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Petitioner

BOARD OF LAND AND NATURAL RESOURCES

STATE OF HAWAII

In the Matter of:)	Case No. BLNR-CC-16-002
)	
A Contested Case Hearing Re)	PETITIONER CLARENCE
Conservation District Use Permit)	KUKAUAKAHI CHING'S SECOND
(COUP) HA-3568 for the Thirty Meter)	SUPPLEMENTAL EXHIBIT
Telescope at the Mauna Kea Science)	DESIGNATION; EXHIBIT B.19e [New
Reserve, Kaohe Mauka, Hamakua)	Worlds, New Horizons in Astronomy
District, Island of Hawai'i, TMK (3) 4-4-)	and Astrophysics; National Research
015:009)	Council (2010)]; CERTIFICATE OF
)	SERVICE
)	
)	
)	Hearing Officer: Riki J. Amano.

CLARENCE KUKAUAKAHI CHING'S SECOND SUPPLEMENTAL EXHIBIT DESIGNATION; EXHIBIT B.19e [New Worlds, New Horizons in Astronomy and Astrophysics; National Research Council (2010)]

Comes now Petitioner Clarence Kukauakahi Ching, pro se, and hereby submits his Second Supplemental Exhibit (Exhibit B.19e) Designation.

Exhibit No.	Description	Rec'd Into Evidence
B.19e	New Worlds, New Horizons in Astronomy and Astrophysics; National Research Council (2010) - pgs 223-234	

DATED: Kailua, Hawaii, 1/6/17

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Clarence Kukauakahi Ching, Petitioner



**New Worlds,
New Horizons**
in Astronomy and Astrophysics

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

New Worlds, New Horizons

in Astronomy and Astrophysics

Committee for a Decadal Survey of Astronomy and Astrophysics

Board on Physics and Astronomy

Space Studies Board

Division on Engineering and Physical Sciences

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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Cover: Complexity abounds in the universe, especially during the birth phases of stars and planetary systems. The M17 region, also known as the Omega Nebula, in the constellation Sagittarius is rich in massive stars, including those recently formed and already impacting their environment (bright nebulous regions—e.g., back lower), as well as those still in the process of formation within cold dense clouds (dark regions—e.g., front center). Provinces such as this within our galaxy and others allow astronomers to understand and quantify the cycling of matter and energy within the cosmic ecosystem. The image depicts mid-infrared emission at 3.6- to 24-micrometer wavelengths as detected by NASA's Spitzer Space Telescope, although the region has been studied from high-frequency gamma-ray to low-frequency radio energies. Image courtesy of NASA/JPL-Caltech.

Dedication (p. xxxiii): Photo courtesy of American Astronomical Society.

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Recommendations for New Ground-Based Activities—Large Projects

Priority 1 (Large, Ground). Large Synoptic Survey Telescope (LSST)

The Large Synoptic Survey Telescope (LSST) would employ the most ambitious optical sky survey approach yet and would revolutionize investigations of transient phenomena. It would address the pressing and fundamental question of why the expansion rate of the universe is accelerating, and would tackle a broad range of priority science questions ranging from understanding the structure of our galaxy to elucidating the physics of stars. LSST (Figure 7.8) opens a new window on the time-variable universe and therefore promises discoveries yet to be imagined. LSST's observations repeatedly cover large areas of sky following a preordained and optimized sequence to create a data set that addresses a majority of SFP-identified questions.

LSST's dark energy program centers on using weak gravitational lensing to constrain the rate of growth of large-scale structure, as well as detecting supernova explosions. For these studies LSST's data are an essential complement to the near-infrared measurements performed by WFIRST from space. LSST's data set would permit both real-time investigations for studying variable objects and a vast archive that will be mined far into the future. In time-domain studies, LSST's specific goals include mapping of near-Earth objects (as mandated by Congress), supernovae, gamma-ray bursts, variable stars, and high-energy transients. Its archival science will include mapping the Milky Way and the distant universe, creating an accurate photometric and astrometric data set, studying stellar kinematics, and performing a census of the solar neighborhood. It is also seen as a prime discovery engine.

LSST is proposed as an 8.4-meter telescope to be sited in Chile. It is specially designed to produce excellent images over a very wide 3.5-degree field of view. It will image the sky repeatedly in six colors in the visible band (0.3 to 1.0 micrometer). Over its lifetime of 10 years, it will observe each region of the sky 1,000 separate times. The 1,000 separate images will be used to make a "cosmic movie" to search for objects that move or whose brightness varies. By adding these images, it will also produce a very deep map of roughly half of the entire sky. LSST will produce a calibrated data set and analysis tools for the astronomy and astrophysics community. It will also facilitate the creation, by researchers outside the project, of additional science products that may be incorporated into the LSST data system. The data will be open access with no proprietary period for U.S. and Chilean astronomers; other non-U.S. partners that join will be expected to contribute to the cost of operations. LSST was conceived as a joint NSF-DOE project, with the latter taking responsibility for the camera. It has benefited from private donations and has acquired international partners. The combined primary-tertiary mirror has been cast and the grinding has begun.

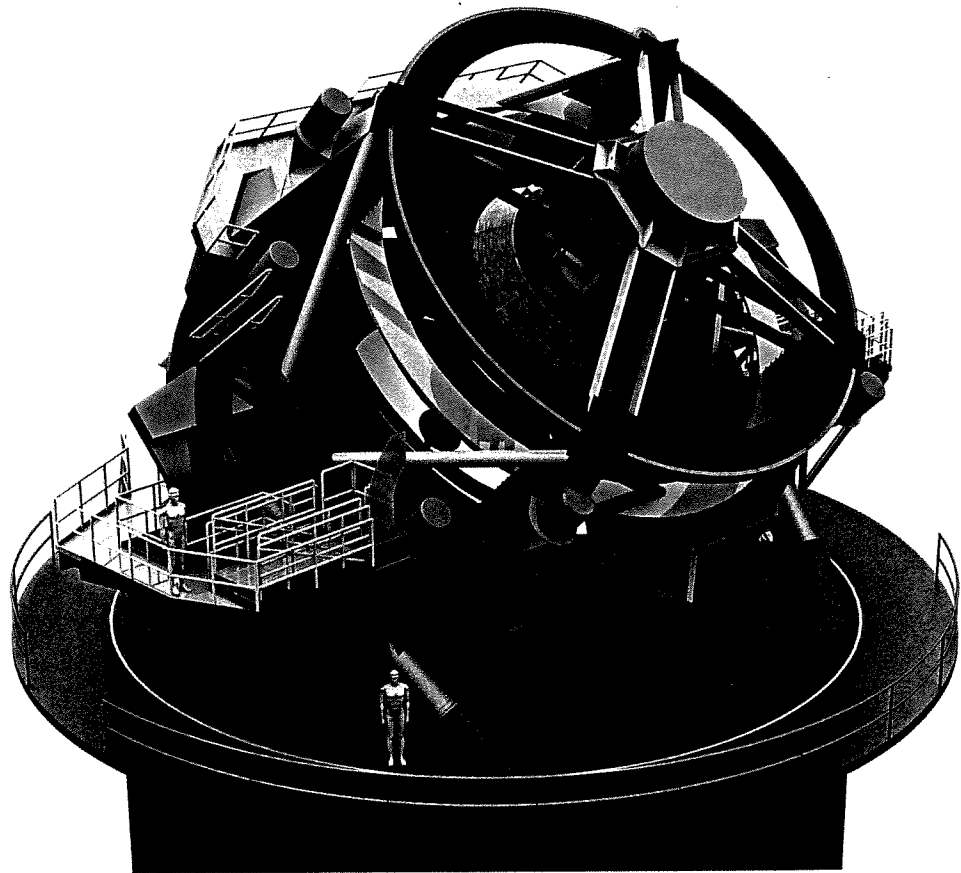


FIGURE 7.8 LSST has a three-mirror design with the primary and tertiary mirror combined and cast from a single blank. Preliminary grinding is already underway, and the secondary mirror has also been cast. An important figure of merit for a survey telescope is the etendue, which is the product of the field of view and the area. This is $320 \text{ m}^2 \text{ degree}^2$ for LSST. The 3 GPx camera will read out in less than 2 seconds every 15 seconds, and more than 100 petabytes of data will be accumulated over the 10-year project lifetime. The limiting magnitude in a single visit is $r = 24.5$. The camera pixel scale is roughly 0.2 arcsecond, and the median seeing at the site is roughly 0.67 arcsecond. SOURCE: LSST Corporation.

The technical risk of LSST as determined by the survey's cost appraisal and technical evaluation (CATE) process was rated as medium low. The committee did identify additional risk with establishing data management and archiving software environments adequate to achieving the science goals and engaging the astronomical community. The appraised construction cost is \$465 million with a time to

completion of 112 months. The committee recommends that LSST be started as soon as possible, with, as proposed by the project, two-thirds of the construction costs borne by NSF through its MREFC line and a quarter by DOE using Major Item of Equipment (MIE) funds. The estimated operations cost is \$42 million per year over its 10-year lifetime, of which roughly \$28 million is proposed to be borne by the U.S. agencies—the committee recommends two-thirds of the federal share of operations costs be borne by NSF and one-third by DOE. It is recommended that any extended mission should only happen following a successful senior review. By its very nature LSST will stimulate a large number of follow-up studies, especially of a spectroscopic character. The planning and administration of an optimized plan for follow-up studies within the public-private optical-infrared system could be carried out by the National Optical Astronomy Observatory.

The top rank of LSST is a result of its capacity to address so many of the identified science goals and its advanced state of technical readiness.

Priority 2 (Large, Ground). Mid-Scale Innovations Program

Science and technology are evolving rapidly. Each decade, new discoveries open new opportunities, and scientists and engineers find novel and innovative approaches to designing instruments. Although there are regularly competed opportunities on timescales shorter than a decade for moderate-scale missions in space, on the ground there is no program that can compete and select mid-scale projects based on scientific merit and technical readiness as instruments mature and science advances. The committee was impressed by the large number of white-paper submissions for mid-scale ground-based projects that offer compelling science and novel technical approaches but that cannot be evaluated without a proper scientific and technical peer review.

The committee recommends, as its second-highest priority, a competed program, based on NASA's highly successful Explorer model, that would enable moderate-scale projects to be frequently selected through peer review. Like the Explorer program, a mid-scale instrumentation and facility program at NSF—a program that the committee calls the Mid-Scale Innovations Program—would provide first-class science at moderate cost and would address the need to involve and train students in experiment design and instrumentation.

The need for such a program is driven by the fact that NSF-AST does not have a formal mechanism for competing proposals in the price range between the Major Research Instrumentation (MRI) program (less than \$4 million) and the MREFC line (greater than \$135 million in FY2010). It does accept unsolicited proposals in the mid-scale category, several of which have been funded, but without the head-to-head competitive peer review that ensures that the highest-priority needs are met. The committee therefore recommends the establishment of a competed Mid-Scale

Innovations Program for instrumentation and facilities in order to capitalize on a large variety of exciting science opportunities over the upcoming decade.

The program should issue roughly annual calls for proposals in two categories: (1) conceptual and preliminary design activities and (2) detailed design and construction projects. Important elements of the program include standard peer review and selection criteria with special attention to scientific merit, relevance to community-established strategic goals and roadmaps, project management, and planning for both operations and data archiving funding. Operations and data archiving could be proposed, but not necessarily fully funded, by the program. A periodic review of ongoing projects with clearly stated procedures for funding continuation or termination is recommended. Co-funding of mid-scale projects from non-NSF sources would be allowed but not required. The Mid-Scale Innovations Program funding line should be established at a level that enables the selection of a minimum of seven such projects spanning a range of scales over the decade—a rate that provides regular opportunities and accomplishes a broad range of science.

Of the 29 proposals for ground-based mid-scale projects submitted as white papers to the survey, a subset was considered compelling by the committee. Although it is not appropriate for the committee to rank concepts for a competed line, it lists in Table 7.1 the activities it found compelling. The indicated cost categories are based on submitted descriptions and not on any independent committee review. Appendix D provides additional background information on these projects. Other examples may be found in the PPP reports. Many similar instrument and small-facility concepts will undoubtedly emerge over the decade. It is important that the Mid-Scale Innovations Program maintain a balance between large and small projects. Indeed, such a program in NSF-AST could take on some of the larger Advanced Technologies and Instrumentation (ATI) projects, so that ATI would emphasize advanced technology development together with instrumentation below ~\$2 million.

The recommended Mid-Scale Innovations Program is aimed primarily at instrumentation and facilities in order to be consistent with the goals of the program at NSF's Directorate for Mathematical and Physical Sciences (NSF-MPS) and with the recommendations of the National Science Board (NSB)²¹ and NRC reports, but proposals for other types of initiatives in this cost range could be considered for funding if they present an especially compelling scientific case.

To support the committee's recommendation, almost \$400 million would be needed in this line over the decade, in addition to the funds needed to complete

²¹ National Science Board, *Science and Engineering Infrastructure for the 21st Century*, National Science Foundation, Arlington, Va., 2002; National Research Council, *Advanced Research Instrumentation and Facilities*, The National Academies Press, Washington, D.C., 2006.

TABLE 7.1 Projects Thought Compelling for the Mid-Scale Innovations Program (in alphabetical order)

Project Name	Science Goal	Cost Range ^a
Big Baryon Oscillation Spectroscopic Survey	Determine the cause of the acceleration of the universe.	Upper
Cosmic Microwave Background Measurements	Detect the signature of inflation and probe exotic physics in the earliest moments of the universe.	Middle
Exoplanet Initiatives	Develop radial velocity surveys and spectrometers to determine the properties of extrasolar planets; understand extrazodiacal light levels.	Middle and Lower
Frequency Agile Solar Radiotelescope	Understand the Sun's atmosphere.	Upper
High-Altitude Water Čerenkov Experiment	Map the high-energy (>1 TeV) gamma-ray sky.	Lower
Hydrogen Epoch of Reionization Array	Determine how the universe is ionized after the formation of the first stars.	Upper
Next Generation Adaptive Optics Systems	Enable near-infrared and visible wavelength imaging and spectroscopy at spatial resolution better than that of HST to address a broad science program from exoplanet studies to galaxy formation.	Middle and Upper
North American Nanohertz Observatory for Gravitational Waves	Detect gravitational waves from the early universe through pulsar timing.	Upper

^a Upper: \$40 million to \$100 million, middle: \$12 million to \$40 million, lower: <\$12 million where costs are total project costs.

similar projects already started. The committee recommends funding of this program at a level that builds up to \$40 million per year by mid-decade (additional funds over the decade would fall between \$93 million and \$200 million). The current level of funding for mid-scale projects in NSF-AST, which occurs on an ad hoc basis, is estimated at roughly \$18 million per year, including some technology, design, and development work for LSST, GSMT, and SKA.

The principal rationale for the committee's ranking of the Mid-Scale Innovations Program is the compelling number of highly promising projects with costs between the MRI and MREFC boundaries, plus the diversity and timeliness of the science that they could achieve. There are advantages to putting this program at the NSF-MPS level where it would serve all the divisions, and also those to putting it at the NSF-AST level.

Priority 3 (Large, Ground). Participation in a Giant Segmented Mirror Telescope (GSMT)

Large telescopes in the 8- to 10-meter class have revolutionized the world of optical and near-infrared astronomy. Newly developed adaptive optics systems, which remove image distortions caused by the atmosphere, have made them even more powerful. Astronomers are poised to take the next major step—adaptive optics telescopes with 3 times the diameter, 10 times the optical collecting area, and up to 80 times the near-infrared sensitivity compared to existing telescopes. These Giant Segmented Mirror Telescopes (GSMTs) will be essential to understanding the distant galaxies discovered by JWST and to obtaining spectra of the faint transients found by LSST, and they will be transformative for a broad range of science aimed at understanding targets ranging from stars and exoplanets to black holes. Although they will function as observatories, they are integral parts of each of the survey's target science areas as explained in Chapters 1 and 2. Operating in the optical and infrared (at 0.3 to 2.5 microns), the GSMTs excel at high-spectral- and high-spatial-resolution spectroscopy and will have a relationship to JWST similar to that of the 8- to 10-meter-class telescopes to HST.²²

With every enormous leap in sensitivity come new discoveries we cannot anticipate, but the broad impact the GSMTs will have on the survey's identified science questions is clear. The very first galaxies in the universe that will be found by JWST will require GSMTs for follow-up so as to determine their internal dynamical properties by studying the bulk motions of stars in a way that complements the gas observations of ALMA. GSMTs would also monitor how the chemical elements are built up. Their superb spatial resolution and astrometric capabilities would enable them to follow the orbits of individual stars around the several-million-solar-mass black hole in the center of our Milky Way galaxy so as to obtain precision measurements of fundamental galactic parameters. Direct imaging of exoplanet systems using the advanced adaptive optics cameras on these telescopes would also be an exciting area of study, given that GSMTs will have the highest angular resolution in the visible through infrared of any existing or planned facility, ground or space. They would also be able to study the reflected infrared emission of planets in the habitable zone. The ability of a GSMT to perform direct spectroscopy on very faint galaxies would be crucial in efforts to elucidate the properties of dark matter and merging black holes. These telescopes would transform understanding of stellar astronomy by taking high-dispersion spectra of local stars, mapping the flow of gas into and out of massive galaxies during their formative stage, and studying the formation of protoplanetary systems.

²² Specifically, HST discovered many new classes of objects, and the larger ground-based telescopes with their superior spectroscopic capabilities were needed to determine where and what they are.

As discussed in Chapter 3, there are three projects underway in the world to construct and operate a new generation of extremely large telescopes with diameters in the range of 23 to 42 meters (Figure 7.9). The Giant Magellan Telescope (GMT) is composed of seven 8.4-meter mirrors and has an aperture equivalent to a single 23-meter mirror; it will be sited at the Las Campanas Observatory (Chile). The GMT design builds on the success of the two 6.5-meter Magellan Telescopes. The Thirty-Meter Telescope (TMT) is composed of almost 500 1.44-meter segments, has an aperture equivalent to a single mirror 30 meters in diameter, and will be sited at Mauna Kea (Hawaii). It builds on the success of the two 10-meter Keck Telescopes. The European Extremely Large Telescope (E-ELT) has a segmented mirror design with an aperture equivalent to a single mirror 42 meters in diameter. Its recommended site is at Cerro Armazones in Chile. The project is led by the European Southern Observatory (ESO) and has a mirror segment design similar to that of TMT.

The committee concluded that more than one GSMT will be required in the world to fully exploit the identified science opportunities. The reasons are that there are advantages to having capability in two hemispheres, or two in the same hemisphere with different instrument capabilities requiring different optimizations of telescope design, and that so many new scientific problems can be addressed that any credible number of GSMTs is likely to be oversubscribed. It is imperative that at least one of the U.S.-led telescope projects have U.S. federal investment. Such a federal role will leverage the very significant U.S. private investment, will maximize the potential for the project's success, will help to optimize the U.S. scientific return on other federal investments (ALMA, JWST, and LSST), and will position the NSF for leadership in future large-telescope projects beyond GSMT. Since both GMT and TMT are already international public-private partnerships, federal involvement with either one is consistent with the international collaboration strategy that is a recurring theme in this survey and would ensure U.S. leadership in one international large telescope. Such leadership would further another important strategy advocated in this report: cooperation with other countries so as to develop complementary capabilities that will maximize the science output. In the case of GSMT this means coordination with ESO on technology development and instrument selection to create a global system of GSMTs with optimal complementary and scientific reach. The committee notes that public time on a GSMT would, in principle, be subject to the open skies policy in effect for all federally supported U.S. telescopes. It is the committee's hope that a result would be corresponding reciprocal access to major optical-infrared telescopes abroad.

The committee reviewed a technical risk assessment and sensitivity analysis of the anticipated cost and schedule for GMT and TMT that indicated the risk is medium to medium high. A cost sensitivity study based only on the telescope optics and instruments concluded that the construction costs of GMT and TMT would be \$1.1 billion and \$1.4 billion, respectively (at a 70 percent confidence

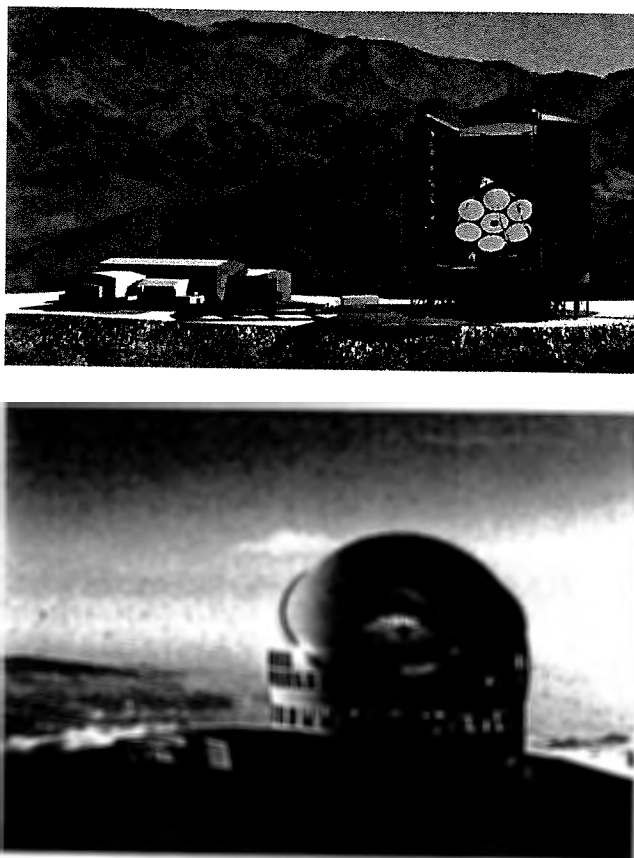


FIGURE 7.9 The two U.S. Giant Segmented Mirror Telescope projects. *Upper:* The Giant Magellan Telescope is a 25-meter-class telescope comprising seven 8.4-meter subapertures, one of which is already undergoing polishing. Laser tomography will provide adaptive optics correction in small fields over much of the sky, and correction for ground-level seeing will be incorporated over large fields. The baseline project includes an initial suite of three to four instruments to be selected in 2011 from eight concepts currently in development. Artist's rendering of GMT and support facilities at Las Campanas, Chile. SOURCE: Courtesy of GMTO; image by Todd Mason/Mason Productions. *Lower:* The Thirty Meter Telescope primary mirror comprises 492 hexagonal segments with active control and a 30-meter-effective-diameter aperture. An on-axis segment has been cast and polished, and an off-axis segment is currently undergoing polishing. Nine instruments are planned for the first decade of operations, of which three are planned for first light. Most of these instruments operate in conjunction with sophisticated adaptive optics systems. SOURCE: TMT Observatory Corporation.

level). Assuming the current status of the projects, the dates for full operations of the two telescopes (defined as including three instruments and the adaptive optics system) were estimated as spring 2024 for GMT, and between summer 2025 and summer 2030 for TMT depending on assumptions about segment manufacture and delivery. The telescope projects estimated their annual operations costs (including facility and instrument upgrades) as being \$36 million for GMT and \$55 million for TMT. Although the committee did not analyze these estimates in detail, they are far below the usual rule of thumb for large projects (10 percent of construction costs per year); should the projects go forward, their operations costs will need to be scrutinized in considerable detail. The committee did not evaluate the cost estimate or risks for the E-ELT, but the ESO estimate is €1 billion with a start of operations in 2018.

The two U.S.-led projects, GMT and TMT, are in fairly advanced states of design. GMT has already cast one of its six off-axis mirrors, which is currently being polished. TMT has cast, polished, and mounted an on-axis segment and is in the process of polishing an off-axis segment. Furthermore, through a combination of private and international partnerships, both projects have made considerable progress on their financing. The question, now, is whether or not the federal government can afford to become a partner in one of these projects and, if so, which one. The arguments for federal partnership are strong. First, the science case for a GSMT is highly compelling, and a federal share will ensure access to observing time for all U.S. astronomers, not just those associated with partner institutions.²³ This is a principle that is similar to the Telescope System Instrumentation Program (TSIP) program philosophy that has been so successfully implemented with respect to existing privately operated telescopes. Second, partnership can greatly enhance and improve these projects by bringing a much larger experience base and resources to them. This will be particularly important during the operations phase when funds to run the telescopes must be found and new and expensive instruments will need to be constructed.

In the committee's judgment, due to the severe budget limitations, a federal partnership in a GSMT will be limited to a minority role with one project. For the construction phase, a potential MREFC funding wedge opens up in the second half of the decade (after ALMA, ATST, and LSST have passed their peak funding) that would allow for a federal share in a GSMT to be supported by the MREFC line by the end of this decade. For the operations phase, in the optimistic budget-

²³ Institutional members as of May 2010 were, for GMT, Astronomy Australia Limited, the Australian National Observatory, Carnegie Institution for Science, Harvard University, Korea Astronomy and Space Science Institute, Smithsonian Astrophysical Observatory, Texas A&M University, the University of Texas at Austin, and the University of Arizona, and for TMT were the Association of Canadian Universities for Research in Astronomy, California Institute of Technology, and the University of California.

doubling funding scenario, some funding could be available by the last few years of the decade; in the flat budget scenario, few if any operations funds would be available in this decade.

However, the GSMT projects are at a pivotal point where some form of commitment from the U.S. government at this time will encourage additional collaboration and is crucial to having the projects go forward at all. Owing to the highly compelling science case for this class of telescope, the committee recommends immediate selection by NSF of one of the two U.S.-led GSMT projects for a future federal investment that will secure a significant public partnership role in the development, the operation, and telescope access. This action should facilitate access to and optimize the benefit of the largest ground-based telescopes for the entire U.S. community, by leveraging the significant private and international investments in this frontier endeavor. The committee further recommends as a goal that access should be sought at the level of at least a 25 percent share. This share could be secured through whatever combination of construction (that is, MREFC), operating funds, and instrumentation support is most favorable.

The committee believes that access to a GSMT will, as opportunities opened by large telescopes have in the past, transform U.S. astronomy by means of its broad and powerful scientific reach, and that federal investment in a GSMT is vital for the United States to be competitive in ground-based optical astronomy over the next two decades. These are the main reasons for its strong recommendation by the survey. The third-place ranking reflects the committee's charge, which required the prioritization to be informed not only by scientific potential but also by the technical readiness of the components and the system, the sources of risk, and the appraisal of the costs. LSST and several of the concatenation of candidates for the Mid-Scale Innovations Program were deemed to be ahead of GSMT in these areas.

Priority 4 (Large, Ground). Participation in an Atmospheric Čerenkov Telescope Array (ACTA)

The last decade has seen the coming of age of very high energy (TeV) astronomy. Very high energy gamma-ray photons are observed from cosmic sources through the flashes of Čerenkov light that they create in Earth's atmosphere. These events can be observed by large telescopes on the ground on moonless and cloudless nights, and the directions and the energies of individual photons measured. After a long U.S.-led period of development of this technique which yielded the discovery of a handful of sources, the field has taken off. The European facilities, HESS in Namibia and MAGIC in the Canary Islands, together, now, with the U.S. facility VERITAS in Arizona, have discovered 100 sources. These include active galactic nuclei, pulsars, supernova remnants, and binary stars. Astrophysicists have learned much about particle acceleration and can now rule out some models of

fundamental physics as well as constrain the properties of putative dark matter particles. Further progress is now dependent on building a larger facility exploiting new detector technology and a larger field of view so that the known sources can be studied in more detail and the number of sources can be increased by an order of magnitude (Figure 7.10).

Both the U.S. and the European communities are developing concepts for a next-generation array of ground-based telescopes with an effective area of roughly 1 square kilometer. The U.S. version of this facility (AGIS, the Advanced Gamma-ray Imaging System) was evaluated by the survey and the total cost, estimated to exceed \$400 million, was considered too expensive to be entertained, despite technical risk being medium low. The European Čerenkov Telescope Array (CTA) is in a more advanced stage, and there is advantage in sharing the costs and operations in a Europe-U.S. collaboration. The committee recommends that the U.S. AGIS project join CTA for collaboration on a proposal that will combine the best features of both existing projects. Funding availability is likely to permit U.S. participation only as a minor partner, but the promise of this field is so high that continued involvement is strongly recommended. U.S. funding should be shared among DOE, NSF-AST, and NSF-PHY, as happened with VERITAS, and a notional \$100 million spread between the agencies over the decade is recommended. Given the large project cost uncertainties, the current lack of a unified project plan, the project ranking, and the likely budget constraints in the coming decade, it will be necessary for the agencies to work quickly with the AGIS/CTA group to define a scope of U.S. involvement that is both significant and realistic.

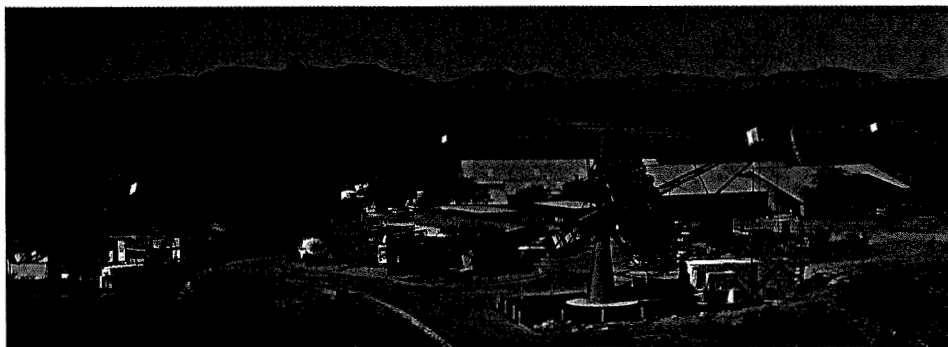


FIGURE 7.10 ACTA would be, like the pictured VERITAS (Very Energetic Radiation Imaging Telescope Array System), an array of Čerenkov telescopes used to detect very high energy (TeV) gamma rays emanating from astrophysical sources. The proposed ACTA telescope would be a larger-scale international version of this facility and similar ones located in Namibia and the Canary Islands that would increase the sensitivity by roughly an order of magnitude. SOURCE: Image courtesy of Steve Criswell, SAO.

The recommendation for ongoing U.S. involvement in TeV astronomy is based largely on the demonstrated recent accomplishments of this field and the prospect of building fairly quickly a much more capable facility to address a broad range of astronomy and physics questions over the next decade.

Recommendation for New Ground-Based Activities—Medium Project

Only one medium project is called out, because it is ranked most highly. Other projects in this category should be submitted to the Mid-Scale Innovations Program for competitive review.

Priority 1 (Medium, Ground). CCAT

CCAT (formerly the Cornell-Caltech Atacama Telescope) would be a 25-meter telescope operating in survey mode over wavelengths from 200 microns to 2 millimeters (Figure 7.11). CCAT is enabled by recent, dramatic advances in the ability to build millimeter-wave cameras with more than an order of magnitude more spatial elements than previously possible. This technical advance will enable a powerful submillimeter and millimeter telescope that can perform sensitive imaging surveys of large fields. ALMA, operating over the same band, is scheduled to begin full operations in 2014 and will produce high-resolution images and spectra of faint, and in some cases distant, sources. However, ALMA has a small field of view and is therefore inefficiently used to find the sources that it studies. CCAT will therefore be an essential complement to ALMA. It would excel as a sensitive survey facility, both for imaging and multiobject spectroscopy, with a field of view 200 times larger than that of ALMA. With a broad scientific agenda, CCAT will enable studies of the evolution of galaxies across cosmic time, the formation of clusters of galaxies, the formation of stars in the Milky Way, the formation and evolution of planets, and the nature of objects in the outer solar system.

The committee estimates a total development and construction cost of \$140 million and an estimated start of operations in 2020.²⁴ The technical risk was assessed as medium. It is recommended that NSF plan to fund \$37 million of the construction cost. This funding amount, as well as a potential NSF contribution to operations at the requested level of \$7.5 million, is contingent on an arrangement being negotiated that allows broad U.S. astronomical community access to survey products and competed observing time on a facility that should significantly enhance the U.S. scientific productivity of ALMA.

²⁴ The total construction cost is estimated to be \$110 million, and so with a third share for the federal government CCAT falls in the “medium” cost category.

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Telescope at the Mauna Kea Science)
Reserve, Kahohe Mauka, Hamakua)
District, Island of Hawai'i, TMK (3) 4-4-015:009)
_____)

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We hereby certify that a copy of the foregoing was served on the following via email unless otherwise specified below:

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