Mauna Kea Science Reserve
Astronomy Research Development Plan 2000-2020--Summary
UH Institute for Astronomy
August 1999

I. Mission

The University of Hawaii, through its Institute for Astronomy, is actively and creatively advancing mankind's understanding of the physical Universe, and our place within it, through the operation and development of astronomical research and training facilities on Mauna Kea. These facilities are known collectively as the Mauna Kea Observatories. The astronomical activities in the Mauna Kea Science Reserve enrich the educational and research mission of the University, while at the same time expanding mankind's knowledge of the Universe, in the spirit of the early Hawaiian explorers.

II. Background

In January 1982, the UH Board of Regents approved the Institute's first Research Development Plan (RDP) for the Science Reserve. The basic goal of the RDP was to develop the Science Reserve as a pre-eminent State, national, and international resource for astronomical observations in cooperation with other State agencies and constituencies. For nearly 20 years, the RDP has served as the master plan for the development of astronomy research and related activities on Mauna Kea. The RDP identified the areas of the Science Reserve which were most suitable for the various types of telescope facilities, while making it clear that most of the Science Reserve was intended to remain undeveloped, as a buffer zone. The RDP foresaw the establishment of thirteen telescope facilities on the mountain by the year 2000, a number which was based on projected demand, not on physical capacity. That section of the RDP concludes with the following statement:

> *"It should be emphasized that the actual number of telescopes on Mauna Kea will be shaped by a wide variety of factors, many of them beyond the scope of this plan. However, this plan is clearly achievable and does not approach the capacity of Mauna Kea for telescopes nor does this plan compromise, in any way, the other uses of the mountain."*

Thirteen is, in fact, the number of telescope facilities on Mauna Kea today. That the actual scope of development should end up being so close to the RDP projection is quite amazing, in view of the time span and uncertainties involved. The RDP also foresaw the need for several major infrastructure improvements including: provision of commercial electric power; improvements to and paving of the access road; and expansion of the mid-level facilities. Commercial power is now in place, together with fiber-optics communications infrastructure of essentially unlimited capacity. The upper half (~4 miles) of the access road has been paved, and the addition of Dormitory D has expanded the astronomer bedroom count at the mid-level facilities to 72.

The purpose of this document is to extend the astronomy development component of the RDP for the next 20-year period. In doing so, we retain the underlying philosophy and methodology of the original plan. One of the basic goals of the 1982 RDP was the preservation and protection of the multi-use objectives of Mauna Kea. This goal is the dominant theme in the current master planning process. Another goal was to ensure that the potential sites for astronomy facilities were reserved for the highest and best use. The Institute's astronomy development plan for Mauna Kea for the period 2000-2020, as presented below, is strongly guided by these two top-level goals. As was true for the 1982 RDP, the scope of proposed development is not constrained by physical capacity, but rather by an analysis of the projected demand for appropriate facilities, combined with the need to avoid adverse impacts on environmental and cultural resources and on other uses.

III. Astronomy Development 2000-2020

III.1. Introduction

In the early decades of the next millennium, we expect that astronomy will focus on the questions posed in NASA's Origins program, which has the goal of understanding how our Universe evolved, how galaxies and the stars within them form, and how many stars contain planetary systems—most importantly planets like our own Earth, where life could have developed. Major space missions such as the 8-m Next Generation Space Telescope and various interferometric missions will be launched by NASA to address these questions, but much of the work will be done from the ground using the next generation of large optical and millimeter/submillimeter wave telescopes. It has already been decided that the next major millimeter/submillimeter telescope, the Atacama Large Millimeter Array, will be built in Chile by a consortium of the U. S., Europe, and possibly Japan. As a result, proposals for further development of major submillimeter facilities on Mauna Kea during the next 20 years will probably be limited to expansion of the existing Submillimeter Array. In the optical and infrared wavebands, however, we can expect that several international consortia, and possibly some private university groups, will want to build powerful 30-m class optical/infrared telescopes and possibly interferometers. With their much larger collecting areas, and in the case of interferometers, very high angular resolution, these powerful new instruments will complement the space missions. In addition, existing observatories will need to replace or refurbish their aging facilities with new technology. If Mauna Kea is to remain as the world's pre-eminent location for astronomical observations in the face of increasing competition from developing sites such as those in Chile, and if UH is to continue to maintain a world-class astronomy program, then our plans for the next two decades must include the elements outlined below.

III.2. Redevelopment of Existing Observatory Sites on the Summit Ridge

All nine of the optical/infrared telescopes at the Mauna Kea Observatories are located on the ridgeline of the summit cinder-cone complex (we count Keck I and II separately here). They extend in an arc counter-clockwise from the UH 24-inch (0.6-m), the smallest and oldest, around to Subaru, one of the largest and newest. The RDP identified this area as the most suitable for optical/infrared facilities, and indeed the Mauna Kea summit ridge is almost universally regarded by astronomers as the best location on the face of the earth for this type of telescope.

The most common type of development over the next 20 years will be the replacement or major upgrading of optical/IR facilities at existing sites on the summit ridge. There are two basic reasons for this. First, two of the nine existing facilities (UH 2.2-m and 0.6-m) are 30 years old, and three more (United Kingdom Infrared Telescope (UKIRT), Canada-France-Hawaii Telescope (CFHT), NASA Infrared Telescope Facility (IRTF)) are 20 years old. By historical standards, these telescopes would still be considered young, but the recent dramatic advances in telescope technology (thin mirrors, space-age materials, computer-assisted design, thermal control) and enclosure design have rendered them old beyond their years. The four organizations operating these telescopes will soon be very eager to replace them with modern state-of-the-art technology, so as to get the full benefit of the site conditions and to maximize the return from the substantial operational expenditures. The CFHT community is already discussing the possibility of replacing the existing 3.6-m telescope with a new-technology facility in the 8-m range, but with an enclosure of approximately the same size. Similarly, IfA, at the request of NASA, is exploring the scientific and technical aspects of replacing the 3.0-m IRTF with a 6.5-m New Planetary Telescope (NPT). The increased aperture and improved technology will dramatically increase both the sensitivity (ability to study faint objects) and angular resolution (ability to discern fine detail in images) for these facilities.

Any national or international organization wishing to develop a new world-class optical/infrared telescope of “conventional” size (4-12 m aperture) will almost certainly want to locate on the Mauna Kea summit ridge, unless a location in the southern hemisphere is preferred for programmatic or other reasons. This leads to the second reason for expecting substantial demand for the reuse of existing sites, as the summit ridge is already nearly filled to capacity. It would be possible to add one, or perhaps two modest-sized telescopes, but a large facility would require the replacement of an already existing one.

We expect that over the next 20 years, proposals will be developed to upgrade or replace each of the five telescopes mentioned above. As was true for the 1982 RDP, it is very difficult to predict the actual scope of development that far into the future. At present, we estimate that at least three, but perhaps all five of these aging telescopes will be upgraded or replaced within this time frame. Such replacement upgrades, with their minimal impact, must be a very high priority for future development.

We also expect to see a trend toward specialization for these conventional-size optical/infrared telescopes. For example, one facility may decide to concentrate on wide-field imaging, while another focuses on using adaptive optics to achieve the highest possible angular resolution over a small field. The NPT, mentioned above as a possible replacement for the NASA IRTF, is designed to minimize scattered light in order to study faint objects which lie close to bright ones (e.g., a planet in orbit around a star). Specialization will allow the telescope facility to achieve the ultimate in performance within the chosen area of research, while at the same time simplifying the operation and thereby reducing costs. Specialization will provide a strong incentive for joint operating arrangements and shared use among the observatory organizations. In this way, each affiliated astronomer community will have access to a wide range of observing capabilities, without the need to provide them all on any one telescope.

III.3. Expansion of Existing Observatories

Expansion of two of the existing facilities, the W. M. Keck Observatory and the Submillimeter Array (SMA) is planned for the period 2000-2020.

III.3.a. W. M. Keck Observatory

At Keck, the expansion will be the addition of four to six 1.8-m “outrigger” telescopes to create a powerful infrared interferometer on the existing Keck site. This is primarily a NASA project, with funding for four of the six outriggers already in hand. The primary scientific mission is to search for and study planets around nearby stars. This is an important step in answering the fundamental questions of how unique our Earth is and whether there may be life elsewhere in the Universe. The Keck Interferometer is a stepping stone to future NASA space-based interferometry missions such as the Space Interferometry Mission (SIM) and the Terrestrial Planet Finder (TPF), which are aimed toward these questions. It will also test the feasibility and capability of large-aperture ground-based optical/infrared interferometry. This information will be extremely valuable in assessing the scientific potential for a large-scale optical/infrared interferometer array (see III.6 below). The Keck Outrigger Project is the only new project for which a detailed proposal exists at present. Because of the link with space missions, for which the planning is already well underway, this project is on a tight schedule and needs to start construction in 2000.

III.3.b. Submillimeter Array

The SMA is a collaborative project of the Smithsonian Astrophysical Observatory and the Institute of Astronomy and Astrophysics of Taiwan.
The SMA is the world’s first submillimeter-wavelength radio interferometer. Consisting of up to 12 interconnected 6-m antennas which can be arranged in various configurations on 24 antenna pads, the SMA will provide sub-arcsecond resolution in the submillimeter region of the spectrum. The SMA is expected to be in operation with eight antennas by 2001. During the ensuing 20 years, there will be a strong scientific need to enhance both the angular resolution and the imaging power of the array. The former is achieved by adding additional pads to provide longer baselines. Imaging power is directly related to the number of

distinct baselines (antenna pairs) in the array. For N antennas, the number of baselines is $N(N-1)/2 \approx N^2/2$. Since the imaging power increases roughly as the square of the number of antennas, a modest increase in antenna count can produce a dramatic enhancement in scientific capability. The expansion plan for the SMA includes 24 additional antenna pads, increasing the maximum baseline by at least a factor of two, and the addition of 12 antennas for a total of 24. This will increase the imaging power by a factor of 4 and the angular resolution by more than a factor of 2.

III.4. New Sites for Conventional Optical/Infrared Telescopes

As explained previously, the preferred location for any new conventional optical/infrared telescope will be the summit ridge because of its proven superb astronomical quality and the already existing infrastructure. Space is limited there, however, and major new telescopes can be accommodated only by replacing existing ones. We expect that over the next 20 years, there will be one or two proposals for new conventional optical/infrared telescopes which have excellent scientific potential and offer strong benefits for the UH astronomy program, but for which there is no site on the summit ridge. In our master planning, we need to identify new sites for optical/infrared telescopes which are not on the summit ridge, but which have excellent observing conditions. Detailed seeing measurements will be particularly important.

III.5. Next Generation Large Telescope

The world astronomy community is just now completing the giant step from the 4-m class telescopes that have been its mainstay for the past 40 years to the 8-10 m class instruments such as the Kecks, Gemini, Subaru, and the European Southern Observatory’s Very Large Telescope. It will be several years before we know the real impact of this major advance in both aperture size and technological sophistication. Nonetheless, astronomers are already beginning to discuss what the next step beyond the 8-10 m class will be (i.e., the Next Generation Large Telescope). Some of the impetus for this discussion comes from NASA’s plan to launch the Next Generation Space Telescope (NGST) within the next decade. With an aperture diameter of 8m, NGST will have eleven times the collecting area of the Hubble Space Telescope. We know already that the current 8-10m telescopes are an excellent complement to Hubble, for example providing spectroscopy of objects which are discovered in Hubble images. The Next Generation Large Telescope (NGLT) is seen as playing the analogous role for the NGST. During the coming two decades, Earth-based telescopes will continue to retain some very substantial advantages over space telescopes in spectral regions which can be observed from the ground. First and foremost, they can be made larger, and for a given size, are 10-100 times less expensive to build and operate. In addition, they are much easier to service and upgrade; this is particularly important for the instrumentation attached to the telescope. Finally, recent major advances in adaptive optics allow ground-based telescopes to achieve angular resolution equaling or exceeding that from space telescopes in the infrared region of the spectrum.

Once every ten years, the U. S. National Academy of Sciences appoints a blue-ribbon panel to survey astronomy goals for the coming decade and to set priorities for new facilities. The latest Decadal Survey is currently underway, with its report due early in 2000. There is widespread expectation that the report will recommend some type of NGLT, possibly in the 25-50 m range. Only the most preliminary of design concepts exists at present, with most of them employing some type of segmented mirror.

We consider it likely that a NGLT will be proposed for Mauna Kea within the next ten years, with the expectation that such a facility could be completed before the year 2020. We need to identify a suitable site in our master plan. As with the new conventional optical/infrared telescopes, any final site selection would be contingent on detailed seeing studies.

III.6. Site for Optical/Infrared Interferometer

Another possibility for a next-generation ground-based optical/infrared facility is a distributed aperture telescope (i.e., an interferometer array). Currently there is a vigorous debate among astronomers concerning the relative merits of the interferometer and the filled-aperture NGLT. Roughly speaking, the former would emphasize high angular resolution, while the latter would emphasize sensitivity to faint objects. It appears likely that this debate will continue for at least five years and probably longer. During this period, a number of modest-sized interferometers, including the Keck (see III.3.a. above) and the European Southern Observatory’s Very Large Telescope Interferometer will begin operation. These facilities are expected to inform this debate by providing a wealth of practical information about the feasibility and scientific potential of ground-based optical/infrared interferometry.

Should a large-scale optical/infrared interferometer be proposed for Mauna Kea, it would require a large and relatively flat area of up to 1 km in diameter. Such an area should be identified in the master plan. The number and size of the individual apertures cannot be accurately predicted at present, although an array of six 3-m apertures would appear to be a minimum. The light collected by each aperture would be transported to a central location and then combined with the light from the other apertures, after path-length compensation, to produce a high-resolution image of the object being studied. In current-day interferometers, light transport is achieved by directing collimated beams through pipes located either above or below ground. This approach appears both impractical and environmentally problematic for a large-scale interferometer such as might be proposed for Mauna Kea. Similarly, path-length compensation is currently accomplished with optical delay lines whose dimensions are similar to the size of the array. This also would be problematic for a large array on Mauna Kea. At present the most promising solution to these two problems appears to be the use of fiber optics. With fiber optics, light transport could be incorporated into the small utility line to each aperture, and the delay line system could be reduced to a manageable size.

For present planning purposes, we should reserve a suitable location in case we may wish to consider an optical/infrared interferometer during the coming 20-year period. Whether or not such a proposal will be forthcoming and favorably considered will depend on the scientific and technical issues outlined above.

III.7. Temporary Facilities

We also expect to receive over the 20-year period several strong proposals for temporary facilities. A recent example of a temporary facility is the Optical Test Sites installation at the W. M. Keck Observatory. This system, comprising two siderostats and underground light pipes, will be used for testing and debugging the beam-combining equipment for the Keck Interferometer. Once the Interferometer is operational, in 2002, the temporary test sites will be removed.

Taiwanese astronomers are currently developing a proposal for a temporary facility called the Array for Microwave Background (AMIBA). AMIBA would measure the spatial variations in the microwave background radiation which originated with the Big Bang and which allow us to understand the earliest stages of the formation of our Universe. In its current concept, AMIBA consists of 19 1-m antennas mounted on a single steerable platform measuring about 10 meters across. AMIBA would have an operational lifetime of approximately five years.

IV. Conclusion

The Institute's Astronomy Research Development Plan 2000-2020 extends the astronomy development component of the 1982 Research Development Plan for the Mauna Kea Science Reserve, while retaining the fundamental philosophy and methodology of the original plan. The scope of the planned development is based not on physical capacity, but rather on the expected demand for facilities which would make the highest and best use of the Mauna Kea site, combined with the need to accommodate other uses and minimize adverse impacts. Although this plan is based on the best information currently available, it must be kept in mind that there are many large scientific and technological uncertainties outstanding, especially in view of the 20-year planning horizon. This plan will probably require adjustment as new information and scientific priorities arise.