ASTRO 2020 FACILITIES WHITE PAPER

A Decade of US Community Access to the Large Millimeter Telescope *Alfonso Serrano*

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I. INTRODUCTION

The full 50m-diameter surface of the Large Millimeter Telescope *Alfonso Serrano* (LMT) was completed in 2018, and the telescope and many of its initial instruments have begun commissioning and early science activities.   Thus, as far as planning for the next decade goes, the telescope is ready to assume its place as a major facility for millimeter-wave astronomy. At this time, responsibility for funding the operation and future development of LMT falls on the partnership which built the telescope: the country of Mexico, led by the Instituto Nacional de Astrofísica, Óptica, y Electrónica (INAOE), and the University of Massachusetts at Amherst (UMass).   The central idea of this white paper is to encourage the US federal government to become an additional partner in this endeavor and thereby gain access to telescope time for the US scientific community during the coming decade.

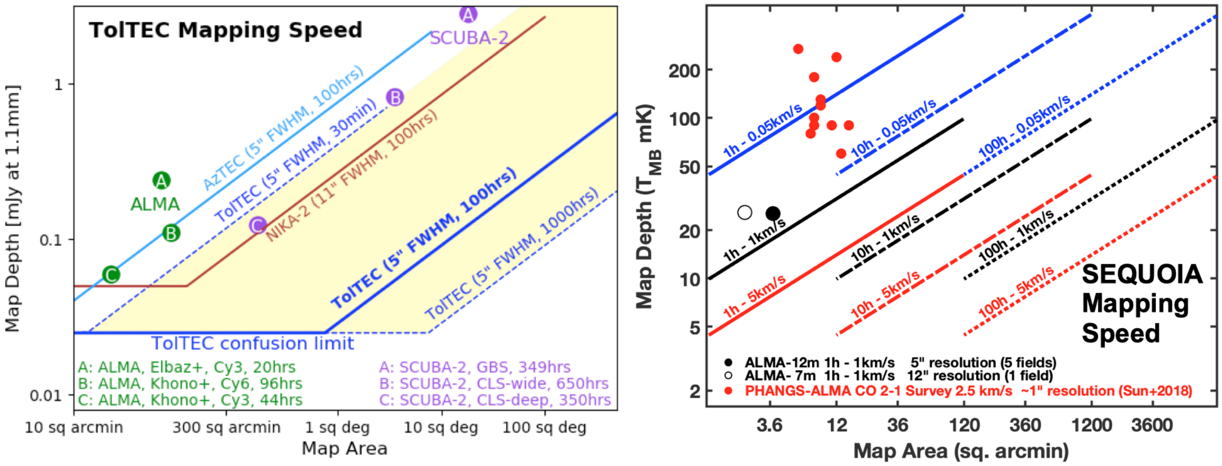

Figure 1 – Mapping speed calculations for LMT instruments compared to possible surveys with ALMA and other telescopes.. (Left) calculations for the TolTEC instrument compared to SCUBA2 and ALMA surveys. TolTEC represents a massive step forward for future millimeter-wave surveys (Right) Map speed for SEQUOIA focal plane array based on actual performance achieved during commissioning tests. Each curve notes total *required telescope time and spectral resolution. ALMA points (black) are based on Cycle 6 sensitivity calculator for 1h of integration time. Red points are map results from PHANGS-ALMA survey (Sun et al. 2018). All map depths are given at the 1-sigma level.*

Astronomers have little doubt about the value of a 50m-diameter millimeter-wave antenna, even in the era of the Atacama Large Millimeter Array (ALMA).   Although ALMA is an extraordinary and powerful instrument, it is recognized that a large single-dish antenna provides important capabilities that either cannot be achieved at ALMA or would require unrealistic investments of observing time to achieve. A large single-dish telescope can complete surveys of the sky in the continuum thousands of times faster than ALMA and identify large numbers of new sources for ALMA followup. Spectral line mapping surveys may be carried out on a large single dish at speeds comparable to or exceeding ALMA capabilities, depending on the investment in focal plane array instruments for the antenna. Large single dish facilities will also be highly complementary to proposed future facilities like the ngVLA. The ASTRO 2010 Decadal Survey recognized the desirable features of a large filled aperture telescope with the identification of a 25m-scale submillimeter antenna as its sole “intermediate-scale” priority for the 2010-2020 decade. This telescope was not built, but the desire for such a system remains, as evidenced by the recent recommendation of the concept as a part of the ALMA Development Roadmap and development activities in Japan (LST: Kawabe et al 2016) and in Europe (AtLAST: Klaassen et al. 2019).

Given the above argument, the main requirement for this document is to present the case that the 50m-diameter LMT, specifically, will be able to tackle the scientific projects that are most appropriate to a large single dish. Thus, in the next section (II), we highlight some of the scientific questions described in ASTRO 2020 science white papers that are well addressed with the LMT's capabilities. We then address the question of whether LMT is up to the job and provide a description of the tasks that are needed to bring a "national-class" millimeter-wave observatory based on the LMT to the US Community. With the support of that community and the federal government, we seek to make LMT accessible to and useful to astronomers from outside the original LMT collaboration so that they may *immediately* pursue the compelling science questions posed in the ASTRO 2020 survey.

II. EXAMPLE LMT SCIENCE PROJECTS FOR ASTRO 2020

II.1 The Cosmic History of Star Formation. The coming decade will see incredible increases in our ability to map out wide areas of the unobscured Universe (e.g. WFIRST, Euclid, LSST, DES, HETDEX, PFS, etc. at optical and near-IR wavelengths). The LMT can uniquely provide the US community with a complementary probe of the obscured Universe at millimeter wavelengths, which is crucial for both completing our census of cosmic star formation and understanding what drives it over cosmic time. The surveys that can be contemplated offer opportunities to address many key questions about the cosmic history of star formation found in the ASTRO 2020 science white papers:

- How do gas flows into and out of galaxies regulate star formation and supermassive black hole growth over cosmic time?
- What are the physical conditions in star forming clouds and how are they related to star formation and feedback processes?
- When and how does the growth of large scale structure/environment ("cosmic web") impact this process?
- When and how do the first galaxies and seed black holes form and what are the physical conditions of the gas fueling these processes?

LMT's Role: Our census of the cosmic star formation rate density of the Universe remains incomplete above z>3. At z~2-3 galaxies are forming stars ~20 times faster than similar mass galaxies in the local Universe, and the majority of this star formation activity is obscured by dust (see Madau & Dickinson 2014 for a review). At higher redshifts, observations of dust-obscured star formation have been limited by the large beams and low sensitivities of small single-dish telescopes and limited areas of interferometric observations. While UV observations assume the dust corrections are minimal at early times, there are many examples of individual galaxies which violate these assumptions. The only way to make a complete census of star formation over all cosmic time is to directly detect the dust-obscured activity which is redshifted to millimeter wavelengths at z>3 (Casey et al. 2019 [NOTE: all references to ASTRO2020 science white papers are underlined]).

The LMT will use two important tools for this purpose. The TolTEC instrument, which is due to be installed on the LMT in the coming year, is a multicolor (1.1, 1.4, and 2.1mm) camera / polarimeter with approximately 10,000 pixels. TolTEC on the LMT provides a quantum leap in continuum mapping and surveys that will far exceed the capabilities of ALMA. The Redshift

Search Receiver is an ultrawideband (38 GHz) receiver/spectrometer for the 3mm atmospheric window. This capability is already available at the LMT (see figure 2) and allows blind searches to be made for objects at high redshift that have been identified through continuum surveys.

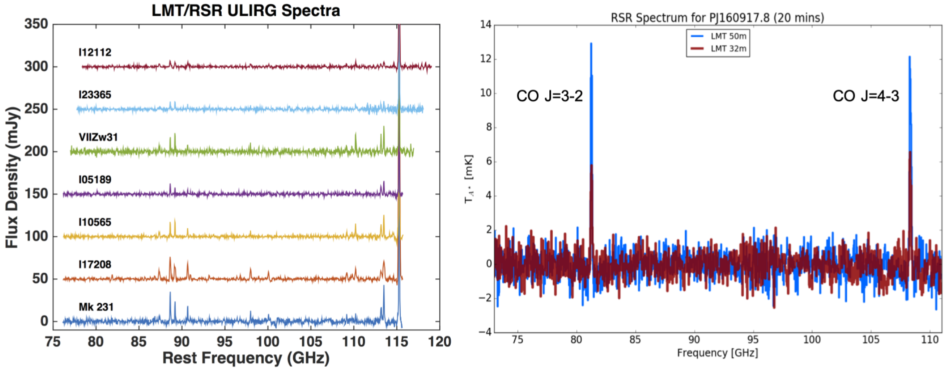

Figure 2 – Examples of spectra from the Redshift Search Receiver on LMT. (left) Sample spectra obtained on several ULIRG sources; (right) Comparison of spectra obtained with 32m LMT (red) and 50m LMT (blue) on lensed source PJ160917.8 at redshift of 3.2. The increase in signal agrees with expectation for the 50m-diameter dish.

With TolTEC on the 50m LMT, we will detect all galaxies with dust-obscured star formation rates down to 10Msun/yr at any redshift, thanks to the strong negative K-correction at millimeter wavelengths. Ultra-deep surveys with LMT/TolTEC in premier extragalactic fields (on order of a square degree) will yield tens of thousands of millimeter detections, roughly 1/3 of which are expected to be at z>3 (Pope et al. 2019), providing the necessary statistics to make an unbiased census of the dust-obscured star formation at these early epochs. These surveys will provide the crucial bridge between the faint UV-selected galaxy populations from HST and JWST with the extreme lensed dusty galaxy populations discovered by SPT, ACT, and Herschel. Wider area (>100 sq. deg.), deep surveys with the LMT/TolTEC can provide the survey volume to overcome cosmic variance and are ideally suited for identifying the first dusty galaxies into the epoch of reionization (Cooray et al. 2019 and Casey et al. 2019).

The LMT will not only fundamentally measure the total cosmic star formation obscured by dust, but it will also measure what drives the rise and fall of the star formation rate density over cosmic time. While it is clear that the evolving gas supply from the intergalactic medium, feedback from AGN and star formation, and the environment are all important, their relative roles as a function of redshift are unknown. The LMT will uniquely probe each of these major drivers of galaxy evolution to map out how these drivers of star formation evolve with redshift: 1) by detecting redshifted lines of CO and/or dust continuum as a proxy for the ISM mass (Scoville et al. 2016), the LMT will constrain the molecular gas supply in significant statistical samples of galaxies over a range of environments (Walter et al. 2019 and Harrington et al. 2019); 2) by measuring the SZ signal from stacks of galaxies (selected to be star forming or AGN), the LMT will measure the heating of individual galaxy halos (Battaglia et al. 2019); and 3) by imaging wide areas (50-100 sq. deg) at 1.1, 1.4, and 2.1 mm wavelengths, the LMT will detect galaxy clusters through the SZ effect (Mroczkowski et al. 2019) and determine how the locations of dusty star forming galaxies within the cosmic web evolve with redshift (Dannerbauer et al. 2019).

II.2 Detailed Studies of Star Formation. Our understanding of star formation requires both a broad knowledge of its history in the Universe as well as detailed studies of the process at work in nearby galaxies and within our own galaxy. Most information comes from the molecular interstellar medium of galaxies, which is the reservoir of material from which new stars form. The gas in this molecular phase is usually cold (T ~ 10-20 K) and dense (n > 500 cm-3) relative to the overlying substrate of neutral atomic gas, and it is best probed with velocity resolved observations of spectral line emission from the low excitation rotational transitions of molecules in the millimeter and submillimeter bands. The chemical composition of molecular gas is a product of time and local conditions such as the FUV radiation field, cosmic ray ionization and dissociation, dust grain properties, optical depth, density, and temperature. Abundances of key molecules offer insight to the relevant chemical processes that may operate in a given environmental domain. The mean gas density and temperature along a line of sight through a cloud is derived from line ratios of different rotational energy levels for a given molecule. Spectroscopy also provides kinematic information on both systematic and chaotic (MHD turbulence) flows within an interstellar cloud or across a galactic disk. Such flows are responsible in part for the formation of giant molecular clouds at kpc scales and dense gas configurations within molecular clouds from which protostars and protoclusters develop (Dobbs et al. 2014).

Studies of the molecular interstellar medium, its relationships to the other phases of the interstellar medium, and its properties in star forming regions will allow a number of ASTRO 2020 scientific questions to be addressed:

- What processes regulate the formation and fragmentation of gravitationally unstable dense gas configurations in molecular clouds and the rate, efficiency, and mass distribution of stars that ultimately form?
- How do dense, star forming regions arise in a galaxy? What physical, chemical, and dynamical parameters determine the balance and transition between different gas components (e.g., atomic, low-density molecular, high-density molecular) on a galactic scale?
- How does this balance affect the efficiency of star formation within galaxies; how has this balance evolved with cosmic time, and how does it depend on both the internal and external galactic environment; what conditions within the galactic environment determine the fraction of dense gas that will ultimately result in a bound star cluster?
- What is the interplay between gravity and stellar feedback in determining the turbulence of the interstellar medium?
- What role does dust play and how has it affected galaxy evolution as a function of cosmic time?

LMT's Role: Studies of the distribution and properties of molecular clouds in nearby galaxies and within our own Galaxy are key to probing the detailed behavior of star forming clouds and thereby addressing the above questions. This work relies on two critical strengths of a large filled aperture millimeter-wave telescope: (1) the ability to make high resolution maps with sensitivity to low brightness tracers of physical properties within the clouds; and (2) the ability to trace structures with equal sensitivity spanning a very wide range of physical (angular) scales. LMT provides two important focal plane arrays for spectral line mapping observations designed to address these questions. The 16-element SEQUOIA focal plane array for 85-115 GHz observations has been installed and commissioned on the LMT (see figure 3). The 16-element OMAyA focal plane array receiver for spectral line mapping observations in the 210-280 GHz window will be completed and installed on the LMT within the next year. These receivers provide excellent mapping speed capabilities for molecular clouds in the Milky Way and nearby galaxies and are superb complements to the incredible continuum speed of TolTEC.

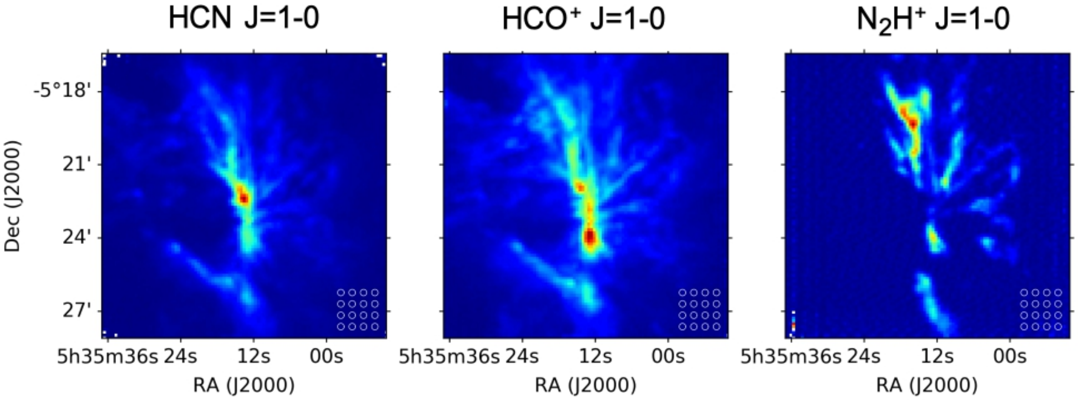

Figure 3 – Commissioning maps of the central region of the Orion Molecular Cloud obtained with the 16-element SEQUOIA focal plane array on 50m-diameter LMT. (left) peak intensity of HCN J=1-0; (center) peak intensity of HCO^+ *J=1-0; (right) peak intensity of* N_2H^+ *J=1-0. The footprint of the SEQUOIA array is shown in lower right corner of each figure. RMS per Nyquist cell (7”) is approximately 65mK in a 1 km/s channel; maps took approximately ½ hour to complete.*

Within the Milky Way, we seek to understand the formation and fragmentation of gravitationally unstable dense gas configurations in molecular clouds and the nature of the stars that eventually form. These topics may be addressed with both thermal dust continuum imaging with LMT/TolTEC and with spectral line maps of key diagnostic molecular line transitions using the SEQUOIA and OMAyA arrays (Friesen et al. 2019; Gutermuth et al. 2019; Kauffmann et al. 2019). In addition, polarimetric imaging with TolTEC will provide extremely detailed maps of the magnetic field lines that thread the dense gas (Fissel et al. 2019). Key targets are those cores that have not yet formed stars (pre-stellar cores) as deduced by Spitzer, Herschel, or JWST infrared observations (Sokol et al. 2019). The early evolution state of these cores, together with their temperatures and densities, are measured through the relative abundance of deuterated to non-deuterated molecules (ex. $[N_2D^+]/[N_2H^+]$), Caselli et al. 2002; Fontani et al. 2011; Kong et al. 2016) and molecular transitions in the 1 and 3 mm bands (CH_3C_2H, CH_3CN, HC_3N) (Bergin et al. 1994, 1996). Other spectral line combinations mapped across areas larger than the targeted core yield information on infalling motions, velocity gradients, and the converging flows that may lead to formation of the cores (de Vries & Myers 2005). Observations of large samples of cores across a range of environmental conditions enables the development of an observationally constrained view/theory of how cores form and how their masses are determined by local conditions. With this foundation provided by the LMT, ALMA can probe to much finer scales to resolve the question of how stars derive their mass (Tobin et al. 2019).

Observations of external galaxies will yield lower spatial scales than studies of the Milky Way, but they provide the linchpin to connect star formation to the galactic ecosystem by covering the full range of galactic locales, from individual molecular clouds to entire structures (e.g., spiral arms, circumnuclear rings of star formation, starbursts, etc.). With its ability to measure the low surface brightness emission of mm-wave molecular lines (CO, HCN, HCO^+, etc.), including their isotopologues, and the 1mm thermal dust continuum emission, the LMT probes the cold gas distribution and kinematics across the spatial and density regimes of the entire interstellar gas sequence (Murphy et al. 2019, Simon et al. 2019, Thilker et al. 2019). The LMT will be able to map several hundred galaxies over their optical diameters, covering the full range of chemical and physical galactic properties within the local 20 Mpc, and resolving structures from ~10 pc (the size of a small molecular cloud) to 1.5 kpc, depending on distance. The LMT and ALMA cover complementary and adjacent spatial scales, which will enable continuous coverage of the star formation sequence covering scales from the largest LMT maps (several sq. deg. at 6-15 arcsec resolution) to the ALMA angular resolution (~0.1 arcsecs).

II.3 Probing Supermassive Black Holes with the Event Horizon Telescope: The announcement of the first image of a black hole on April 10, 2019 was a major milestone in astrophysics. This achievement was accomplished by the Event Horizon Telescope, which is a Very Long Baseline Interferometry experiment that includes ground based millimeter-wave telescopes from all over the world. EHT is expected to continue its work into the next decade and provide ever improving imaging of the supermassive black holes in M87 and the Milky Way. Important goals of the improved array include: (1) testing of General Relativity on the scale of the Event Horizon; (2) imaging of the black hole and jets to study the origin of jets; and (3) construction of “movies” of the emission from the black hole accretion disk to study the flows of material in these structures (Doeleman et al 2019).

LMT's Role: Future plans for the EHT depend heavily on the LMT. The 50m-diameter LMT has one of the largest collecting areas in the array, and its geographical location within the EHT array make it a critical participant in EHT experiments.

III. TECHNICAL DESCRIPTION

III.1 Background: The LMT is a 50m-diameter millimeter-wave radio-telescope designed to operate at wavelengths between 0.85 and 4 millimeters. It is recognized that building this large, complex system has been a significant challenge for the LMT partners. A change in project leadership in 2011 led to significant advances in the state of the telescope so that, by 2013, the inner 32.5m of antenna surface was completed to an accuracy of approximately 85 microns RMS. Successful use of the telescope in early science campaigns between 2013 and 2017, and the demonstration of new techniques for assembly of the surface ensured the necessary investment by the Mexican Government to complete the full 50m-diameter structure in early 2018.

The current capabilities of the LMT are documented in detail on the telescope's web site: www.lmtgtm.org. The telescope makes use of an active primary surface to maintain alignment of its 2000 square meter collecting area over all elevation angles. The years of experience using the antenna's inner 32.5m-diameter for commissioning and early science activities have allowed the group to develop the expertise needed to bring the full 50m dish on line. At this time, surface setting activities for the full 50m antenna surface continue with the expectation of RMS values similar to or better than the 85 micron RMS setting achieved for the inner 32.5m. The antenna pointing has proved to be reliable under thermally stable night-time conditions with offset pointing accuracies of 1 arcsec or better for wind speeds under the nominal operational specification of 10 m/s.

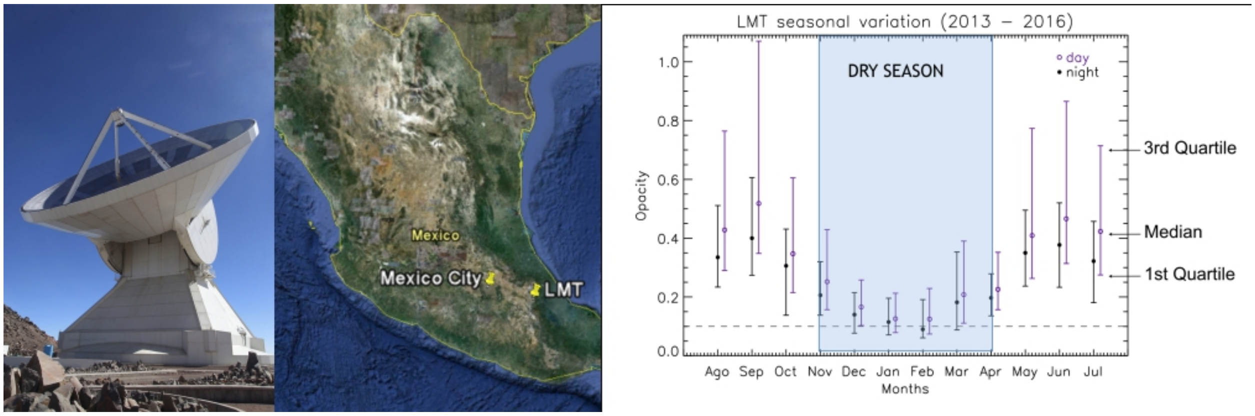

Figure 4 (left) LMT; (center) LMT location in Mexico; (right) Seasonal opacity at 225 GHz.

The LMT is located in the state of Puebla, Mexico atop a 4600m peak. The site conditions are seasonal, but qualitatively better than those of other existing large millimeter-wave antennas. Figure 4 shows the results of measurements of the 225 GHz opacity at the site during the period 2013-2016. The winter months at LMT have a significant number of observing hours available (~300) with submillimeter quality opacities.

During the past year of commissioning work, the LMT schedule has been impacted by a security challenge posed by criminal activity in the region of the telescope and its surrounding communities. The LMT has been advised on this matter by the Mexican Government and by professional security consultants in the US, and it has been determined that safe operation requires security escorts for personnel going to the site. Accessibility to the site is therefore now limited to critical personnel, and the LMT is responding to its user community by moving to an operational model of service observing and increased remote access to allow observers to conduct their science program on the telescope.

III.2 ASTRO 2020 Project Description: We seek to create a *national-class* observatory that will support the use of the LMT by the US astronomical community. By agreement with Mexico, UMass controls 30% of the observing time on the LMT. We propose to make half of this time (15% of the total, corresponding to 50 days each year) available to the US Community in return for financial support. In addition to this baseline commitment, we believe that the engagement of NSF as a partner in the LMT will lead to a negotiation with their Mexican counterpart that might make additional time available given a willingness to invest in system infrastructure projects. In the paragraphs below, we summarize the tasks that need to be supported in order to accomplish this goal.

<u>III.2.1 Operations Support</u>: The nominal annual operation cost of the LMT is $72 million Mexican Pesos, corresponding to approximately $3.6 million US Dollars. The annual budget for operation includes all costs associated with basic scientific operation and maintenance of the telescope, the site facilities, and other relevant infrastructure. It also includes some modest funding for ongoing development of the facility. We seek to support a portion of the base cost of

operating the telescope to enable users from outside the original LMT collaboration to gain access to the telescope.

III.2.2 Science Support: Opening access to the LMT through operational support is only part of the story. Users from outside the LMT collaboration will rightly expect the same efficiency and user support that would be found at any of our national observatories. These expectations place additional requirements on the telescope's general performance and on the staff of the LMT Observatory. Fulfilling these expectations will require additional funding. The most pressing needs are: *(1) Telescope Systems and S/W Personnel [four staff members]* to maintain and develop the telescope's active control systems and work to improve telescope performance; *(2) Science S/W Personnel [four staff members]* to write and maintain S/W for data reduction and analysis pipelines and develop a data system archive to allow for storage and archival use of LMT data; and *(3) Scientists for Observer Support [four postdoctoral fellows]* to carry out "support observing" so that there is no requirement for travel to the LMT site for persons outside the collaboration, though interested observers could participate remotely if they so chose. The Support Scientists would also play a central role in the development of telescope capabilities by conducting engineering observing tests and participating on technical improvement teams.

III.2.3 Telescope Infrastructure Support: It is in the best interest of the LMT user-community to enhance the performance of the telescope, improve the reliability of telescope systems, and expand the amount of useful time that is available. The most critical and cost effective investments are:

Active Surface Actuator Replacement. The LMT's active surface relies on a system of actuators to continuously maintain the alignment of the antenna surface. Although the initial set of actuators developed in 2005 and acquired for the inner 32.5m of the antenna (approximately half of the total number) has performed adequately so far, it is expected to require replacement within the next 2-3 years. For replacement we would use a new design installed during the recent completion of the outer part of the antenna surface. Testing of the new design demonstrates a 30-year lifetime for these devices.

Drive System Upgrade. The LMT antenna drive system is now approximately 15 years old and some replacement/spare components of the system are becoming hard to purchase. The LMT Collaboration seeks to upgrade portions of the system to guarantee continuous operation through the lifetime of the telescope.

Real Time Surface Measurement. At the present time, observations at the LMT have been limited to night-time conditions in order to minimize the effects of temperature gradients induced by solar heating. The performance of the telescope could be enhanced, and the available observing time increased, if the shape of the surface could be measured in real time to remove deformations. Laser scanner and laser truss technologies have been demonstrated on other antennas and should be straightforward to implement at LMT. Improved surface control would make more observing hours available on the LMT and increase the telescope's efficiency, particularly at the highest frequencies.

Spectrometer Upgrade. The LMT's existing focal plane arrays have 16 pixels. At present the telescope has a single spectrometer that allows a spectrum to be obtained for each pixel. However, the receiver bandwidth is much greater than the single spectrometer, and it is straightforward to increase the number of spectral lines that could be observed simultaneously with the focal plane arrays by a factor of 4 by simply replicating the existing system. Time multiplexing is a cost effective way to make more observing hours available on the telescope for the community of observers.

III.2.4 The Future of LMT Instrumentation: The remarkable capabilities of the TolTEC instrument demonstrate that the LMT, equipped with advanced instrumentation for spectroscopic work, will be a potent force in the future. The existing spectral line focal plane arrays only cover about 1/16th and 1/100th of the antenna's 4 arcminute field of view at 3mm and 1.3mm respectively. Thus, one may imagine new, larger, focal plane arrays that would improve the mapping performance of the telescope by over an order of magnitude. Moreover, a modest change to the optics of the antenna could quadruple the field of view to allow a full array to achieve two orders of magnitude improvement.

In this project concept we have concentrated on enabling useful access to the LMT and make no specific proposals for new instrumentation. Nevertheless, our long term goal is to provide the LMT user-community with new instrumentation that best exploits the capabilities of the antenna, and we are interested in working with groups outside the original LMT collaboration to accomplish this.

IV. TECHNOLOGY DRIVERS

The 50m LMT has been completed, and the proposed elements of the ASTRO 2020 plan for LMT contain no “technology drivers” to be considered.

V. ORGANIZATION AND PARTNERSHIPS

The LMT was built by a partnership including institutes in Mexico, led by the Instituto Nacional de Astrofisica, Optica, y Electronica (INAOE), and the University of Massachusetts at Amherst. The working relationship is codified under a Memorandum of Understanding (MOU) between INAOE, UMass, and the Consejo Nacional de Ciencia y Technologia (CONACyT), which is the federal science agency in Mexico. The current governing body of the collaboration includes representation from all three parties to the MOU.

Looking toward the future operation of the telescope, the LMT collaboration has agreed to form a new Observatory structure dedicated to the maintenance and development of the telescope and its systems. The Observatory organization will be governed by a Board with representatives of the collaboration from Mexico and UMass. Under the agreement, UMass has access to 30% of the observing time on the LMT each year, assuming payment of 30% of the annual costs of operating the telescope.

VI. SCHEDULE

The major tasks to support the ASTRO 2020 program are a level of effort for support of the operation. The duration of the telescope infrastructure projects is each approximately 2 years.

VII. COST ESTIMATE

Table 1 summarizes the costs of the various components of the LMT's ASTRO 2020 concept.

VII.1 Annual Operations Cost: The annual operating costs of the LMT are based on the telescope's current operating costs. UMass is required to pay 30% of this cost to maintain control of a 30% share of the observing time. As noted in the project description, we intend to supplement the nominal LMT operating effort with additional personnel in order to enable the staff to provide a level of service commensurate with the expectations of a national-class Observatory.

VII.2 Infrastructure Project Costs: The cost estimates of the four infrastructure projects are based on catalog prices or on costs actually incurred in the procurement of similar systems for the telescope.

TABLE 1

ITEM		COST (USD)	BASIS FOR ESTIMATE
ANNUAL OPERATIONS COSTS		**2,300,000**	
Site Operations	1,080,000		30% of current annual operating budget (72 million Mexican Pesos)
Support Personnel (8 staff; 4 postdocs)	1,220,000		Cost of UMass Professional Staff (including fringe benefits); Support Scientists budgeted as postdocs.
INFRASTRUCTURE PROJECT COSTS		**4,142,000**	
Actuator Replacement (inner 32.5m)	2,000,000		Cost of actuators and control system procured for the outer section of the antenna surface, including all support H/W, cables, shipping and import taxes.
Drive System Upgrade	800,000		Adjusted cost of original unit.
Real Time Surface Measurement H/W	526,000		Catalog prices of hardware
Spectrometer Upgrade	816,000		Engineering estimate based on cost of components for the present spectrometer at LMT.
ASTRO 2020 PROJECT SUMMARY		**27,142,000**	
Operations Costs (10 years)	23,000,000		
Infrastructure Projects	4,142,000		
Number of Observing Days (15%)		500	Adopt 50 days observing per year given 10% of total time for maintenance and engineering.
Cost per Day		54,284	

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