time, I flew to Washington on Monday and hand-delivered the necessary copies to the NSF. Three months later the NSF announced a grant of $75,200 for the Five College Astronomy Department to build a radio observatory to improve undergraduate teaching and research.

The Five Colleges had committed $105,000 in matching funds for the COSIP and the Fleishman proposals, and each institution in fact did contribute to founding the new observatory, which was accordingly named the Five College Radio Astronomy Observatory (FCRAO). In particular, Hampshire College purchased computing equipment worth $27,900, Amherst College donated about $20,000, Smith College and Mount Holyoke College each gave $2,000, and the University provided more than $30,000. That fall (1970) the private Research Corporation granted $73,000 to Huguenin and newly hired radio astronomer Joseph Taylor for their research on pulsars (at the time one of the largest grants the Research Corporation had ever made).

As the construction began, I suggested to North Burn that it was an appropriate time to formally name a director of the new observatory, and in October 1970 Richard Huguenin accepted his appointment as Director of the Five College Radio Astronomy Observatory from the Five College Directors (the designation for the four college presidents plus the chancellor of the University and the Five College Coordinator).

Given the minimal budget available, construction of the antennas was truly a do-it-yourself endeavor. An old telephone company line truck was obtained to drill holes for the utility poles. However, its lifting arm was too short to pick up the tallest poles above their center of mass, so that graduate students, faculty, and even the Department Chairman had to act as ballast when these poles were inserted into the ground. Huguenin hired a “construction supervisor” to act as a contractor, and even the Research Engineers helped in pouring concrete for the Observatory control building. The issue of who actually owned the building and telescopes remained helpfully unsettled over the years, so that the University's Physical Plant could both be called upon occasionally to provide some maintenance and avoided when (normally) it proved faster and cheaper to work "in house".

Huguenin had some success in soliciting donations in kind from industry, including locally from the General Radio Company in West Concord, MA, Vitramon, Inc., in Bridgeport, CT, and the Sprague Electric Company in North Adams, MA, as well as nationally from the Hewlitt Packard Corporation. More innovatively, he made extensive use of the federal government's excess property program, through which institutions with federal grants could receive equipment that had been declared surplus at the termination of any government-sponsored activity. Over time he became the most active NSF-sponsored participant in this program, through which FCRAO received many tens of millions of dollars of equipment and supplies, ranging from sophisticated electronics to vehicles to ammunition cases (used for storing electronic components!). This material was a tremendous boon to the Observatory, not only during its initial development, but also for many years later. Of course there were a lot of things received under this program that were not useful, since available lots had to be taken as a whole; however, Huguenin became quite adept at trading or even selling items. Before it was ruled illegal, FCRAO had an account in a local bank that neatly avoided burdensome University red tape!

And red tape there was, as the University (and presumably the state) had never dealt with as large and active a research program as Huguenin developed. Lacking appropriate official titles for the recruitment and retention of professional staff, Huguenin obtained approval for the title of Research Engineer and pushed hard for Research Assistant/Associate/Full Professor (ultimately approved many years after his original request). Purchasing and registering a state vehicle initially was a major endeavor, requiring approval from an official colloquially known as the Commonwealth's "Admiral of the Fleet". Conflicts with the Procurement Department went on for years, in an effort to speed and simplify the purchase of items needed quickly for research instruments or observatory repairs. The Accounting Office was slow and unreliable, so the Observatory maintained a duplicate set of records. A few years later the situation had grown so burdensome that Irvine organized an *ad hoc* group of faculty that called itself the "Concerned Principal Investigators", in an effort to prod the University into recognizing and addressing the problems of carrying out research on campus (see Section VIII below).

In the mean time the first Observatory antenna was completed in November 1970, and the first observations of pulsars were made in December. The development and fabrication of the necessary electronics and control system were carried out by the radio astronomers and senior engineers: the antenna pointing software by Joe Taylor, the computer interface and digital electronics by Research Engineer George Orsten, the antenna drive and control servo-system by Research Engineer Antal Hartai, the broadband antenna “feed” system by their counterpart Al Rodman, and the electronics for linking the antennas (delay system) and the broadband “front end” receivers by Hartai and Huguenin. During the spring and summer of 1971 four University students and one Amherst College student (future University PhD and Columbia University Professor David Helfand) undertook research projects on pulsars. FCRAO thus began the tradition that has been maintained ever since, that a successful university-based observatory must be based upon three pillars: pioneering research, the development of state-of-the-art instrumentation, and the training of students.

At this time the University was fortunate to have Australian radio astronomer Richard N. Manchester join the faculty for a three year appointment and take an active role in pulsar research. He went on to become a Fellow of the Australian Academy of Science and one of Australia’s leading astronomers, serving as President of the Astronomical Society of Australia.

## VII. Change in Direction for the Five College Radio Astronomy Observatory

Even before the four initial antennas were in operation, we began efforts to raise funds for “Phase II” of the Observatory, the expansion from 4 to 8 antennas. National Science Foundation support had been obtained for operating the FCRAO, but additional capital proved difficult to obtain. At just this time a completely new possibility for future growth presented itself.

FCRAO operated at the long wavelength end of the radio spectrum (meter wavelengths), where the emission from pulsars was strong. The other end of the radio spectrum, at frequencies a thousand times higher and consequently wavelengths a thousand times shorter, had tended to be neglected by radio astronomers --- receivers were expensive and didn’t work well, and there were not obvious sources of astronomical interest. That the latter situation might change was first intimated in 1963, when radio emission from an interstellar molecule (OH) was first observed by MIT astrophysicists. Although the OH emission was at a wavelength of 18 centimeters, other more complex molecules were known from laboratory data to emit primarily at shorter wavelengths. Five years later radio emission from interstellar water ($H_2O$) and ammonia ($NH_3$) was detected at about 1 centimeter wavelength by scientists at the University of California, followed in 1970 by the detection of emission from carbon monoxide (CO) molecules at even shorter (millimeter) wavelengths by Bell Laboratories physicists. It appeared that a whole new field of radio astronomy had been opened, the study of the chemistry and physics of the interstellar gas from which new stars form.

Among the first to recognize the opportunities for such research was Olof Rydbeck, Director of Chalmers University of Technology's Onsala Space Observatory in Sweden. The capability to detect weak radio signals depends both on the aperture of the telescope and on the sensitivity of the electronics which processes the signal. The latter is quantified in terms of the receiving system's "noise temperature", which measures the amount of "static" added to the astronomical signal. Rydbeck had realized that his relatively low budget university observatory could compete with the much larger efforts at the US National Radio Astronomy Observatory and elsewhere, provided that his group could build better (lower noise) receivers. He succeeded in this regard by developing extremely low noise, solid-state maser preamplifiers as a critical first stage in the Onsala receivers (in an odd turn of fate, most of the early research with these receivers centered on the observation of *astronomical* masers, regions where interstellar or circumstellar molecules amplify radiation by the maser mechanism; Rydbeck and Hjalmarson, 1985).

Moreover, Rydbeck appreciated that the Onsala radio telescope, designed for work at centimeter wavelengths, could not operate efficiently at the shorter wavelengths where most molecular emission was expected, and he began the procurement of a higher frequency telescope from the Electronic Space Systems Corporation (ESSCO) in West Concord, Massachusetts. Fortuitously, one of Rydbeck's former PhD students, Sigfrid Yngvesson, had joined the University of Massachusetts's Electrical and Computer Engineering Department in 1970, after a postdoctoral position at the University of California at Berkeley. Yngvesson was a pioneer in the development of maser receivers at ever-higher frequencies, using both ruby and a new material, iron-doped rutile (titanium dioxide). His presence and the proximity of ESSCO, then in the midst of fabricating the new radio telescope for Onsala, persuaded Rydbeck to spend a sabbatical year in Amherst during 1972-73.

At some earlier stage ESSCO had offered Rydbeck a smaller telescope that they had designed (14 meter diameter), pending Onsala's purchase of the larger system which eventually was procured (with a 20-meter diameter reflecting surface). ESSCO had also contacted Yngvesson to explore the possibility of providing a research grant to his program, in exchange for access to new receiver technology, which ESSCO President Albert Cohen saw as important for selling future radio telescope systems. In late 1972 Rydbeck proposed to ESSCO that instead they donate the smaller telescope pedestal and servo-system to UMass, in consideration of future business and collaboration. In a meeting with Rydbeck, Huguenin, and others on December 28, 1972, Cohen made the counter proposal that ESSCO provide UMass with a complete telescope system, including a 14-meter (45 foot) diameter dish inside a protective, radio-transparent radome. Cohen estimated that the cost of such a system, with a surface accuracy of 0.15 millimeters and a pointing accuracy sufficient for observations up to 300 GHz (1 mm), might be about $400,000, of which ESSCO might donate $150,000.

This potential opportunity prompted Huguenin and me to abandon the effort to raise funds for expanding the FCRAO meter wavelength facility, and to concentrate on the possibility of acquiring a new radio telescope which would be the largest in the US operating at millimeter wavelengths. A Five College Microwave Facility Planning Committee was quickly formed, including Huguenin, Irvine, Rydbeck, Yngvesson, and UMass School of Engineering Associate Dean Lester van Atta. At its first meeting (Van Atta, 1973) it was pointed out that such a new facility would "provide desirable competition to the nationally supported effort which is tending to concentrate in NRAO" and would "introduce another opportunity for Five-College cooperation in radio astronomy and electronics". Huguenin estimated that, in addition to the $400,000 ESSCO system, another $400,000 would be required for instrumentation and a 2-year commissioning phase. Plans were made for consultations with University officials, the NSF, and ESSCO.

Van Atta, describing Rydbeck and Yngvesson as "prime movers in the early phases of the planning" for the proposed telescope, persuaded the School of Engineering to commit two technician positions as part of a University contribution to an NSF proposal. He stated that there was the potential for related engineering research in areas such as receivers, antenna properties, servo-control systems, atmospheric radio propagation, and earth-to-satellite communications. Fortunately, the Department of Physics and Astronomy had recently moved into a new building, the Lederle Graduate Research Center. The Commonwealth of Massachusetts always appropriated funds for the equipping of new buildings, and some of this money could be used as an additional matching contribution for our NSF proposal. Moreover, Huguenin and I persuaded Provost Robert Gluckstern (the same Gluckstern who had helped rejuvenate the joint astronomy department in 1965-66) to commit two

University professional positions for engineers who would be part of an expanded Observatory staff, despite concerns from Physics and Astronomy Head Roy Cook that such a large commitment might compromise University support for future physics expansion. A proposal for the new telescope was submitted to the NSF in April 1973 and funded later that year. To the best of my recollection, we requested $750,000 over 3 years, with $250,000 for the telescope itself and the remainder for the development of required instrumentation and for commissioning the new facility, with the University pledging substantial matching equipment funds, plus the professional positions indicated above. Yngvesson was also funded by the NSF Astronomy Section to develop maser receivers for millimeter wavelengths (frequencies in the range 80-120 GHz).

Subsequent follow-through with ESSCO had to cut through University red tape. The Procurement Department balked at the sole source purchase, even though ESSCO's contribution to the project and the University's promise of technological collaboration were clearly necessary elements in keeping the cost at an affordable level, as the NSF had recognized by agreeing to fund the proposal. Nonetheless, bids were required and hence sought for building a 45-foot telescope; not surprisingly, there was no serious competition for ESSCO. The Procurement Department insisted on re-bidding, in an effort to find at least one other bidder. The consequent delays were threatening to seriously increase the cost of the telescope, and at this point Gluckstern intervened and insisted that the University proceed in obtaining the telescope from ESSCO.

The sensitivity provided by maser receivers was stressed in the proposal, using what was locally called "the Rydbeck factor". Rydbeck had written an internal memorandum justifying the location of a millimeter-wavelength telescope in New England, in spite of the typically higher opacity at these wavelengths compared with mountaintop facilities in the Southwest. He emphasized that the observing time needed to detect a point radio source was proportional to the square of the receiver system temperature and inversely proportional to the square of the antenna's effective collecting area. Compared to the current receivers employed on the NRAO 36-foot telescope at Kitt Peak, Arizona, he calculated that a new 45-foot Massachusetts telescope with Yngvesson's masers would be 244 times faster; that is, what NRAO could do in 8 months could be done at the new facility in one day! The masers, he argued, were too sophisticated to be developed and maintained except at a research university and so would not be employed at NRAO.

An innovative engineer and astrophysicist, Rydbeck was also a notorious practical joker. According to one story, when one of his associates had taken leave in the United States, Rydbeck quietly moved all the belongings from the family's apartment in Sweden and installed other lodgers. Apparently it was quite a shock when the true owners reappeared, until the no-doubt-smiling Rydbeck arrived and explained. With such stories in mind, Yngvesson's PhD student Apostle (Butch) Cardiasmenos decided to plan a surprise for Rydbeck before he returned to Sweden at the end of the 1972-73 academic year. With the cooperation of graduate students working with several senior physicists and radio astronomers, including Nobel Laureate Charles Townes at UC Berkeley, Cardiasmenos managed to have Rydbeck receive messages with impressive letterheads warning him that these important scientists had received inquiries from the CIA as to whether a certain Swedish radio astronomer might be too cozy with the Soviet Union. The ruse was sufficiently convincing that, at a farewell party at his home, Rydbeck grabbed an innocent neighbor who wandered by, shook him, and asked whether he worked for the CIA! Hopefully, some amends were made when Rydbeck's role in promoting radio astronomy at the University of Massachusetts was recognized with the award of an honorary D.Sc. degree.

Before attempting to build a maser that would function in the 3-millimeter range, Yngvesson and Cardiasmenos adapted a ruby maser design originally developed at Berkeley for use on the NEROC Haystack radio telescope. In a gigantic break with astronomical tradition, Yngvesson, Rydbeck and Cardiasmenos persuaded the Director of the Haystack Observatory to grant them about a month of observing time and essentially free rein with this new receiver, in return for making it generally available to Haystack users. Rydbeck and Cardiasmenos established themselves at the Groton Inn near the Observatory, and, together with Yngvesson and students and colleagues from UMass and Sweden, made the most sensitive observations to that date of interstellar water vapor masers (Yngvesson et al., 1975; Cato et al., 1976).

For several years FCRAO continued to operate the original 4-element meter-wavelength telescope while bringing the new millimeter telescope into use. The most important FCRAO discovery during this period was in fact made at the Arecibo Observatory in Puerto Rico by Taylor and graduate student Russell Hulse. Using electronics developed at FCRAO, they were conducting a survey for new pulsars as part of Hulse's PhD thesis. Hulse noticed a curious periodic variation in the arrival time of the pulses from one of the newly detected pulsars, and he and Taylor deduced that it must be revolving around another object. This was completely unexpected, since it was thought that the supernova explosion that produced a pulsar would disrupt any binary star system containing the precursor star. More importantly, they quickly realized that the new pulsar must be orbiting another collapsed object, and that this binary system provided a wonderful laboratory for testing gravitational theory (Hulse and Taylor, 1975). Ultimately, this research would provide evidence for a major prediction of general relativity, the existence of gravitational waves, resulting in a Nobel Prize in Physics for Hulse and Taylor in 1993. Hulse's PhD thesis (Hulse, 1975) is thus one of very few anywhere that can be said to be worth a Nobel Prize! In 1981 Taylor became the first resident University of Massachusetts faculty member elected to the National Academy of Sciences. Unfortunately, it became too difficult at that time to continue to operate both the new telescope and the pulsar array. The latter was decommissioned and Taylor resigned that year to accept a position at Princeton University. The University awarded Hulse and Taylor honorary D.Sc. degrees in 1994.

The Five College Astronomy faculty grew during this time, reaching, for example, a total of 17 (in 16 full time positions) for the 1974-75 academic year. Hampshire and Smith Colleges expanded to two full time astronomers each, following the appointment of Richard White at Smith and former astronaut Brian O'Leary at Hampshire. George Greenstein at Amherst, Tom Dennis at Mount Holyoke, and ten astronomers at the University made up the remainder of the Department. The number of postdoctoral research associates was also growing; in 1975-76 there were 3 working in radio astronomy and one working on light scattering problems with me.

Smith College remained a bulwark of the Five College Astronomy Department, being the only one of the four private colleges to consistently maintain two full-time astronomers. In contrast, O'Leary resigned from Hampshire after a year, frustrated by the difficulty of carrying out an active research program in the College environment. Following the departure of Courtney and Kurt Gordon in 1984, no astronomer at all was resident at Hampshire College. This was technically a violation of the Presidents' agreement establishing the Department, but Hampshire continued to make an extra annual contribution to the Department budget.

One of the critical new faculty members at the University was Nick Scoville, hired in 1974. Nick played a major role in bringing the new 14-meter telescope on line, by writing much of the data reduction software and becoming one of its most active users. In later years he became FCRAO Co-Director, before leaving for the California Institute of Technology as Director of the Owens Valley Radio Observatory. The new FCRAO telescope was dedicated in 1976 at a ceremony at the Quabbin site (Davis, 1976; Arny and Valeriani, 1977), highlighted by a speech in which local Congressman Silvio Conte speculated that scientific research at the Observatory would contribute to curing cancer!

The collaboration with Electrical and Computer Engineering (ECE) had become even closer with the appointment in 1975 of Assistant Professor Peter Wannier in a joint faculty position shared between ECE and Physics and Astronomy (whether this implied that half of him was also in the Five College Astronomy Department was probably never clarified!). When Wannier left after one year, the joint position was offered to Paul Goldsmith, who joined the University in 1977. Paul, like Nick, was crucial in making the 14-meter telescope productive. Paul had his PhD from perhaps the world's foremost center for the training of "hands-on" radio astrophysicists, the University of California at Berkeley, and he had then joined the Bell laboratories in New Jersey. He was interested in designing and building more sensitive equipment for radio astronomy and, importantly, using such new instruments to solve astrophysical problems. He continued to be central to all aspects at FCRAO until he left to become Director of the Arecibo Observatory in 1992.

The collaboration between Astronomy and Electrical and Computer Engineering fell apart some time around 1980. Goldsmith found it too difficult to have commitments in two departments and switched completely to Astronomy. Yngvesson had not succeeded in building a stable maser receiver to work at 3 mm wavelength, and his NSF support for that research expired. Nonetheless, the then Dean of Engineering wanted a large portion of the overhead funds earned by the NSF grant that supported FCRAO. Huguenin was incensed and essentially broke off relations with Engineering.

## VIII. Concerned Principal Investigators

As he attempted to expand the University of Massachusetts' first large and complex research program, Huguenin found himself consistently frustrated by the University's cumbersome, inefficient bureaucracy. The "service" side of the administration seemed more intent on preserving procedures appropriate to past decades than in providing assistance to research-minded faculty. I decided that grass roots pressure might be effective and proceeded in late 1975 and early 1976 to organize a group that called itself the Concerned Principal Investigators. This "League" included active scholars from the departments of Physics and Astronomy, Computer and Information Science, Psychology, Chemistry, Biochemistry, Anthropology, Polymer Science and Engineering, Forestry and Wildlife, Geology, Sociology, Zoology, Mathematics and Statistics, Electrical and Computer Engineering, Mechanical Engineering, and Civil Engineering. A basic complaint was that the University administration had regulations of all sorts that directly affected research on campus, but which had been adopted with no consultation with grant Principal Investigators and no consideration of the possible effect on grant research. Examples ranged from parking regulations (a matter of obvious concern to FCRAO, which used several vehicles to transport both people and equipment to the Quabbin site) to the salary of postdoctoral research associates, which had been recently set to a standard value for departments as diverse as Polymer Science and Sociology. Complaints were usually met with the response that the edict in question had been mandated by Boston, which more often than not turned out to be untrue. As an example, there was a requirement that all purchases involving more than $100 had to go out for external bids, a procedure obviously incompatible with the rapid response required by scientists trying to quickly modify an experiment or repair a broken instrument. Investigation revealed that this limit was not mandated by the state, and was in fact considerably less than the corresponding limits at the University's Boston and Worcester campuses. Another complaint, which in fact remains a sore point in the twenty-first century, was the perceived failure of the Controller's Office to provide accurate and timely accounting records. Most large grant holders felt it necessary to duplicate the University's bookkeeping, which was doubly aggravating since such personnel had to be hired on grant funds on which overhead was paid. Worse than the errors made by accounting, was "the unconscionable time it takes to correct mistakes ..." (Irvine, 1976). Processing of personnel forms was another area of concern, since even routine matters often required a month to complete; the delayed paychecks usually hurt most deeply the lower salaried clerical and technical staff, rather than the professional staff. Also, the difficulty in getting Physical Plant to provide services to the research community led Huguenin (and, no doubt, other investigators) to have some plumbing and renovation work for the campus laboratories carried out by radio astronomy staff, a clearly illegal procedure that was driven by continuing frustration. These "end runs" stopped, or at least became much more surreptitious, after I was visited by a couple of very burly plumbers from the local union!

The Principal Investigators' complaints did get a hearing. The Chancellor, Randolph Bromery, was a geologist who could understand the problems that had been raised. Regular meetings were arranged with the heads of major campus administrative units, and some changes were made. In 1977 the University raised the limit at which bidding was required on purchases from $100 to $250 and relaxed the criteria for exemptions from bidding due to emergencies (such as failure of a key telescope component) or sole-source availability. Over the years, in fact, procurement went from being a major roadblock to becoming perhaps the most responsive service unit interacting with researchers. Probably due to the leadership of Director of Procurement Jake Bishop, innovative purchasing options were developed, including University credit cards for specific research accounts, a greatly expanded Massachusetts Higher Education

Consortium list of approved vendors from whom purchases could be made without bidding, and a simplified procedure for obtaining quotes when required.

However, serious problems remained. In a letter to incoming University President David Knapp, Irvine (1978) cited the long lead time in renovations to research laboratories, the lack of an effective development office to raise funds, travel reimbursement levels that were "niggardly compared with federal guidelines" (returning to this question a few years later, I noted that *per diem* rates were lower than those provided to minor league baseball players, suggesting that the University policy was truly "bush league"), continuing problems with accounting, the lack of such university research services as drafting, typing, and even furniture, and a recent jump in the University's overhead rate charged on federal grants to 76%, "a figure artificially inflated by the current policy of lumping this campus with the Medical School". Long delays in personnel appointments and reappointments led me to complain to President Knapp that there existed "either a cynical disregard for the welfare of their professional employees and/or a degree of incompetence which would be intolerable in anything but a state-funded institution" (in fairness to the individuals in the Personnel Office, it must be pointed out that they were following procedures which, in the case of new appointments on grants, required a series of steps that needed 3 1/2 typed pages to describe, while the instructions for reappointments covered a page and a half; Camerino, 1976). The Concerned Principal Investigators recommended the creation of a senior administrative position for the campus with responsibility for promoting research and scholarship. Although it took a few more years, in 1984 the University created the position of Vice-Chancellor for Research and merged it with the existing position of Dean of the Graduate School. Although this presumably provided a voice for research at upper administrative levels, the Vice-Chancellor had no control over most of the issues of immediate concern to researchers, such as personnel and accounting. I continued to raise complaints about "Research Services" even years later, as indicated in a memo to Provost Richard O'Brien deploring problems with accounting (Irvine, 1989). In 2003, I am told, problems continue to exist in spite of the best efforts of both Accounting and individual departments, due to both administrative understaffing and to the University's adoption of the "PeopleSoft" software for essentially all administrative purposes --- generally considered an inexcusable and expensive disaster by faculty and students.

Partly in frustration at the University's bureaucracy and partly in anticipation of a new challenge, in 1982 Huguenin transferred much of his attention to founding a company to develop "spin off" technology from the Observatory. Millitech, Inc., sold millimeter-wavelength devices to scientists and engineers around the world. Huguenin formally resigned from the University the following year, although he subsequently served on the University's Board of Trustees.

### *VIIIa. Another Personal Digression*

*I had planned to spend my sabbatical year of 1973-74 in the Soviet Union, working with a famous Russian astrophysicist on light scattering problems. However, a week or so before my scheduled departure the Russians refused to issue me a visa (perhaps because I planned to place three potentially outspoken children in Soviet schools?). This provided me with a stimulus to reconsider my research directions, given the new FCRAO telescope then being planned. Since I had had no direct experience in radio astronomy, I appealed to Olof Rydbeck to allow me to spend the year at his Onsala Space Observatory. He graciously housed my family in "The Apartment" at Onsala, on a hill with a beautiful view of the sea that separates Sweden from Denmark. The three boys thus went to a Swedish rather than a Russian school, and Rydbeck plunged me into the search for radio emission from the CH molecule in space.*

*The detection of new interstellar molecules was a very competitive area at that time, promising fame for both the successful astronomers and their observatory. Rydbeck was particularly energized by the competition with much better funded American facilities. A major difficulty in the search for CH was the lack of a measured laboratory spectrum, so that the frequency of emission was known only very roughly from theoretical calculations (interstellar CH had been observed at visible wavelengths in the spectra of distant stars, but a radio detection would probe different regions of space). However, the rough theoretical predictions were good enough to allow Rydbeck's group to build a maser specifically designed for the CH search. The team, including at times my 13-year-old son Doug, spent many hours peering at chart recordings of the spectra from particular astronomical sources, looking for patterns that might reveal the desired signal. Shortly after we had found such a pattern, the rumor arrived that American astronomers were also searching! A paper claiming the first detection was hurriedly prepared for the British journal* Nature*, and, when we found confirmatory evidence shortly thereafter, I personally flew to London with a "note added in proof" (Rydbeck et al., 1973). This adventure was certainly an exciting way to enter a new field of research, and I have continued to study interstellar chemistry ever since.*

*I stepped down as Chairman of the Five College Astronomy Department after the 1977-78 academic year and resigned as Chair of the University's Astronomy Program the following year, prior to taking leave to serve as Acting Scientific Director at the Onsala Space Observatory upon Olof Rydbeck's* *retirement. The latter position was extremely enjoyable, as I again lived at the Observatory in "The Apartment" and the new 20-meter telescope was poised to begin the first comprehensive surveys of the millimeter-wavelength spectra of the closest region where massive stars were forming (the Orion molecular cloud) and the expelled envelope around the evolved star IRC+10216. The "Onsala Spectral Scan", thanks in large part to the theoretical interpretation led by Åke Hjalmarson, provided a detailed view of the chemical composition of these two important but very different regions (Ellder et al., 1980; Johansson et al., 1984, 1985; Irvine, Schloerb, et al., 1985).*

*Since many interstellar molecules are key reactants in laboratory experiments on prebiotic chemistry (e.g., $H_2O$, $NH_3$, and such organics as $H_2CO$ and HCN) and since the majority of identified interstellar molecular species are organic, Nick Scoville suggested that I apply for research funding to NASA's Exobiology Program (Nick was then on a NASA advisory panel). NASA defined Exobiology and subsequently Astrobiology to include the evolution in space of material which might play a role in the origin of life, so that organic chemistry in interstellar space and in the solar system was definitely relevant. As a result, I have been funded as an "astrobiologist" by NASA since 1982 and have been a member of the International Society for the Study of the Origins of Life since 1980.*

*At about this time British astrophysicist Fred Hoyle and his colleague N. C. Wickramasinghe were propounding the theory that both interstellar dust grains and cometary material included bacterial spores and/or viruses, and that influenza was spread by cometary dust settling through the Earth's atmosphere (Hoyle and Wickramasinghe, 1979). This coincided with my developing relationship with my future wife, UMass microbiologist Sue Leschine. Partly for fun and partly because we thought that we could easily show that comets were never warm enough for biologically relevant chemical reactions to occur, we joined with Pete Schloerb in a study of the thermal history of comets. Although it turned out to be difficult to exclude the possibility that radiogenic heating might produce liquid water in some cometary nuclei, we did introduce a new physical unit which has unfortunately not been generally taken up by the scientific community --- "the sneeze", used to quantify the annual flux of viroid-sized nucleic acids incident on the Earth from space (Irvine, Leschine, and Schloerb, 1980, 1981)!*

*Some of the greatest thrills in science come from knowing that you have just discovered something entirely new, and I have found the detection of new interstellar molecules particularly exciting. One such personal peak came in 1984, when Canadian astronomer Henry Matthews and I planned an observing* *run at the National Radio Astronomy Observatory's 140-foot telescope in Green Bank, West Virginia. We noticed that laboratory spectra for the curious molecule tricarbon monoxide, $C_3O$, had just been published by Australian chemists Ron Brown and Peter Godfrey. But the frequency of one of the $C_3O$ transitions was just in the band that Matthews and I had been given permission to observe for entirely different reasons! Naturally, we monitored the expected $C_3O$ frequency carefully, and, after an hour or so, a clear feature emerged from the noise. I telephoned Brown somewhat apologetically, since I knew that he and Godfrey had announced plans to search for interstellar $C_3O$ themselves, and we all agreed to publish together (Matthews, Irvine, et al., 1984). Confirmation of the identification came from observations of higher frequency transitions at FCRAO, the NRAO 12-meter telescope at Kitt Peak, and in Japan at the Nobeyama Radio Observatory (Brown et al., 1985; Figure VIII-4). The latter observing run began my fruitful collaboration over many years with Masatoshi Ohishi, which included a very pleasant sabbatical in Nobeyama in 1990.*

*Subsequent to the $C_3O$ experience, I participated in the detection of some 12 more new interstellar molecules. Among the most interesting were the small ring $C_3H_2$, which turned out to be nearly ubiquitous in the dense interstellar medium (Matthews and Irvine, 1985); $CH_2CN$, which yielded a real forest of previously unknown lines (Irvine, Friberg, et al., 1988); propynal, HCCCHO, which we sought and detected in the cold interstellar cloud TMC-1 (Irvine, Brown, et al., 1988); and another cyclic molecule, oxirane ($C_2H_4O$), the search for which was stimulated by suggestions that its more complex relative oxiranecarbonitrile might play an important role in prebiotic chemistry (Dickens et al., 1997).*

*Shortly after my second stay at Onsala, I found myself involved in a very different kind of major project, the International Halley Watch (IHW). On my way back to the United States from Sweden, I gave a talk at the Meudon Observatory on the outskirts of Paris, France. While I was there, planetary scientist Eric Gérard, knowing my long-time interest in the solar system, suggested that I try to organize American radio astronomers to participate in the NASA-sponsored IHW. This was a major program to maximize the scientific return from observations of Comet Halley during its 1986 apparition. The goal was to stimulate, coordinate, collect, and archive various types of observations of the comet (Newburn, 1983; Sekanina and Fry, 1991). We successfully formed a team of Radio Science Discipline Specialists which included Eric Gerard, myself, Ron Brown and Peter Godfrey from Monash University in Australia, and Peter Schloerb at UMass (who did most of the nitty-gritty work). Our benefits included many years of funding from NASA and meetings at various interesting locations in Europe and the US --- I recall for example, drinking rauchbier and* *wandering around the lovely old city of Bamberg, Germany (see also Figure VIII-2. As to radio astronomy, we did obtain some of the first convincing measurements of a molecular component of comets, HCN (e.g., Schloerb et al., 1986; Crovisier and Schloerb, 1991).*

*A few years later the appearance of two "new" comets, Hale-Bopp and Hyakutake, coupled with advances in receiver sensitivity, enabled us to discover 2 new cometary molecules, HNC and NS (Irvine, Bockelee-Morvan, et al., 1996; Irvine, Senay, et al., 2000). The former seemed to Schloerb and me to be a perfect probe of the idea that interstellar molecular ices were incorporated into comets when the solar system was forming, an hypothesis relevant to the nature of organic material falling on the early Earth. HNC is abundant in cold interstellar clouds and had been considered to be the prime example of a species which requires such conditions for its formation. Our delight in detecting HNC in Comet Hyakutake was subsequently tempered by our demonstration that its abundance in Comet Hale-Bopp was inversely dependent on the Comet's distance from the Sun, which required that HNC be produced by some process deriving from the solar flux on the comet, rather than being an intrinsic component of the cometary ices (Irvine, Dickens, et al., 1998). The origins of cometary HNC and, for that matter, NS are still actively debated.*

## IX. Continuing Growth

My successor as Five College Astronomy Chair was Tom Arny, who served from 1978-81. During the 1978-79 year FCAD reported 48 scientific publications (Five College Astronomy Department, 1980). These included theoretical studies by Greenstein on thermal instabilities in neutron stars, predictions concerning molecular spectral lines in planetary atmospheres by Dick White at Smith College, a joint paper by Kurt and Courtney Gordon on hydrogen line emission from galaxies, a theoretical model of cometary nebulae by Arny, continuing observations of variable extragalactic radio sources by Dent and his student Tom Balonek, multiple studies of pulsars by Joe Taylor, Dick Manchester and their students, a series of papers on interstellar molecular clouds by Scoville and collaborators, research on both cosmology and the interstellar medium by Ted Harrison, my studies of Saturn's rings and comets, and three theoretical papers on stellar atmospheres by David van Blerkom. Richard Huguenin's brother Robert, a planetary scientist, had also joined the Department at this time, paying most of his salary through his own research grants; his laboratory work was aimed at understanding the nature of the Martian soil. Since Richard's new wife was named Ellen Moore, the family claimed to be publishing a joint paper authored by Huguenin, Huguenin, and Moore-Huguenin --- but I have been unable to find an actual reference!

The 8 postdoctoral research associates for 1978-79 included some who went on to lengthy careers in radio astronomy: Jim Cordes, now Professor of Astronomy at Cornell; John Dickey, Professor at the University of Minnesota; Paul Ho, Director of the Academia Sinica Institute of Astronomy and Astrophysics in Taiwan; Joel Weisberg, Professor at Carlton College; and Peter Schloerb, Professor at the University of Massachusetts and Director of the Five College Radio Astronomy Observatory since 1995. Joining the University faculty in 1979 was William Langer, subsequently a senior scientist at NASA's Jet Propulsion Laboratory, while the following year Suzan Edwards joined Dick White as an astronomer at Smith College. Suzan became over time the effective leader among the non-University members of the Five College Astronomy Department, and the most active of the college astronomers in research and in the graduate program. There were 46 astronomy majors in the Five College Department in 1978-79, including 9 graduating seniors. Twenty-four graduate students were enrolled, with one PhD awarded. A total of 2192 students took elementary astronomy courses, the great majority of whom were at the University.

Tom Arny was succeeded as Five College Astronomy Chair by George Greenstein, who served from 1981 to 1984. David van Blerkom took over as Astronomy Program Chair at the University in the fall of 1979 and continued in that position for 18 years. The separation of these two offices led to some confusion and controversy in succeeding years. Within the University's Department of Physics and Astronomy, the physicists tended to consider astronomy to be but one among several research groups in the department, such as high energy or condensed matter physics, and they looked to the Astronomy Program Chair to speak for the astronomers. They viewed the Five College Astronomy Department as solely concerned with undergraduate teaching. The astronomers, in contrast, considered themselves to be at least a "sub-department" at the University, led by the Five College Department Chair, whom the Presidents long before had given authority for both undergraduate and graduate astronomy. The FCAD Chair's position was awkward, however, since it had no University budget or hiring authority (although the joint Five College Astronomy budget gradually increased over the years and provided a source of valuable flexibility). Nonetheless, after often lengthy and vocal discussions, the University astronomers usually succeeded in persuading Physics and Astronomy faculty meetings to adopt their point of view. Much of this success was due to van Blerkom, who was highly respected by both sides for his integrity and devotion to the welfare of the entire Department.

The resignation of Huguenin and Scoville's departure for Caltech left a serious gap in senior leadership, which led to the appointment of Stephen Strom in 1983 and Susan Kleinman in 1984. Steve and his wife Karen, hired as a Research Associate and later as a Senior Research Fellow, were world leaders in the study of star formation and made extensive use of the optical telescopes at the National Optical Astronomy Observatory at Kitt Peak, Arizona, and other facilities. Together with Suzan Edwards, they formed the nucleus of a star-formation group which would be very successful in research and training students over the next decade. Susan Kleinman was hired in the expectation that she would develop a program of observational infrared astronomy, an effort which culminated in the 2MASS project described below.

The fall of 1984 also saw the appointment as assistant professors at the University of Judith Young and Ronald Snell, both of whom had previously been postdoctoral research associates with the Five College Radio Astronomy Observatory. Young, originally a cosmic ray physicist, went on to lead one of the Observatory's major research projects over the next decade, the FCRAO Extragalactic Survey. This study of the gas content of external galaxies was still in 2003 the most comprehensive such database, providing the background for analyses of the efficiency with which stars form from interstellar gas under various conditions. Snell's research on topics such as astrochemistry and the effect of star formation on the surrounding interstellar gas formed a significant part of the FCRAO observational program.

Although the initial appointments in Astronomy at UMass had all been to theoreticians, the subsequent emphasis in the Department had been in observational areas. To provide more balance, theorist John Kwan was hired in 1980 to complement the observational research in radio astronomy. By 1989, however, the Department felt the need for additional strength in astrophysical theory, and Kwan chaired a search committee that hired Martin Weinberg, an expert in dynamical astronomy. Weinberg's interest in the structure of our Milky Way galaxy led him to participate in the 2MASS project, described in Section XI below, since that structure could be partly delineated through observations of the infrared emission from certain classes of stars.

When Greenstein decided to step down as Chair of the Five College Astronomy Department, Strom was elected to succeed him. Despite the weakened position of the Chair within the University's Department of Physics and Astronomy, he managed to set the direction for astronomy, both in terms of new faculty appointments and innovative inter-institutional collaborations. Strom gained leverage by persuading the Five Colleges to increase the budget for joint astronomy activities, and then using part of this budget to improve Five College computational facilities and to establish cooperative programs with, first, the University of Wyoming, and, later, with the Universidad Nacional Autónoma de México (UNAM). The collaborations were efforts to assure access for Five College astronomers to modern facilities for optical and infrared observations. The Wyoming Infrared Observatory proved frustrating to use, however, as observing conditions were often not suitable for the programs proposed by UMass astronomers. That situation led to the second agreement, to use UNAM's observatory at San Pedro Martir in Baja California. Although this again did not produce much in the way of astronomical data for FCAD astronomers and their students, it did open the door to the subsequent collaboration to build the Large Millimeter Telescope (Section X below).

Greenstein's replacement by Strom as FCAD Chair provided a stimulus for some reconsideration of the procedures of the Five College Department. By this time Departmental membership was dominated by the University, so that the traditional policy of taking decisions by majority vote of the astronomy faculty meant in principle that the University could dictate policy to the astronomers at the other colleges. Tom Dennis at Mount Holyoke was particularly vocal in objecting to this possibility. Dick White at Smith agreed to draft a "White paper" that would propose changes in the decision making procedures that would be equitable to all partners. Chief among these was the establishment of an Undergraduate Program Committee (subsequently known as the "Senate"), which would have 2 members from the University and 1 from each of the private colleges. It would oversee the undergraduate teaching program (with its recommendations to be approved by majority vote of the Department), and it would approve the joint astronomy budget prepared by the FCAD Chair. The Senate Chair, elected by majority vote of that body, would be designated as Associate FCAD Chair for Undergraduate Studies. Although Dick White circulated a draft of this proposal in November 1984, the Department only gave official approval in February 1986 (White, 1986). The final document reiterated the decision by the four Presidents in 1964 that the FCAD Chair should have final responsibility for both the undergraduate and the graduate astronomy programs (this to make clear to the physicists in the University's Department of Physics and Astronomy that the FCAD Chair, rather than the University Astronomy Program Chair, was the real leader of astronomy).

The governance document was modified again in 1990. For convenience and to avoid confusion, the FCAD Chair was renamed the Head and the Undergraduate Program Committee became officially the Senate. More importantly, the Senate Chair acquired greater responsibility for preparing and administering the joint FCAD budget. At some time during this period the old practice of sharing among the five institutions that portion of faculty salaries related to teaching

Five College courses was dropped, so that each college/university simply paid the salaries of their own faculty members. The non-faculty FCAD budget, including a secretary, technician, and teaching assistant, amounted to $92,850 in 1990 ($72,400 in salaries). This total had grown to about $130,000 in 1996-97, including $27,000 for Department computational facilities (the "Five College Astronomy Image Analysis Laboratory"), with the University (primarily) and Smith College providing an additional $35,000 for upgrading Smith's telescope in Whately, MA, and for access to the optical and infrared facilities at the Wyoming and, subsequently, the San Pedro Martir Observatories.

Strom buttressed the independence of the Five College Astronomy Department by making more extensive use than his predecessors of Five Colleges, Inc., as a vehicle for applying for federal grants. This procedure had both administrative and fiscal advantages relative to submissions through the University: the cumbersome University bureaucracy was bypassed, and the overhead rate charged for administering such grants was only about one-half that charged by UMass. This UMass "tax" added something like 50% to the cost of a grant, reducing correspondingly the funds available to the faculty Principle Investigator. In theory this charge paid for services supplied by the institution, but University PI's had felt for years that such services were often illusory. In addition, Strom was frequently able to have the overhead charged by Five Colleges, Inc., set aside for use by FCAD, thus providing a flexible and hence extremely valuable source of additional funding for astronomy.

The grants involved were not negligible: in 1992, for example, 10 FCAD grants were being administered through Five Colleges with a combined, multi-year value of some $380,000. The University's Office of Grant and Contract Administration felt naturally aggrieved that University faculty were evading their oversight (and overhead!), but information about the grants was regularly supplied to the UMass Dean of Natural Sciences and Mathematics, who apparently agreed with Strom that the procedures were appropriate for a Five College Department. It should be added that grant funding through Five Colleges was always a small fraction of that flowing through regular UMass channels, and that a significant part of the grants through Five Colleges related to educational, as opposed to research, projects; e.g., the development of innovative undergraduate astronomy curricula. For comparison, at the University federal grant support for Astronomy for fiscal year 1989 had reached almost $2 million annually, from 24 separate grants to a total of ten faculty Principal Investigators, while in 1996 the corresponding totals were $7.9 million, from 23 grants spread over 10 faculty members (OGCA, 2003).

Further textual modification to the governance document was required after the University astronomers separated from Physics to form a Department of Astronomy at UMass (informally in 1999 and officially in 2000), since at that point the position of Astronomy Graduate Program Chair no longer existed.

## X. The Large Millimeter Telescope

Following Huguenin's resignation, Scoville and Goldsmith served as Co-Directors of FCRAO for a couple of years, while I chaired a search committee to find a new Director. The failure of the University's Department of Physics and Astronomy to agree on a suitable candidate led the Dean of the College of Natural Sciences and Mathematics, Fred Byron, to ask me to serve as the new Director. Somewhat embarrassed, as the chair of the unsuccessful search committee, I nonetheless saw no alternative and accepted. As an aside, this procedure illustrated some of the ambiguities concerning the Observatory. Formally, FCRAO did not exist as an official University or Five College organizational unit -- - there was a major NSF grant to operate the 14-meter telescope, with a Principal Investigator (PI) who acted as Observatory Director; there were several other federal grants that supported research and instrument development, some with the Director as PI, some with other faculty members or research staff in that capacity; there was a telescope and associated building on land owned by the Commonwealth of Massachusetts. Richard Huguenin had been given the title of first FCRAO Director by the Five Colleges. But there was no clear definition of who was actually a member of the FCRAO, who owned the facility at the site, and to whom the FCRAO Director reported. In fact, such ambiguities were at times helpful, since the Director could ask the University's Physical Plant for assistance at the site (e.g., to remove asbestos from insulation) while "playing the Five College card" when that seemed advantageous. Both Huguenin and I used our title to go directly to the Dean on personnel and other matters, thus bypassing the Head of Physics and Astronomy. However, the loose organization and multiple funding sources meant that the Director had to often operate by persuasion and consensus; this, of course, was particularly true for any activity involving faculty members (the difficulty of "herding cats" comes to mind). No unified Observatory budget was regularly presented to University administrators, although one prepared for an NSF review gave the fiscal year 1988 budget as $2,003,621, with $1 million from the NSF Astronomy Division, $680,00 from the University (mostly in salaries and benefits), $187,000 from NASA, and the remainder in other federal and in private funds (including regular gifts from ESSCO).

An international conference of some 200 radio astronomers was held in November 1987 to celebrate the (approximately) tenth anniversary of the 14-

m telescope (Dickman, Snell and Young, 1988). This event followed shortly after the installation of a new radome around the telescope, designed to provide better transmission for the shortest wavelengths observed (the one millimeter band). To my knowledge, this remains the only Gore-Tex radome protecting a radio telescope.

Even before the conference was held, however, it was becoming clear that the 14-m telescope was no longer as competitive within international astronomy as at the time of its construction. In an environment in which much larger funding naturally went to national observatories, university facilities had to develop their own niche. Part of the justification for FCRAO continued to be the training of students and the development of state-of-the-art instrumentation. However, the limited aperture of the 14-m compared to new telescopes in Japan and Europe, and the development of competitive coupled arrays of telescopes in California, did pose a threat to the continuation of NSF funding for FCRAO.

Traditionally, radio telescopes analyzed data from only one position on the sky at a time, even though the information from surrounding points was imaged in the focal plane. This was a consequence of the complexity of the necessary receiving equipment --- whereas in optical astronomy photographic film could simultaneously record information from many points in the field of view to form an image, an analogous radio "camera" would need many receivers, each recording the data for one "pixel". But the radio photons were in principle available, and Goldsmith, Schloerb, and Research Professor Neal Erickson decided that the future of FCRAO depended on designing and building the first "cameras" (known as focal plane arrays) for high frequency radio astronomy. The result was hugely successful. The first such instrument, known as QUARRY (for Quabbin Array) had 16 receivers and vastly increased the speed at which the sky could be mapped (Erickson et al., 1992). Among the achievements were computer-constructed panoramic images of interstellar material in the Milky Way and external galaxies, each point of which had an associated radio spectrum. A second-generation version, known as SEQUOIA (SEcond QUabbin Optical Imaging Array), was later produced with twice the number of pixels (Erickson et al., 1999); it is scheduled to be an initial instrument on the LMT (see below).

Even as work on the focal plane arrays was underway, however, the FCRAO radio astronomers dreamed about a larger telescope. The 14-m had been built as a low budget, university endeavor --- could something similar be done to build a much larger instrument? To be internationally competitive, a new telescope for millimeter-wavelength astronomy would have to be significantly larger than the German-French-Spanish 30-meter telescope in Spain, and at least comparable to the Japanese 45-meter telescope, whose surface was inferior to that of the 30-meter. Fortuitously, the National Radio Astronomy Observatory's largest radio telescope in West Virginia collapsed completely in 1988, and that state's influential Senator, Robert Byrd, planned to fund a replacement whether NRAO wanted one or not (in fact, NRAO had hoped to close down its operations in West Virginia in order to concentrate on other projects). This stimulated Peter Schloerb and me to wonder whether ESSCO, the builders of the 14-m telescope, might be interested in building a new, large, inexpensive millimeter telescope in close cooperation with the University; conceivably Western Massachusetts' powerful Congressman, Silvio Conte, could negotiate a congressional addition to Senator Byrd's bill and fund a new facility for Massachusetts. Schloerb, Goldsmith and Observatory Manager Robert Dickman discussed such a plan with ESSCO President Al Cohen on December 19, 1988, and Cohen was definitely interested. He estimated "off the top of his head" that such a telescope might be built for about $15 million, provided that the University collaborated in a substantial way (e.g., building aspects of the servo-system, taking responsibility for the foundation of the radome, etc., much as was done for the previous telescope; Irvine, 1988). Cohen proposed a technical study at a cost of about $30,000.

The study was completed in November 1989, funded jointly by the University's Vice-Chancellor for Research and the Dean of the College of Natural Sciences and Mathematics. For a 50-meter diameter, radome-protected telescope ESSCO's cost estimate was $27.7 million. The following year the US National Science Foundation conducted one in a series of decadal reviews of American astronomy, with the goal of establishing funding priorities for major federally supported astronomy projects for the next ten years. Goldsmith made presentations concerning what we now called the Large Millimeter Telescope (LMT) to the Radio Astronomy subcommittee of the decadal review in the spring of 1990. The following year this radio astronomy panel ranked the LMT as its highest priority among "medium-cost" projects. This endorsement was omitted from the final report of the full decadal review committee, but it nonetheless provided a valuable external evaluation of the project.

In the meantime the UMass-Mexico collaboration took a new and crucial turn. The Mexican government made the decision to significantly strengthen the scientific and technical infrastructure of that country, and successfully applied for a large loan from the World Bank. Strom proposed to his longtime colleagues Alfonso Serrano, Director of the Institute of Astronomy at the Universidad Nacional Autónoma de México (UNAM, the most prestigious university in Mexico), and Luis Carrasco, Director of the Observatory at San Pedro Martir, that Mexico might collaborate with UMass on either the LMT or on a new optical-infrared telescope. The Mexicans choose the LMT, in part because of the technology transfer and stimulus to technical training that they felt would follow from a successful proposal. FCRAO staff built a radiometer to test the adequacy of the San Pedro site for millimeter-wavelength observations, and University radio astronomers assembled a scientific and technical justification for a proposal to the Mexican analog of the NSF, the Consejo Nacional de Ciencia y Tecnología (CONACyT), for half the LMT funding. The American NSF's International Division funded a US-Mexico planning meeting on the project in 1991.

Internal astronomical politics in Mexico complicated the subsequent history --- Serrano was not re-elected as Director of the Institute of Astronomy, but was then made head of a new UNAM division concerned with space science (the Programa Universitario de Investigacion y Desarrollo Espacial, or PUIDE). To broaden support, Serrano brought another Mexican institute into the project, the Centro de Investigación y de Educación Superior de Ensenada (CICESE), a geophysical institute with a large applied physics section that was interested in developing new electronics. After a few years in which PUIDE at UNAM was the lead Mexican institution for LMT, Serrano was named General Director of an entirely different organization, the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), which had grown out of the Observatorio Astrofísico Nacional de Tonantzintla, founded by Luis Enrique Erro in 1942. Erro's successor as Director, Guillermo Haro, converted the Observatorio into INAOE, which is located in Tonantzintla on the outskirts of the lovely colonial city of Puebla. Unfortunately, INAOE and the Institute of Astronomy at UNAM were rivals, with the latter pursuing its own priority for a new Mexican astronomical facility centered on a large optical telescope. As a result, the largest group of astronomers in Mexico, including the only internationally known radio astronomer, took no part in the LMT project.

Nonetheless, the LMT proposal from INAOE to CONACyT was submitted in 1992 and, after international review, was awarded $14,680,000 (46,242,000 pesos) in early 1993. Meanwhile, Strom and I were scrambling for the American counterpart funds. Together with Al Cohen, now Chairman of the Board at ESSCO, his Vice-President Gene Rhoades, and UMass Associate Chancellor Jim Leheny, we made presentations to the Commonwealth of Massachusetts' Secretary of Economic Affairs, to the Undersecretary for International Trade, and to the Governor's Chief of Staff, Stephen P. Tocco (subsequently Chairman of the Massachusetts Board of Higher Education, who referred to our "astrology" department). These presentations ultimately led Massachusetts Governor William Weld to promise Ernesto Zedillo, then Secretary of Education and subsequently President of Mexico, that he would seek legislation authorizing

$5 million for the project in the expectation that it would lead to "the development of new technologies to yield commercial applications which will fuel our economy and employ our citizens" (Weld, 1993). These funds proved particularly valuable to the project, since there was no overhead on personnel hired in this way, who also had their benefits paid from the state treasury, in sharp contrast to the overhead and benefits charged by the University on personnel paid from federal grants (roughly doubling the personnel costs).

In 1992 Michael Hooker, a UMass philosophy PhD and then Chancellor of the University of Maryland's Baltimore County campus, became President of the University of Massachusetts. Before he arrived in Boston, Strom and I met with him in Washington to promote the LMT. Hooker was immediately supportive, writing to CONACyT to express the University's commitment to the LMT and promising to raise the issue with the Governor's staff. Jim Leheny and I made multiple trips to Washington to meet with officials at the NSF, the President's Office of Science and Technology, the Commonwealth of Massachusetts Office of Federal-State relations (the state's lobbyists), the Mexican Embassy, the World Bank, and Congressional staff members for a considerable range of Representatives and Senators. At the time we estimated that the capital costs would be $37 million for the telescope, radome, site preparation, and initial instrumentation. A proposal for the US federal part of the LMT funding was prepared for the NSF, but not submitted when former Congressman and House Appropriations Committee member Chester Atkins reported to us that the NSF would strictly follow the funding priorities in the decadal review, the final version of which had omitted the LMT. In the spring of 1993 conversations with Senator Edward Kennedy's staff had led us to believe that the Senator would find a way to provide the funds, perhaps through an augmentation to the NSF Latin American program. However, in a meeting in his Boston office in June 1993 Kennedy told President Hooker and others present that finding the necessary money for the LMT would be "heavy lifting", essentially refusing to help with the project. At a strategy session in Hooker's office later that summer attended by representatives from the UMass Amherst campus, the UMass President's Office, and ESSCO, Al Cohen proposed using a lobbying firm in Washington that he had previously employed, in order to seek specific Congressional appropriations for the project. The benefits to American industry, and particularly to Massachusetts, would be stressed. It would be argued, assuming that the telescope would be built by ESSCO and the instrumentation developed by UMass, that 75-80% of the total capital costs of the project would be spent in the US, primarily in Massachusetts. Hooker and Cohen agreed to fund such a lobbying effort. This approach was successful, largely through the cooperation of Congressman Moakley, the senior member of the Massachusetts delegation in the House of Representatives, and Hooker wrote to the Director General of CONACyT in September 1994 that a contract between the University of Massachusetts and the Department of Defense's Advanced Research Projects Agency (ARPA, subsequently renamed DARPA, for Defense ARPA) was imminent.

It is appropriate to emphasize the importance of the continuing assistance given to the LMT project by the US Embassy in Mexico City from early in the collaboration. Ahmed Meer (Counselor for Science, Technology and the Environment) and his successors, and the Ambassadors themselves, regularly gained access for us to relevant Mexican officials, argued in favor of the Project, hosted various events for US and Mexican scientists and government officials, and were generally extremely helpful.

As real US federal funding began to seem realistic, however, the relations between the UMass astronomers and ESSCO became difficult. Following ESSCO's suggestion, UMass hired a management consultant to make a detailed cost study of the project, and this revealed that the funds that might now reasonably be expected were not sufficient to complete the LMT. The new Project Manager, Allen Langord, also felt, on the basis of his previous experience with large contractors, that ESSCO's "overhead" charges were difficult to interpret in terms of standard accounting (financial) ratios for a technology company. Efforts to bridge this gap through negotiations with ESSCO were rebuffed. At this point it was necessary to provide ARPA with a detailed cost proposal and work statement, so that a contract could be given to the University. Irvine (1994) wrote to Cohen that, in the time that had elapsed since the submission of the proposal to ARPA, ESSCO's budget had apparently escalated by 18% (approximately $4 million). Cohen disputed these numbers, primarily on the basis of inflation. A meeting of all participants was held in Boston, and Cohen expressed confidence that UMass and ESSCO would be able to complete the project within the $42.8 million "cap" in the ARPA budget for the project, which included the portions to be provided by the state, the University, and Mexico. By this point, however, the mutual trust between the University and ESSCO which had developed over the years had evaporated and been replaced by distrust on both sides.

When ESSCO submitted the required technical and cost proposal to UMass for transmission to ARPA, Irvine and Leheny (1994) found it to be seriously inadequate, stating that it "is a collection of faxes, a mass of figures that are meaningless in the absence of related explanatory text, [which] totally fails to address the issue of the overall radome and antenna cost". ESSCO submitted further material, but proposed a cost-plus-fixed-fee contract, rather than the fixed price contract which the University obviously desired (under the former, ESSCO would submit bills for whatever they claimed their costs to be, plus an agreed-upon fee). The University hired a legal firm in Springfield, MA, to draft a contract, which compromised by accepting the idea of cost-plus-fixed-fee, but which included a series of specifications and milestones: firm specifications for panel accuracy; the participation of Mexican engineers at ESSCO, which had been agreed upon by the UMass-INAOE “Executive Committee”; technical milestones requiring approval by UMass, such as a Preliminary Design Review and a Critical Design Review; the right by UMass to inspect ESSCO’s plant and procedures at any time; and certain deliverables at the end of the design phase, such as CAD (computer-aided design) drawings. That contract was presented to and rejected by ESSCO, which replaced it with a version omitting all the points just mentioned. In addition, the revised contract required UMass to provide ESSCO with the detailed design of all parts of the LMT project not covered by the contract, such as new instruments or anything contributed by the Mexicans!

During this difficult period, President Hooker had given responsibility for his role in the LMT project to Allen Sessoms, UMass Vice-President. Sessoms was a former Foreign Service Officer, most recently Deputy Chief of Mission at the Embassy in Mexico. Presumably on the basis that Hooker had made a commitment to ESSCO, Sessoms lectured Langord and me that we were required to find an accommodation with ESSCO. Feeling that the University had lost control of costs and the technical direction of the Project, I resigned. Strom assumed the role of project Principal Investigator, and Sessoms signed the ESSCO-prepared contract on behalf of the University of Massachusetts (a curious action, since he was not the project Principal Investigator, who is responsible to the government for the appropriate expenditure of federal funds). Hooker announced his resignation as President of the University the next day and Sessoms resigned shortly thereafter, each taking an administrative position elsewhere.

As the ESSCO contract was signed without the approval of our Mexican partners, they were very upset. Unfortunately, this set a precedent for unilateral action by both INAOE and UMass which continued to plague the project for at least the next 10 years. As I look back on these developments, I was certainly both naïve in insisting that such a large project must have a firm budget cap at its inception, and remiss in not bringing the Mexicans more fully into the discussions with ESSCO at an early stage.

Strom subsequently guided the LMT project through some tumultuous years. He managed to establish a working (if not always smooth) relationship with our Mexican partners. A bi-national Executive Management Team (EMT) was set up to make key decisions; it included the Program Managers, Principal Investigators, and a senior institutional official from each side. An expert outside advisory committee (the Scientific and Technical Advisory Committee, or STAC) was also established. Unfortunately, some of the EMT's decisions conflicted with the verbal commitments by the University to those Congressional representatives who had supported funding the project under the understanding that the telescope would be built in Massachusetts. Ultimately, such conflicts led to a breakdown in communication between Strom and the University's Chancellor, David Scott. Strom subsequently resigned from the University in early 1999. Control of the LMT project at UMass then passed to Vice-Chancellor for Research Byron and Project Manager Langord, although the chain of command was not always well defined.

Strom was replaced as scientific leader of the UMass portion of the LMT project by Peter Schloerb, who had become the Director of the Five College Radio Astronomy Observatory in 1995. He and his Mexican counterpart, Luis Carrasco, pushed hard to take some measure of control for the project away from the administrators who had assumed it on both sides, to bring it back to the astronomers. This continued to be a struggle for many years, in both Mexico and the US.

Clearly as large a project as the LMT needed additional scientific participants at UMass. Two significant University faculty appointments in this regard have been Min Yun, a radio astronomer interested in observations of galaxies in both the nearby and the distant universe; and Grant Wilson, who is building key instruments for measuring continuum emission (as opposed to spectral line emission) with the LMT and who is studying the cosmic microwave background, produced when the universe was only a few hundred thousand years old.

In 2006 UMass and INAOE are still striving to establish a single, legal organization to complete and operate the LMT. This entity, to be known as the Large Millimeter Telescope Observatory (LMTO), would be incorporated as a non-profit civil association in Mexico, would hire an Observatory Director and staff, and would be jointly funded by the two sides. As lawyers worked on the details, Alfonso Serrano accepted the position of Interim LMTO Director. A booklet on the project has been published in both English and Spanish versions (Irvine, Carrasco and Aretxaga, 2005; Carrasco, Aretxaga, and Irvine, 2006).

## XI. The Two Micron All Sky Survey (2MASS)

During 1989 Susan Kleinmann began to plan a survey of the entire sky in the near-infrared. Observations at these wavelengths have two principal advantages over optical measurements. First, the infrared radiation is much less attenuated by interstellar dust particles. Since stars form in clouds of interstellar gas and dust, this is very advantageous for studies of star formation. Moreover, the dust in the plane of our own Milky Way galaxy obscures our view of external galaxies over a considerable portion of the sky (the "zone of avoidance", so-called because galaxies appear to "avoid" this region). Second, objects that are too cool to radiate strongly at optical wavelengths, such as very low mass stars or interstellar dust, will emit more strongly in the infrared. Since the dust in regions of active star formation absorbs starlight and reradiates it in the infrared, certain "starburst" galaxies emit much more energy in the infrared than at optical wavelengths.

The most complete near-infrared sky survey had been made some 20 years earlier and covered only part of the sky. Moreover, the new infrared array detectors being developed for use in space were some 50,000 times more sensitive than previously. Kleinmann thus began to build up a team of astronomers to develop an optimum survey strategy and telescope-instrument design, supported by preliminary grants from both the NSF and NASA. It was rather quickly decided that two new telescopes with apertures greater than about one meter, devoted to the project, would be required. Each telescope would be instrumented with three detector arrays, for use at the 1.25 micron (micrometer), the 1.65 micron, and the 2.2 micron wavelength bands (labeled by astronomers the J, H, and Ks bands, respectively). The collected data would be reduced at the Infrared Processing and Analysis Center (IPAC), at NASA's Jet Propulsion Laboratory in California. IPAC had been established to process data from the now defunct InfraRed Astronomy Satellite, and the new project would help justify its continuing existence. For punning and political reasons, the Two Micron All Sky Survey became officially known as 2MASS, led by UMass. Unfortunately for the University, however, 2MASS was sold to the federal agencies as a service project for the astronomical community at large, with relatively little funding for research by the proposers. In consequence, UMass has received much less national recognition than might have been expected from such an important and ultimately successful project.

Long before 2MASS was completed, however, serious conflicts developed over its administration. By late 1993 or early 1994 disagreements existed between Kleinmann and the scientists at IPAC and on the 2MASS science team. Concerned with the conflicts and believing that the project was too large to be administered as a normal university grant with a faculty member as Principal Investigator, NASA requested that a Project Manager be appointed by UMass to oversee the budget and ensure that management decisions were made in a timely fashion. Strom, as FCAD Chair, was worried that the Department might lose control of the project, and he urged Dean of Natural Sciences and

Mathematics Linda Slakey to reassure NASA that the University would appropriately administer the project. Kleinmann was amenable to seeking an experienced science administrator as Project Manager, and Rae Stiening, a physicist with experience working on the recently defunct Super-Conducting Super-Collider project, was chosen. In a somewhat unusual arrangement that was written into the proposal to NASA and then insisted on by Stiening, he reported directly to the Dean, rather than to the project Principal Investigator. Within a few months Kleinmann and Stiening did indeed come to disagree about policies and procedures, and Kleinmann requested that Slakey fire Stiening. When Slakey refused, Kleinmann resigned from the project.

It was unusual to hire a faculty member fresh from graduate school, rather than after several years of postdoctoral experience, but Mike Skrutskie was so appointed in 1987 as part of the Department's effort to build up infrared-optical observational astronomy. He was interested in instrumentation for the infrared, and in its application to the study of low mass stars and circumstellar material. Although reluctant as a still rather junior faculty member, Skrutskie was persuaded by Strom to replace Kleinmann as 2MASS Principal Investigator. In this capacity he kept the 2MASS science team focused throughout the project, while Stiening took charge of much of the technical as well as the management side. UMass faculty members Martin Weinberg, interested in dynamics and galactic structure, and Stephen Schneider, working on galaxies, also played important roles on the science team. Together they brought the 2MASS project to a successful completion, on time and within budget, although some arguments concerning data access vis-à-vis IPAC continued into 2003.

There was at least one other somewhat unusual occurrence during the 2MASS project. The manufacturer of the telescopes was initially a small company that went bankrupt after producing some of the telescope components. Reasoning that UMass had paid for these components, Stiening took a forklift one evening and personally removed them from the company's premises in Arizona. Fortunately, the company had posted a performance bond, which Stiening could then use to pay for completion of the telescopes.

## XII. Later Developments

Whereas in the 1980's the structure and functioning of the Five College Astronomy Department had been questioned by its Mount Holyoke member, in the latter 1990's some University of Massachusetts faculty raised doubts about its relevance. In particular, with no astronomer at Hampshire College (following their departure, Courtney and Kurt Gordon were never replaced) and Tom Dennis at Mount Holyoke largely withdrawn from the Department, the burden of traveling to other campuses to teach the poorly enrolled Five College courses fell more heavily on University astronomers than in the past. The younger UMass faculty members suggested that they might better accomplish their professional goals by integrating more fully into the University's Department of Physics and Astronomy, and withdrawing from the Five College Department. As Dennis also continued to complain that FCAD governance procedures were not being followed, Strom decided in 1997 that an internal re-evaluation of the role and nature of the Five College Astronomy Department was needed.

With strong advocacy from the astronomers at Smith, the Department as a whole reaffirmed its importance and relevance. In order to re-invigorate astronomy on those college campuses where astronomy enrollments and numbers of majors were low, a program of Five College Astronomy Department Fellows, postdoctoral positions combining teaching and research, was proposed and subsequently incorporated into the Department's budget. Three fellows were to be phased in, with the first appointed for the 1998-99 academic year, resident at Amherst College.

The presence of the Five College Department beyond the University was further strengthened by the hiring at Mount Holyoke College of Darby Dyer, marking the first time in more than 40 years that two astronomers were resident there. The difficulties associated with Tom Dennis' negative attitude towards the Department were circumvented by appointing Dyer within the College's Geology Department as well as in FCAD, which was reasonable given that her expertise was in planetary science.

Shortly thereafter, the University astronomers decided to secede from Physics to form a separate Department of Astronomy at UMass (achieved informally in 1999 and officially in 2000). Although such action had been argued back and forth for a couple of decades, it was finally precipitated by the rather cumbersome procedures within the Department of Physics and Astronomy for authorizing searches for new astronomy faculty and the belief that the separation would give astronomers needed flexibility in budgetary matters (it is ironic that subsequent cuts in funding from the state reduced all University department discretionary budgets, including astronomy, to a very low level). The new structure did, however, require further textual modification to the Five College Astronomy Department's governance document, since the position of Astronomy Program Chair no longer existed. The new UMass Astronomy Department Head, Ron Snell, also became FCAD Head. This unification of positions is not required by current agreements, but it seemed clearly reasonable to the assembled FCAD astronomers when they elected Snell in 2000.

The value of the Five College Astronomy structure to the overall strength of astronomy among the participating institutions was demonstrated in a new and critical way in 2002. The University was suffering from the loss in a rather short time of four faculty members, the result of one early retirement, one untimely death (van Blerkom), and two resignations. This occurred at the same time that the state of Massachusetts was undergoing major budget problems, as a result of an economic recession combined with the loss of revenue from tax cuts enacted during the previous economic boom. The resulting cutbacks in University funding from the state were probably the most severe in 50 years or more, and meant that refilling of vacant faculty positions was extremely difficult. In this environment the Five College Coordinator, Lorna Peterson, the Chair of the FCAD Senate, Suzan Edwards, and FCAD Head Snell persuaded the Five College administrators to divert the salaries from the new Fellows program to provide temporary resources to the University to assist in hiring replacement faculty, with the understanding that astronomers hired by this means would subsequently receive full salary support from the state (Edwards and Snell, 2002).

This support has been crucial to the Department's efforts to build a major program in areas related to cosmology and the formation of galaxies in the early history of the universe. Theoretician Neal Katz, a leader in cosmology and computational astrophysics, had been hired in 1997. With the assistance of the Five College funding from the Fellows program, Houjun Mo, also working on simulations of galaxy formation, and Todd Tripp, interested in galaxy evolution from an observational viewpoint, joined the Department in 2003.

A separate new development has been the development of the UMass High Energy Astrophysics Group, spearheaded by Daniel Wang. After his arrival in 1999, Wang put together a dynamic group of postdocs and graduate students who used space-based observations of X-ray emission to study a range of topics from the hot interstellar medium in the Milky Way to energetic processes in distant galaxies.

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## Figure Captions

Figures not otherwise attributed are from the Five College Astronomy Department office or from personal collections

Figure II-1. "The Octagon" at Amherst College in 1861; the building includes the Lawrence Observatory with its 7 1/4-inch telescope, then half the diameter of the largest telescope in the world. From the Amherst College Archives.

Figure II-2. Amherst College Professor of Astronomy David Todd in 1885. From the Amherst College Archives.

Figure II-3. The Amherst College Observatory on Snell Street, built from 1903-1905 to house the 18-inch Clark refractor.

Figure II-4. The 18-inch Clark refractor at the Amherst College Observatory. From the Amherst College Archives.

Figure II-5. An astronomy class at Smith College in 1880. From the Smith College Archives.

Figure II-6. Mary E. Byrd, Smith College Professor of Astronomy and Director of the Observatory, in 1898. From the Smith College Archives.

Figure II-7. Professor Mary Bird and students in the Smith College Observatory. From the Smith College Archives.

Figure II-8. A pastoral view of the Smith College Observatory in 1901. From the Smith College Archives.

Figure II-9. Elisabeth Bardwell, first Director of the Williston Observatory at then Mount Holyoke Female Seminary, observing with the 8-inch Alvan Clark refractor in 1881. From the Mount Holyoke College Archives.

Figure II-10. Elisabeth Bardwell in front of the Williston Observatory. From the Mount Holyoke College Archives.

Figure II-11. Mount Holyoke Astronomy Professor Alice Farnsworth with two students (Date uncertain). From the Mount Holyoke College Archives.

Figure II-12. The Williston Observatory about 1970.

Figure III-1. Albert Linnell in 1961, the Amherst College astronomer who originally proposed the Four (now Five) College Astronomy Department. From the Amherst College Archives.

Figure III-2. Albert Linnell, with senior Amherst Professor of Astronomy Warren K. Green (date uncertain). From the Amherst College Archives.

Figure III-3. Alice Farnsworth and the Williston Observatory at Mount Holyoke College, 1956. From the Mount Holyoke College Archives.

Figure IV-1. UMass Professor Edward (Ted) Harrison. University of Massachusetts Archives (RG120-0000803).

Figure IV-2. Five College Astronomy Department Chair William (Bill) Irvine pretending to use a telescope at Mount Holyoke's Williston Observatory, ca. 1971.

Figure X-15. A mix of undergraduate and graduate students in Professor Grant Wilson's (right) Cryogenic Device Laboratory at UMass Amherst.

Figure X-16. Members of the STAC and the LMT Science Working Group visiting the telescope site, with Citlaltepetl (Pico de Orizaba) in the background.

Figure X-17. The 2500-year-old city of Cholula, with the volcanoes Popocatepetl and Ictaccíhuatl in the background.