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Michael G. Richer[a], William H. Lee[b], Leopoldo Altamirano[c], J. Jesús González[d], Charles Alcock[e], Buell Jannuzi[f], Fabián Rosales-Ortega[g], Marisa García-Vargas[h], Joel Herrera Vázquez[i], Derek Hill[j], María Herlinda Pedrayes[k], Ana Pérez Calpena[l], Mauricio Reyes Ruiz[m], Lino Hector Rodríguez Merino[n], Beatriz Sánchez[o], Hazael Serrano Guerrero[p], Gerardo Sierra Díaz[q], Andrew Szentgyorgyi[r], Jose Teran[s], David Urdaibay[t], Jorge Andrés Uribe Uribe[u], Alan M. Watson[v], Dennis Zaritzky[w], Mario Rascon[x], Urania Ceseña Borbón[y], Francisco Murillo Bracamontes[z], Fernando Quirós Parra[aa], and Erika Sohn[ab]

[a,i,k,m,p,q,y,z,aa]Instituto de Astronomía, Universidad Nacional Autónoma de México, km 107 Carr. Ensenada-Tijuana, Ensenada, BC, Mexico
[b,d,o,t,v,ab]Instituto de Astronomía, UNAM, Ciudad Universitaria, Mexico City, Mexico
[c,g,n]Instituto Nacional de Astrofísica, Óptica y Electrónica, Luis Enrique Erro # 1, Tonantzintla, Puebla, Mexico
[e,r]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA, USA
[f,w,x]Dept. of Astronomy, University of Arizona, 933 North Cherry Ave., Rm. N204, Tucson, AZ, USA
[h,l]FRACTAL S.L.N.E., C/ Tulipán 2, P13-1A. E-28231 Las Rozas de Madrid, Madrid, Spain
[j,s]M3 Engineering & Technology Corp., 2051 W. Sunset Rd., Suite 101, Tucson, AZ, USA
[u]Centro de Ingeniería y Desarrollo Industrial, Av. Playa Pie de la Cuesta No. 702, Desarrollo San Pablo, Querétaro, Querétaro, Mexico

ABSTRACT

The Telescopio San Pedro Mártir project intends to construct a 6.5m telescope to be installed at the Observatorio Astronómico Nacional in the Sierra San Pedro Mártir in northern Baja California, Mexico. The project is an association of Mexican institutions, lead by the Instituto Nacional de Astrofísica, Óptica y Electrónica and UNAM's Instituto de Astronomía, in partnership with the Smithsonian Astrophysical Observatory and the University of Arizona's Department of Astronomy and Steward Observatory. The project is advancing through the design stage, having completed five design reviews of different subsystems in 2016 and 2017 (enclosure and services: PDR, CDR; optical design: PDR; optics: progress review; telescope: PDR). Once completed, the partners plan to operate the MMT and TSPM as a binational astrophysical observatory.

Keywords: TSPM, OAN-SPM, telescope project, optics, enclosure, site, Mexico

1. INTRODUCTION

The Telescopio San Pedro Mártir (TSPM) project intends to construct a 6.5m telescope to be installed at the Observatorio Astronómico Nacional in the Sierra San Pedro Mártir (OAN-SPM) in northern Baja California, Mexico. The project is an association of Mexican institutions, lead by the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE) and UNAM's Instituto de Astronomía (IA-UNAM), in partnership with the Smithsonian Astrophysical Observatory (SAO) and the University of Arizona's Department of Astronomy and Steward Observatory (UA). The project is advancing through the design stage, with the goals of delivering the final design of the enclosure and services as well as initiating the advanced design of the telescope in 2018. This report complements and extends information published previously.[1–4]

Further author information: (Send correspondence to M.G.R.)
M.G.R.: E-mail: richer@astro.unam.mx, Telephone: +52 646 174 4580 x234
W.H.L.: E-mail: wlee@astro.unam.mx, Telephone: +52 55 5622-4020

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The telescope's mechanical design is inspired by the Magellan telescopes (Las Campanas, Chile). The principal change is to move the Nasmyth focal stations slightly farther from the primary to allow a wider field of view. The primary mirror cell will be completely compatible with the MMT telescope's Cassegrain focus. This design is being lead by the Centro de Ingeniería y Desarrollo Industrial (CIDESI) in Querétaro, Mexico. Initially, the telescope is to operate in a f/5 Cassegrain configuration, before future definition and expansion to its other focal stations, including Nasmyth and folded Casssegrain configurations.

The enclosure is being designed by M3 Engineering and Technology Corp., through their branch in Hermosillo, Mexico. The design borrows elements from the Magellan telescopes, but accounts for the particular needs of the San Pedro Mártir site. The primary mirror will be polished at Steward Observatory's Richard F. Caris Mirror Lab. The telescope will initially use the f/5 Cassegrain secondary currently at the Magellan II Clay telescope. The first light instruments are expected to be the Megacam and MMIRS instruments, currently at the Magellan II and MMT telescopes, respectively.

Once completed, we anticipate that the collaboration and coordination of the two observatories will provide their communities the benefits of a binational astrophysical observatory serving astronomers from all partner institutions, with each site focussing upon its strengths. The TSPM, thanks to its wide field imaging capability, will allow state-of-the-art research on planetary, Galactic and extragalactic astronomy, variable sky studies, and large scale surveys. TSPM will be complementary not only to the MMT for large scale, high-impact programs, but also to multi-frequency collaborations that could exploit current Mexican facilities, such as the Gran Telescopio Milimétrico Alfonso Serrano (GTM) and the High-Altitude Water Cherenkov Gamma-Ray Observatory, HAWC. The TSPM will also represent a excellent follow-up complement for 20+m class telescopes after 2020.

2. SCIENCE

In compliance with the TSPM High Level Requirements, the TSPM shall be suitable for general science projects; in the understanding that the TSPM should have comparable flexibility to facilities such as the MMT, Magellan, Keck, Gemini, VLT, and GTC, and not be a single-purpose facility such as LSST, Pan STARRS, and VISTA. At present, the TSPM science case is based almost entirely upon efforts and interests of the Mexican astronomical community. However, a long-term goal is to operate both the TSPM and MMT as a joint bi-national astrophysics laboratory, with access to both telescopes by all of the communities involved in the TSPM project, and to take advantage of the specific capabilities of each telescope in order to perform specific and large-scale scientific programs.

During its first stage of operation (the so-called Day-One operation period), the TSPM is intended to provide a functionally equivalent telescope to the f/5 Cassegrain configuration at the MMT, with a field of view (FoV) of one degree, and instrumentation composed by a suite of optical and infrared cameras, and potentially new instrumentation with spectroscopic and/or polarimetry capability. Subsequently, during a second stage of the project, the general goal is to implement additional Nasmyth focal stations in order to accommodate larger instruments and to provide versatility to the telescope, according to the needs and scientific interests of the partners.

The TSPM key science drivers are complementarity for the current and future large telescopes, specific complementarity with the MMT, and time-domain astrophysics.

In the future era of large telescopes, it is important to stress the scientific potential of a medium-size telescope like the TSPM, and its co-existence with future large facilities such as the LSST, TMT, GMT, E-ELT, and the JWST. The relation of mid-size telescopes with large ones is synergistic, each providing support for the other. Discoveries made at large telescopes can often be most effectively exploited on smaller ones. Current 8-10m class telescopes and the future giant telescopes (+25m) are neither designed nor intended to perform large sky surveys with enough depth that are important for several science programs. The extreme expenses of the giant telescopes strongly limits the observing time available to much less than could be profitably used by the astronomical community. Therefore, a 6.5m class telescope such as the TSPM will be a complementary instrument and will play an essential role in the forthcoming decades in the scenario of the large-scale astronomical infrastructures that will be deployed around the globe. A 6.5m class telescope with a one degree FoV – with spectroscopic and polarimetry capabilities – represents a significant niche and could potentially explore a selection of scientific

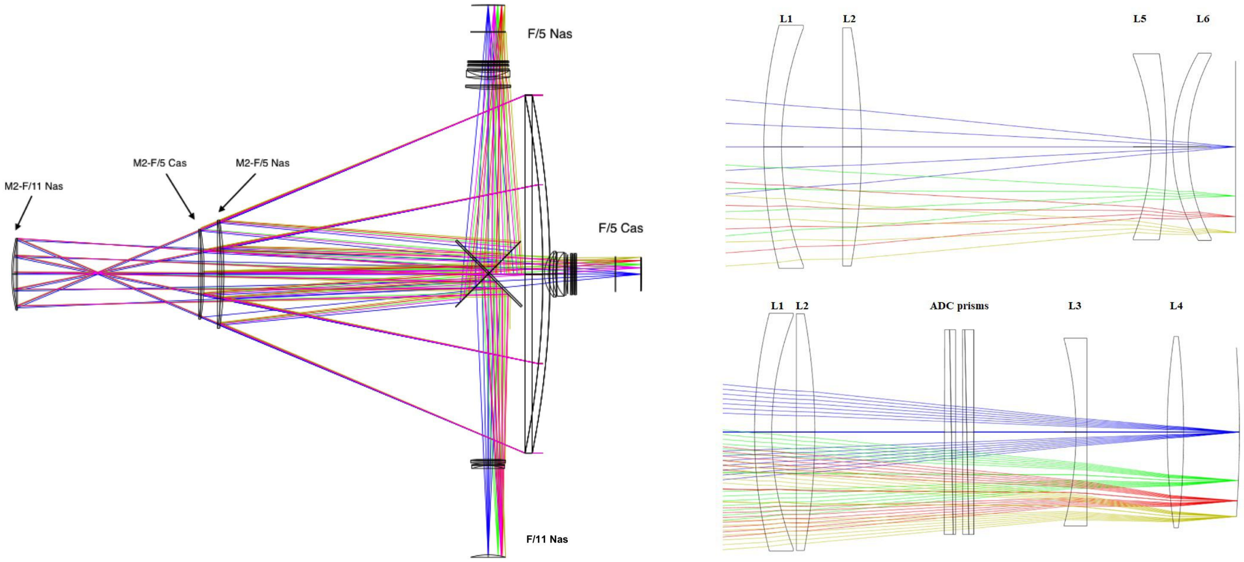
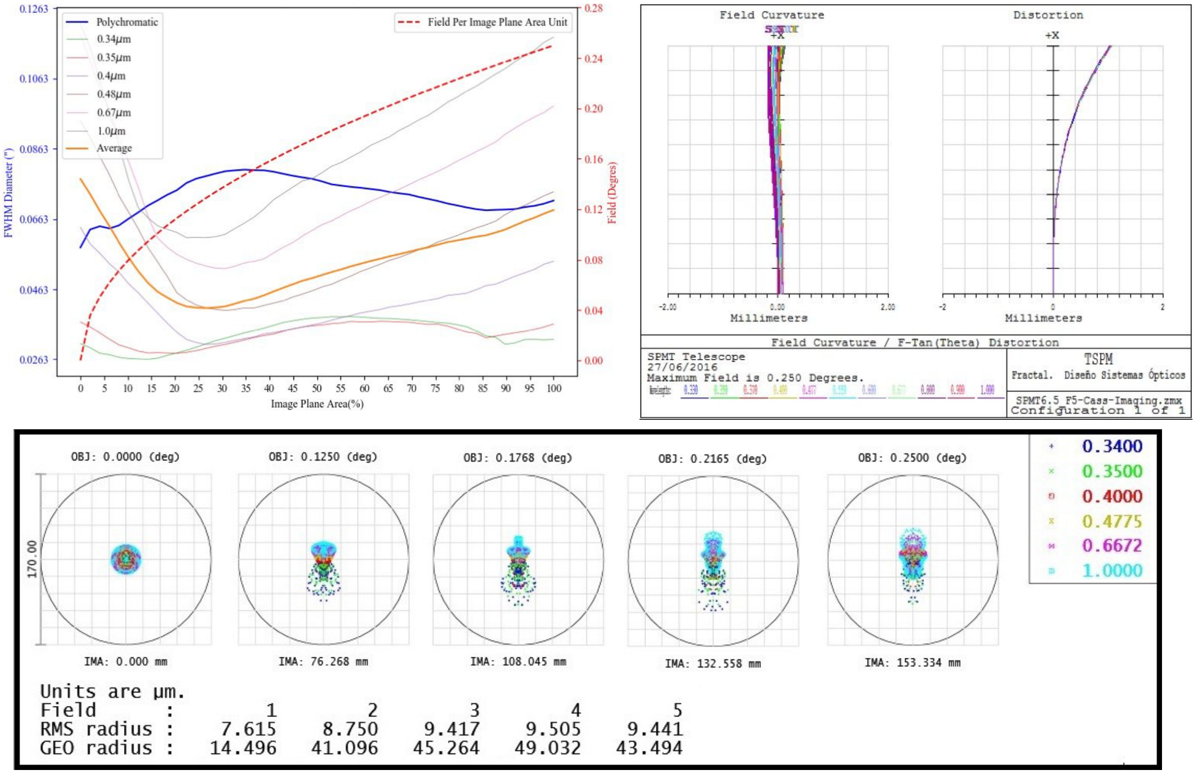


Figure 1. **left panel:** This figure presents the TSPM optical configurations considered in the project design. The f/5 Cassegrain configuration will be the "Day 1" configuration and is functionally equivalent to the f/5 Cassegrain focus at the MMT. The other configurations are indicative and used to dimension the building and telescope structure. The f/5 Nasmyth configuration drives the size of M3 and the telescope structure while the f/11 Gregorian configuration drives the height of the dome. **right panel:** These figures present the wide field correctors for the f/5 Nasmyth configuration in its imaging (top) and spectroscopy (bottom) modes. Both modes have an additional lens compared to the f/5 Cassegrain wide field corrector.

initiatives that span the entire range of astronomical research: from the study of planetary systems, formation and evolution of stars, galaxy dynamics, to the evolution of the Universe at large scale.

The operation of the TSPM and MMT telescopes as a joint observatory will optimize the use of both facilities considering the characteristics of each site and the configurations of both telescopes. The OAN-SPM is a darker site, optimal for large field of view observations in the optical. The MMT has a modern adaptive optics system (AO) when the secondary mirror of the shortest field of view is deployed, which makes it suitable for the study of individual objects in the near infrared, where the sky brightness is not an important issue. The versatility given by having two telescopes that could mount complementary instrumentation is an important added value that could duplicate the scientific return and productivity. Furthermore, as has been the case for every previous increase in capability of any astronomical infrastructure, it is very likely that the scientific impact of the joint TSPM/MMT observatory will go far beyond what the project envisions today. Therefore, considering the functionality expected from the TSPM during its first stage of operation and the science drivers described above, the niche opportunity for the TSPM would consist on exploiting the combination of the light gathering power of its 6.5-m primary mirror and the large FoV of the Day-One f/5 Cassegrain configuration.

Every time a new domain in astronomy is explored, either in sensitivity or wavelength, astronomers have discovered staggering information about the content, origin and evolution of the Universe. However, there is an important domain that remains largely unexplored: the study of targets that modify their brightness and/or characteristics as a function of time. Despite important efforts in the community, we remain largely ignorant of rapidly variable and transient sources in the sky. This is a rapidly evolving field and will play a very important role in the understanding of the evolution of astrophysical systems and their observable properties. Next Generation Imaging Surveys (NGISs), such as Pan-STARRS and LSST, will soon routinely produce hundreds to thousands of transients per night. The phase space for new discoveries is enormous and the TSPM could position itself in the international arena to capitalize it. Monitoring variable objects, especially if full phase coverage is essential, requires telescopes with stable instrumentation and very flexible schedules. The TSPM project acknowledges that this is only possible during the envisaged second stage of the project, i.e. a telescope of a large field of view



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Units are µm.
Field      :       1        2        3        4        5
RMS radius :   7.615    8.750    9.417    9.505    9.441
GEO radius :  14.496   41.096   45.264   49.032   43.494
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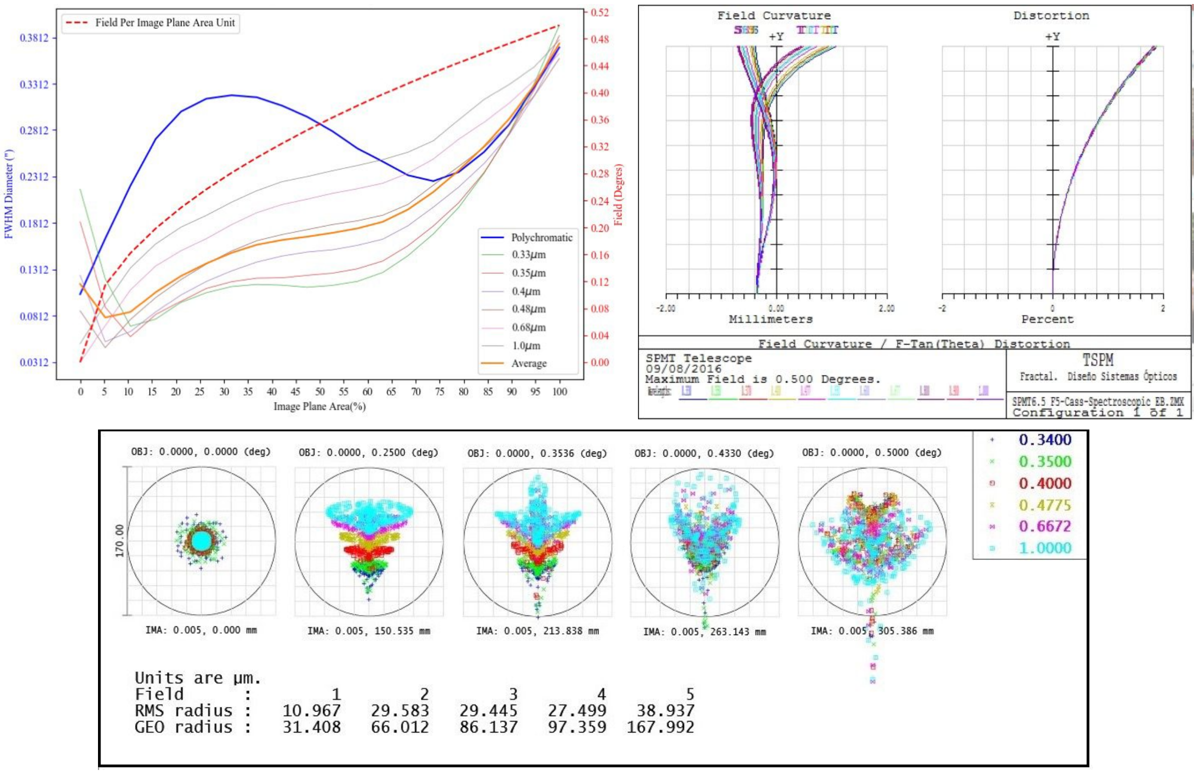
Figure 2. These figures present the design performance for the f/5 Cassegrain configuration in imaging mode. **left panel:** The solid curves present the average spot size (FWHM) as a function of the field size. The average is over equal areas while the field area is expressed as a percentage of its total area (0.25° radius). The single dashed curve plots the field size in degrees as a function of the fractional area. **right panel:** The field curvature and distortion, both measured in mm, are plotted as a function of radius and wavelength. The maximum radius plotted is 0.25 degrees. **bottom panel:** The spot diagrams for different wavelengths are plotted for different radii from the optical axis.

and the versatility offered by the implementation of additional Nasmyth and folded-Cass focal stations and new instrumentation. This potential configuration might open the verge of a whole new parameter space and will stand in the forefront of modern astronomy through revealing the time domain, making significant contributions in the field.

3. OPTICAL DESIGN

The TSPM uses a 6.5 m honeycomb primary mirror (M1) cast by the University of Arizona's Richard F. Caris Mirror Lab, contributed by the INAOE and UA, and polished to the same prescription and specifications as the primaries of the MMT, Magellan, and Tokyo Atacama Observatory (TAO)[5] telescopes. The TSPM will use the existing f/5 secondary from the Magellan II (Clay) telescope together with its wide-field corrector (WFC),[6] contributed by the UA and SAO. The "Day 1" optical configuration is thus functionally equivalent to the f/5 Cassegrain configurations at the MMT and the Magellan II (Clay) telescopes. Two other optical configurations are currently under study that affect the telescope structure and the dome.[1] Since the long-term goal is that the TSPM be dedicated to wide-field, general science uses, one of the post-Day 1 optical configurations under study is f/5 Nasmyth. This optical configuration affects the telescope structure due to the large tertiary mirror required, which forces the optical/elevation axis away from the primary mirror. The other post-Day 1 optical configuration being studied is an f/11 Gregorian configuration, also at Nasmyth, as used at the Magellan telescopes. This configuration has an important impact on the size of the dome. Figure 1 presents the three configurations.

The f/5 Cassegrain optical configuration has two modes, imaging and spectroscopy, as at the MMT.[6] The maximum fields of view in the two modes are 0.5° and 1° in imaging and spectroscopy, respectively. To achieve



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Units are µm.
Field      :        1        2        3        4        5
RMS radius :   10.967   29.583   29.445   27.499   38.937
GEO radius :   31.408   66.012   86.137   97.359  167.992
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Figure 3. These figures present the design performance for the f/5 Cassegrain configuration in spectroscopy mode. The three panels present the same information as in Figure 2, but in this case the maximum radius is 0.5°.

these two modes, the last lens of the Cassegrain wide field corrector is changed and an atmospheric dispersion corrector is used in spectroscopy mode.[6] Figures 2 and 3 present the nominal performance of the optical design for imaging and spectroscopy modes, respectively, in terms of the image size (FWHM), field curvature, field distortion, and spot diagram. Note that the curve for the polychromatic spot size has a different shape from the others since it is affected primarily by lateral colour shifts (bottom panels, Figures 2 and 3) and also to wavelength-dependent defocus to some extent (right panels, Figures 2 and 3). Table 1 presents the error budgets for the two modes based upon specifications or as-built measurements (M2, Cassegrain corrector). The TSPM's f/5 Cassegrain optical design passed its preliminary design review in November 2017.

Of the two Nasmyth configurations, only the f/5 configuration has been developed to the conceptual design stage.[7–9] The right panel of Figure 1 shows the wide field correctors for the imaging and spectroscopy modes of the f/5 Nasmyth configuration. The two correctors have a 1° field of view, with preliminary estimates for the image quality of 0.55 and 0.57 arcseconds in the imaging and spectroscopic modes, respectively. Thus, the f/5 Nasmyth configuration should match the image quality of f/5 Cassegrain over a 1° field of view.

4. OPTICS FABRICATION

The main optical components passed their progress review in November 2017. These elements were not subject to preliminary design reviews because they are either in a more advanced stage of their design or they are manufactured and in operation. As noted above, the M2 and Cassegrain wide field corrector for f/5 are currently in use at the Magellan II (Clay) telescope.[6] The results from the Magellan II telescope demonstrate their quality and readiness.

The primary mirror system (M1 system) is currently being fabricated by the UA. The M1 system includes fabrication, polishing, and testing of the M1 as well as the M1 cell, the M1 transport box, the M1 supports and their control system, the M1 lifting fixture, the M1 dummy mirror, the design of the thermal control system,

Figure 4. The TSPM's M1 is currently stored in its transport box in Tucson, AZ. It is scheduled to be polished starting in 2019.

Figure 5. These photos show the M1 cell in the shop during its fabrication. **left panel:** The front surface of the top plate is visible. **right panel:** In this view of the rear side of the cell, the cone that will interface to the Cassegrain instrument derotator is visible.

Table 1. f/5 Cassegrain error budget (FWHM)

Item	**Imaging**	**Spectroscopy**
Nominal performance	0.057	0.191
M1 manufacturing, surface irregularity with AO	< 0.184	< 0.184
M1 manufacturing, CC and ROC	0.024	0.061
M1 manufacturing, CC and ROC uncertainties	0.044	0.045
M2 manufacturing, CC and ROC uncertainties	0.028	0.028
M2 manufacturing, surface irregularity, curvature	0.040	0.040
Telescope seeing (5%)	0.06	0.06
Telescope alignment (active optics)	0.028	0.062
Corrector elements alignment	0.009	0.02
Corrector fabrication	0.065	0.22
M2 active system residuals	0.022	0.054
Thermal	0.021	0.029
Guiding	0.07	0.07
Seeing	0.5	0.5
TOTAL (rms squared)	0.545	0.62

spare parts, test stands, and documentation. The M1 for the TSPM project is an existing 6.5 m mirror. It is currently in storage in it transport box in Tucson, AZ, as shown in Figure 4. All of these systems are similar to those built for the MMT, Magellan telescopes, and the TAO. M1 is scheduled to be repolished at the UA's Optical Sciences Center in 2019.

The M1 cell is currently in fabrication, as shown in Figure 5. The M1 cell will be nominally identical to that at the MMT, though in practice it is a copy of the TAO design. In particular, the design incorporates a cone-shaped opening to the Cassegrain derotator. This feature permits complete compatibility with the MMT. Some components, such as the hard points have already been purchased and certified. The software simulator for the M1 cell is already in use.

Table 2. TSPM telescope mass budget

Item	**Mass** (metric tonnes)
Maximum allowable mass	246.0
"Day 1" configuration	228.6
Rotating mass about the azimuth axis	176.2
Rotating mass about the elevation axis	98.3
Azimuth assembly rotating structure	69.7
Telescope wiring and piping	4.6
Telescope mechanisms control system	3.5
Non-rotating mass	52.4
f/5 Cassegrain configuration	245.7
f/5 Nasmyth configuration	245.5

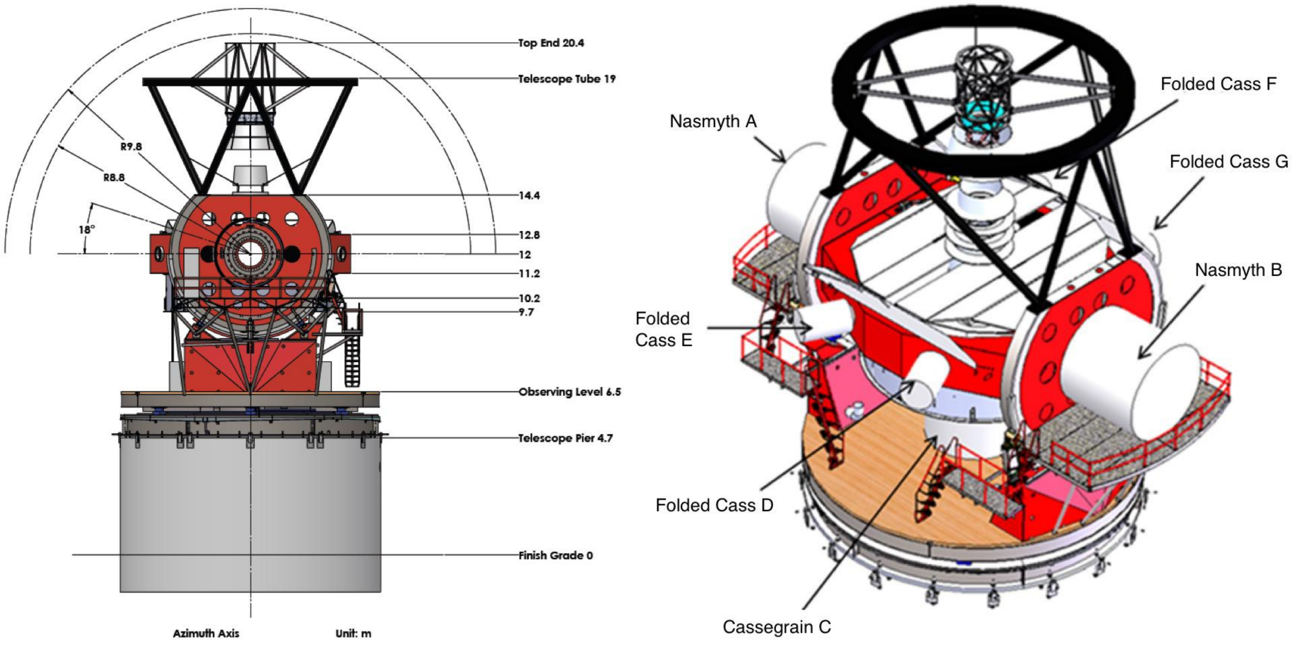


Figure 6. This drawings show the general dimensions of the TSPM telescope structure on its pier (left) and identify the foci that will eventually be available (post-"Day 1"). Given the ground layer seeing at the OAN-SPM,[10] the design seeks to place the elevation axis 10-15 m above the ground level. The folded Cassegrain ports will have half the field of view of the Cassegrain and Nasmyth ports and will support smaller instruments.

5. TELESCOPE DESIGN

The mechanical design of the telescope structure underwent its preliminary design review in November 2017. Its conceptual design has already been documented[3,4] and the preliminary design is presented in these proceedings.[11] The Centro de Ingeniería y Desarrollo Industrial (CIDESI), a Mexican federal industrial technology transfer centre located in Querétaro, Mexico is in charge of the telescope's mechanical design.

Figure 6 presents two views of the telescope structure. Its heritage from the Magellan telescopes is obvious. As already noted, the TSPM is slightly taller, because of the change in the position of the elevation axis and the decision to provide slightly more height between the M1 cell and the floor. Figure 7 offers an exploded view of the structure, identifying the main components. The exploded view is useful for interpreting the mass budget in Table 2.

In Table 2, the masses for three optical configurations are given. The "Day 1" configuration is the least equipped, with no Nasmyth derotators nor any instruments, except at the Cassegrain focal station. The other two configurations assume that the Nasmyth and folded Cassegrain instrument suite is present with the maximum masses allowed at all of these stations. For the "f/5 Cassegrain" configuration, the tertiary mirror is absent, but the Cassegrain WFC and a Cassegrain instrument are present. The opposite is true for the "f/5 Nasmyth" configuration. Also, the secondary mirrors are different (Figure 1) in these two configurations, with that for the f/5 Nasmyth being more massive. In Table 2, only the Day 1 configuration is broken down in more detail since the difference between the three configurations is basically accounted for by differences in the rotating mass about the azimuth axis.

6. ENCLOSURE AND SERVICES DESIGN

The enclosure and services subsystem underwent its preliminary design review in October 2016 and its critical design review in November 2017. The delivery of the final design is expected in 2018. This subsystem has been previously described.[2] As Figure 8 makes clear, the Magellan telescopes were a major inspiration for the design.

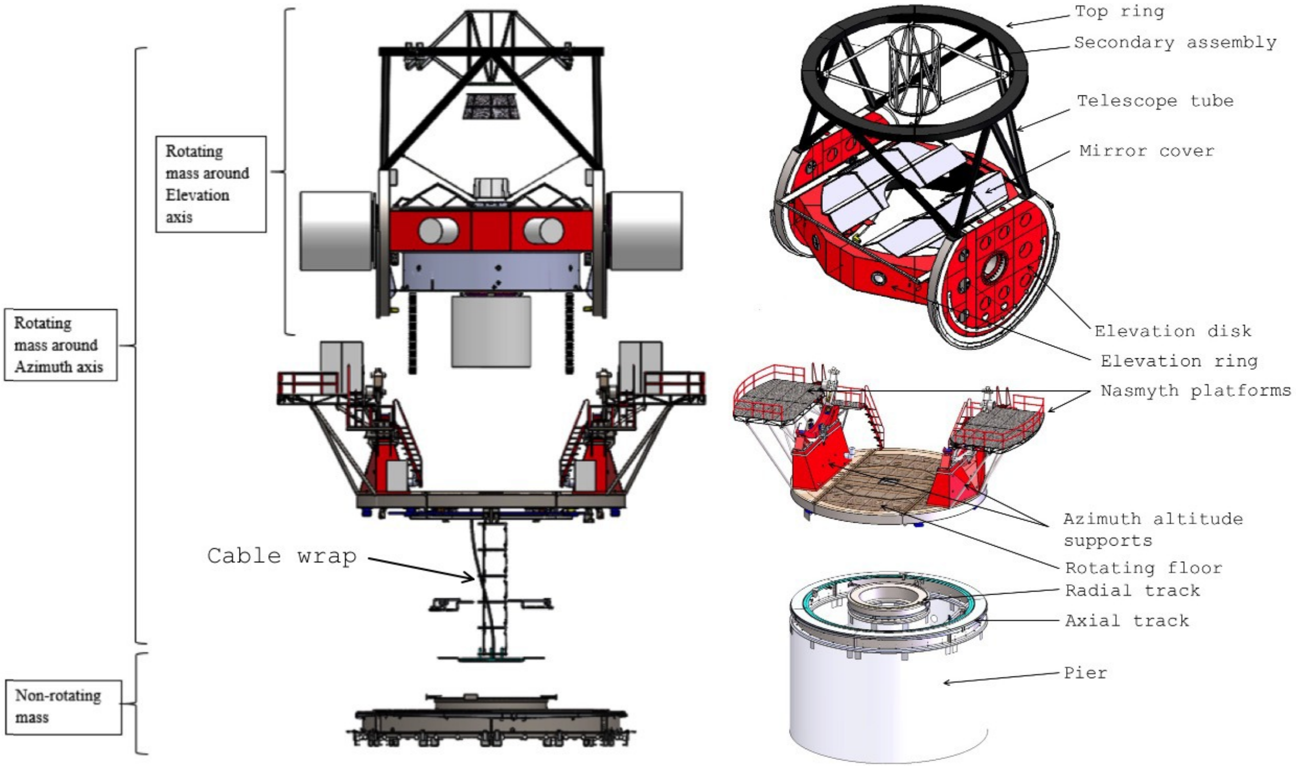


Figure 7. We identify the different components of the telescope structure to ease the interpretation of the mass budget presented in Table 2. Note that the cable wrap is not shown on the right for clarity.

Figure 8. This rendering of the TSPM buildings, viewed from the north-west, illustrates the mirroring of the design since the PDR. The cylinder at the (east) end of the support building is the liquid nitrogen dewar. Although it is not visible in this view, the spectrograph room on the south-east side of the telescope enclosure has also been removed.

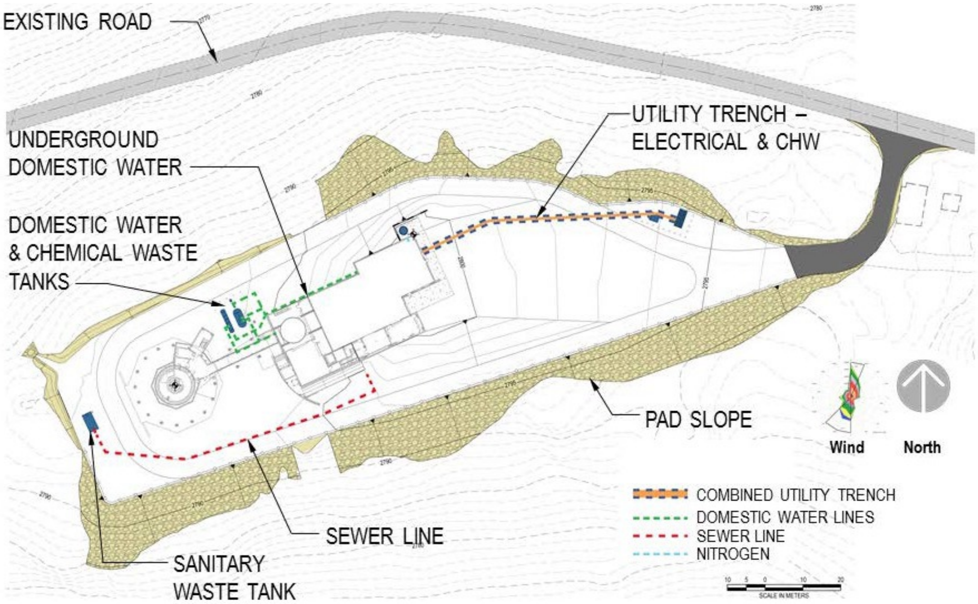


Figure 9. This site plan shows the location and orientations of the components of the TSPM project. The electrical transformer and the chillers for the cooling water are located at the end of the utilities trench. The long axis of the project is nearly perpendicular to the two main wind directions. Strong winds come predominantly from directions from south to south-west

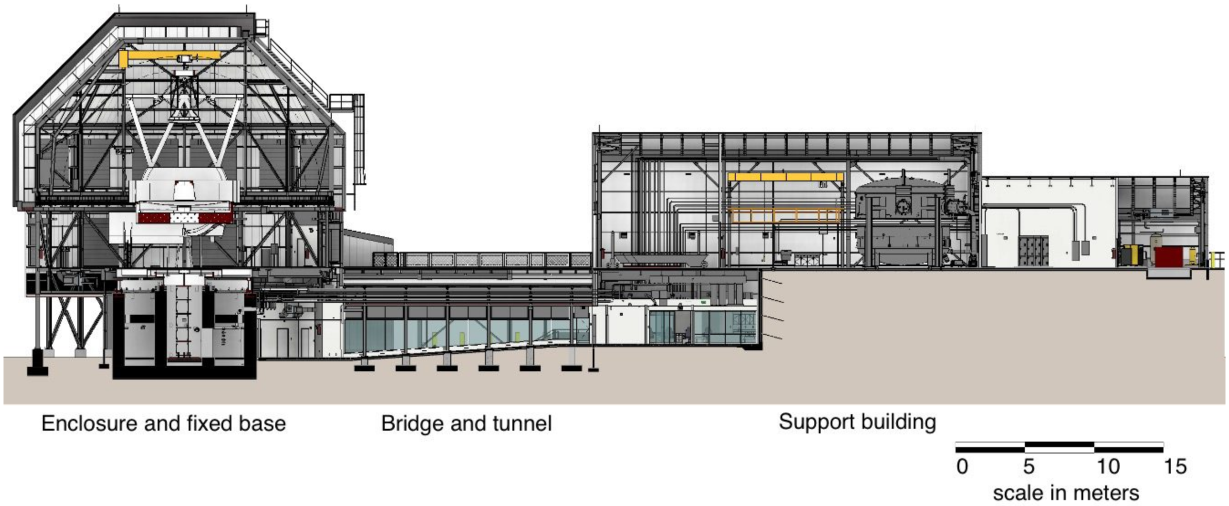


Figure 10. This cross-section of the buildings give an overall impression of the organization of the TSPM project. All telescope- and instrument-related activities occur on the upper level. The support services for the telescope and instruments are also located on the upper level of the support building, with the exception of the chillers for the cooling water that are located outside, aproximately 140 m from the telescope enclosure (Figure 9).

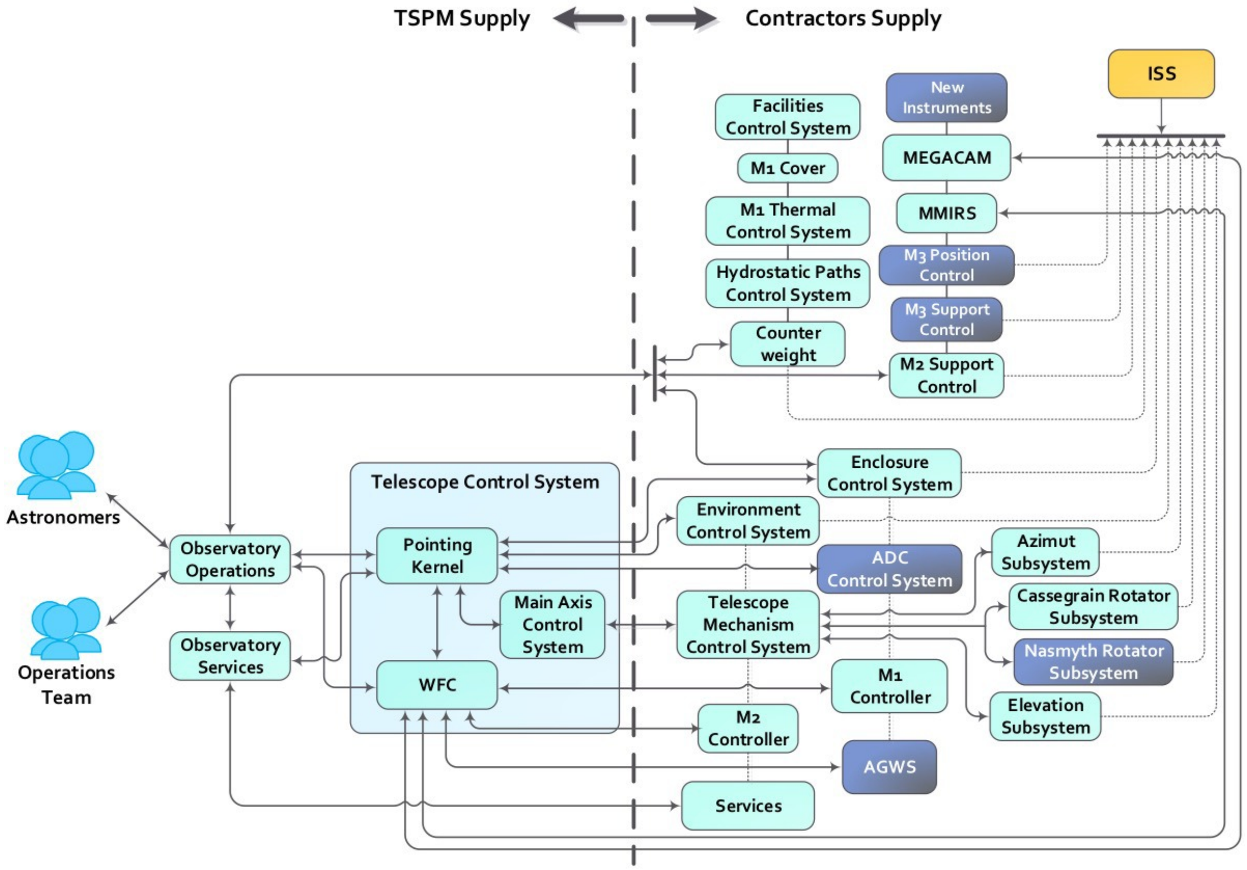


Figure 11. This diagram provides an overview of the organization of the TSPM control system, focussing upon control of the telescope, instrument, and the enclosure and services. The components in light blue are the subsystems that are necessary for "Day 1" operations while those in dark blue are post-"Day 1". The top-level domains are Observatory Operations, Observatory Services, and Telescope Control System. The line denoting the division between TSPM- and Contractor-supplied components attempts to capture the different needs on each side of this line, given that some components already exist and interfaces will have to accommodate them. In the case of components to be built for the TSPM, the control architecture will be the same as on the TSPM-supplied side of the line. Despite its location to the right of the Contractor-supplied line, the interlock and safety system (ISS) is an observatory-supplied component, independent of the control system, and is shown in this way for clarity.

Perhaps, the most noticeable design change was to mirror the buildings about the axis defined by the bridge between the telescope enclosure and the support building (Figure 9). By doing so, the main entrances were moved to the south side of the buildings, thereby giving them more access to sunlight. The main motivation for this change was personnel safety during winter when the Sun's heat will help in melting snow and ice.

Less evident, but nonetheless very important were design improvements to various critical components. The pier, foundations, and all metal structural elements were fine-tuned based upon the results of the geotechnical studies (Section 9). Measures were taken to avoid environmental contamination (in a national park): contention systems were added to prevent oil spills from the hydrostatic oil system and propylene glycol was adopted for the chilled water system. Trips were made to visit the Discovery Channel Telescope (DCT) and the Magellan telescopes to evaluate the reliability of the mechanisms. Subsequent detailed studies of the mechanisms were commissioned to better understand the effects of design choices and the lessons learned at the DCT and Magellan telescopes. As a result, many of the mechanisms are expected to be significantly improved, especially the dome bogies and the wind screen. A good deal of effort was invested in organizing the mirror washing area.[12]

Figure 10 offers an overall impression of the layout of the TSPM project. The upper level of the telescope enclosure includes two cranes for manipulating instruments, optical elements, and other components. The lower level provides access for all services to the telescope pier. The bridge serves both to transport instruments or the telescope mirrors between the telescope enclosure and the support building and as the conduit for all of the support services. The closed tunnel under the bridge permits easy, safe personnel access between the lower level of the support building and the telescope enclosure. All telescope- and instrument-related activities occur on the upper level of the support building. The main areas on the upper level of the support building include the instrument storage bay, a clean room for instrument maintenance and commissioning, the mirror wash area, and the mirror coating plant. The support services for the telescope and instruments (air, water, hydrostatic system, liquid helium eventually) are also located on the upper level of the support building, with the exception of the chillers for the cooling water that are located outside (Figure 9).[12] The electrical and mechanical rooms as well as the hydrostatic oil system are at the extreme end of the support building to better isolate the telescope enclosure from any heat and vibrations. The lower level of the support building includes the telescope control room, the computer room, offices, a break area, and a health room.

7. INSTRUMENTATION

At present, the Day 1 instruments planned for the TSPM are the Megacam[13] and then MMIRS[14] instruments that currently operate at the f/5 Cassegrain focal stations at the Magellan and MMT, respectively. We envisage the commissioning proper to occur with Megacam and, once the most important issues have been worked out, MMIRS could then be brought online. In this way, the TSPM would begin its scientific operation with a bright- and a dark-time instrument. These instruments are a contribution of the SAO and UA.

The Mexican community has also begun to discuss future instrumentation, including an imaging Fourier transform spectrograph and a spectro-polarimeter, though both concepts are in their initial stages.

8. CONTROL SYSTEM

The control system for the TSPM project is very closely modelled on that adopted by the Giant Magellan Telescope.[15, 16] Although this model is very ambitious in its scope, this system allows incorporating the different needs of the different user communities involved in the project. Most of the work done so far has focussed upon the interaction between the telescope, instruments, and the enclosure and services, as shown in Figure 11.

9. SITE

The TSPM will be built at the OAN-SPM, operated by the IA-UNAM, in northern Baja California, Mexico within the Parque Nacional Sierra de San Pedro Mártir national park. The OAN-SPM, its location, climate, logistics, and state of operation are documented elsewhere.[1, 17] Four telescopes are in operation (0.84m, 1.5m, 2.1m, BOOTES-5) and another five projects are in various stages of development.[18]

Work continues to connect the OAN-SPM to the national electricity grid. The first part of the power line's trajectory will be aerial, but the last 23 km to the observatory will be underground. In 2017, work finished to install all of the conduits for the underground electrical lines while work will begin this year on the infrastructure for the aerial electrical lines. The entire electrical line is expected to be completed by 2019. This electrical connection will be accompanied by optical fiber that will provide the OAN-SPM with a high-bandwidth internet connection for the first time.

A detailed geotechnical study of the TSPM site was completed in summer 2016 by the Comisión Federal de Electricidad's Gerencia de Estudios de Ingeniería Civil. This study included detailed topographic and geologic surveys, core samples to a depth of 30m, as well as electrical and acoustic soundings, whose locations are shown in Figure 12. The results have been used to set the boundary conditions for the building footings, telescope pier, roadways, the electrical grounding system,[2, 12] and the site-specific seismic hazard analysis. The original site-specific seismic hazard analysis was updated in 2017 to better reflect the needs of the project.

Currently underway are studies of the wind flow over the site. Both computational fluid dynamics modelling and wind tunnel testing will be done, though so far we have focussed our efforts on the former. These studies contemplate heat flow from the surroundings, including the TSPM's water chillers, located to the north-east of

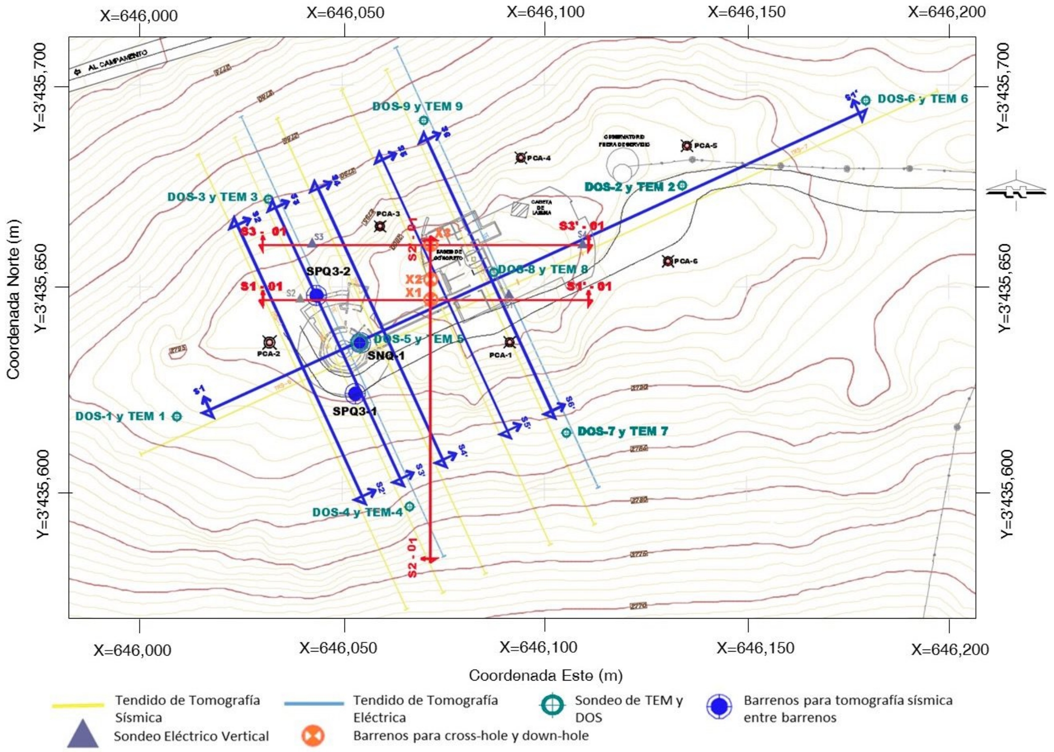


Figure 12. This map shows the locations of the boreholes and transects used for the geotechnical studies of the TSPM site. The ground floor of the TSPM enclosure is shown in outline, as are other buildings currently at the site.

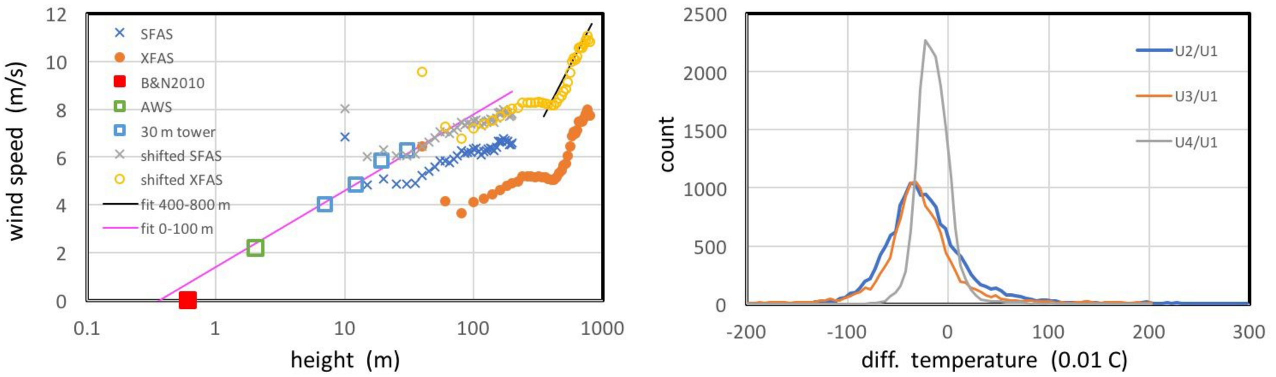


Figure 13. **left panel:** This figure presents all of the data available concerning the vertical velocity profile of the wind for the TSPM site. Note that the abscisa is logarithmic. The raw SODAR data are shown with filled symbols. The SODAR measurements must be shifted by +1.2 and +3.1 m/s for the SFAS and XFAS instruments, respectively. Once this is done, the velocity profile is continuous over the entire range of heights, from the roughness length (0.6 m[19]) at which the air is stationary to a height of 800 m. The fit shown with the black line includes all data between 400 and 800 m. The fit shown with the magenta line is to all of the data below 100 m, except the lowest data points from both SODAR instruments. **right panel:** This figure presents the main peak of the distributions of difference in temperature at 12 m, 19 m, and 30 m above the ground with respect to the temperature at a height of 7 m. The distribution of temperature differences at 19 m and 30 m is very similar, both in mean/median value and dispersion. In contrast, the distribution of temperature differences at 12 m differs, being shifted to lower values and with considerably less dispersion.

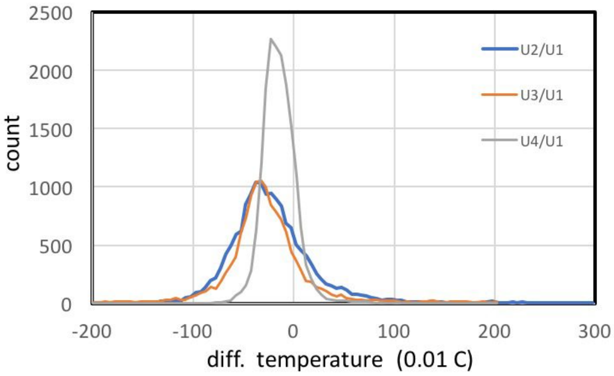


Figure 14. This figure presents the main peak of the distributions of difference in temperature at 12 m, 19 m, and 30 m above the ground with respect to the temperature at a height of 7 m. The distribution of temperature differences at 19 m and 30 m is very similar, both in mean/median value and dispersion. In contrast, the distribution of temperature differences at 12 m differs, being shifted to lower values and with considerably less dispersion.

the support building (see Figure 9). Heat sources within the telescope enclosure have not yet been included, but will be. The baseline configuration that we are studying includes the telescope enclosure, support building, and the closed tunnel under the bridge between the two buildings, as shown in Figure 8. In addition, we will study the effect of opening up the tunnel under the bridge and including a spectrograph room beneath the south-east side of the telescope enclosure. Having an open tunnel would presumably improve the airflow around the telescope enclosure, though it would complicate personnel safety during winter. Although snow storms are not that common, snow does persist on the ground for up to months at a time. An open walkway under the bridge would thus be liable to be regularly snow- covered, presenting a safety issue. Installing the spectrograph room below the telescope enclosure would provide an additional obstacle to the wind flow around the telescope enclosure, so it is important to understand the magnitude of its effect upon image quality.

To support the wind flow studies, Figures 13 and 14 present the vertical profiles of the wind velocity and wind temperature, respectively, at the TSPM site. These data are available from the instrumentation deployed by the LSST and TMT projects.[10, 20] The wind speed increases very quickly with height at the TSPM site, increasing proportional to the logarithm of the height over the first 100 m. The rate of increase of the wind speed then slows, reaching an approximately constant wind speed between 200 and 400 m. Thereafter, the wind speed increases linearly with height to the limit of the data available at 800 m. We are able to probe the change of temperature with height over only the first 30 m above the ground. The data clearly show that there is a change of approximately 0.15 C from 7 to 12 m in height, and another similar change between 12 and 19 m, but no change between 19 and 30 m. One issue we are investigating with the wind flow studies is whether the changes in temperature observed up to 19 m in height are due to the heat flux from the ground.

Also currently underway is the permitting process for the construction. This process is expected to conclude in 2018.

10. OPERATION

The current plan for operations is very similar to that described for the MMT.[21] The main difference concerns the total number of technical and scientific personnel. Given the OAN-SPM's distance from Ensenada, the telescope, instrument, and science support personnel must live on-site. Thus, for every person required daily at the TSPM, at least two must be hired. The lodging and maintenance of the TSPM personnel at the OAN-SPM will be contracted as a service from the OAN-SPM.

11. SYSTEMS ENGINEERING AND PROJECT MANAGEMENT

A complete Project Management plan has been established for TSPM and it is continuously updated. We are using the web-based tools from the FRACTAL Suite: MANATEE for organization, budget and, schedule tracking;

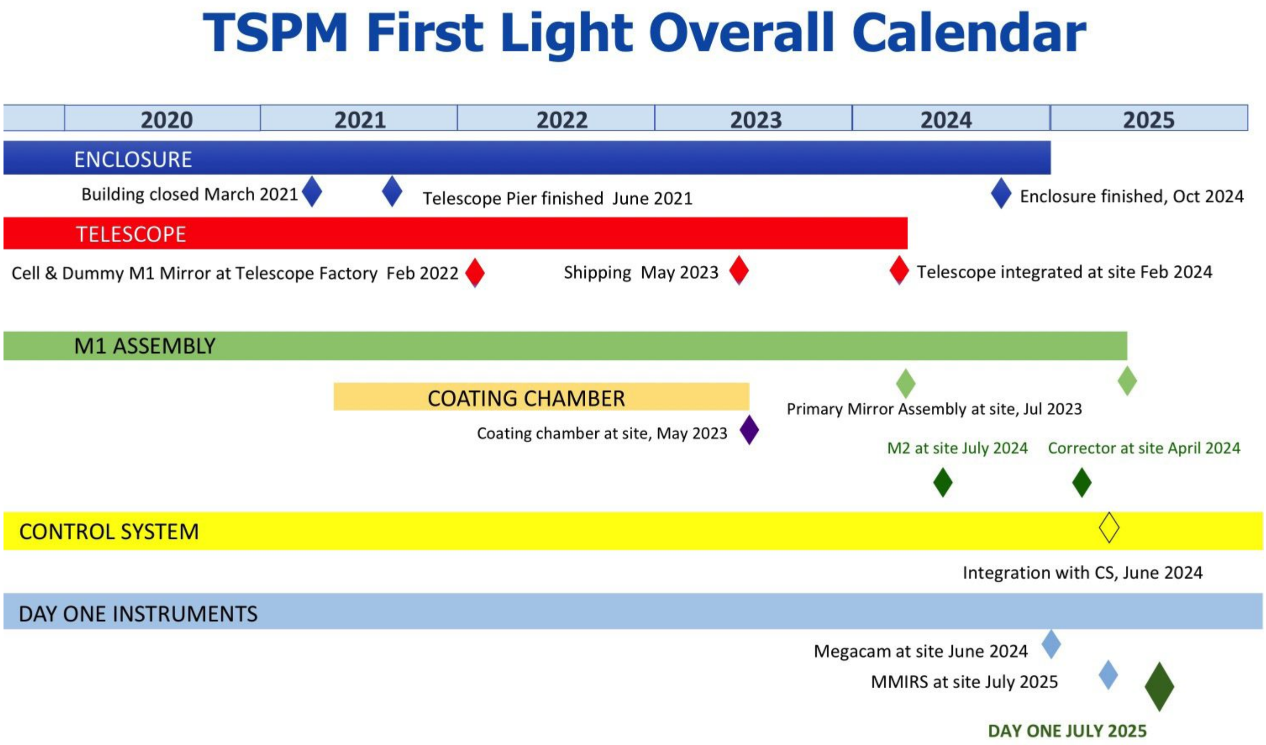


Figure 15. The current timeline for the TSPM project contemplates arriving at "Day 1" in mid-2025, contingent upon the required funding being available from the beginning of 2019.

and GECO and DOCMA for scope tracking through configuration and documentation control, respectively. The calendar's control follows the PERT methodology, based on individual milestones that are linked to their parent dates. One milestone can be linked to several others and the critical path towards a given milestone is automatically computed. MANATEE provides information not only on the milestones belonging to the actual critical path but also on the milestones that are nearby since they could become critical. This utility is being used to assign priorities and to avoid deviations from the calendar. There are an exhaustive set of utilities in MANATEE for budget control. We can classify the origin of the different contributions (by partner or sub-project source and by class: monetary or in-kind). The tools also allow control over the exchange rate among the different currencies (the main currency is the MXN, but there are items in US$ and €) and the possibility of computing and updating the budget items in their native currency. We have also introduced a quality classification for budget items according to the way in which the numbers have been obtained (as an estimate, a quotation, a firm-fixed price contract, etc.) so that we can get a figure of merit of the budget reliability anytime to allocate the corresponding level of contingency.

At this moment, the project is driven by the budget and the associated cash-flow. The scope for Day One is limited to the f/5 Cass Optics, although the telescope will be prepared for Nasmyth, including the rotators and the tertiary tower, as far as these elements have to be integrated as part of the entire structure. The current calendar contemplates an interval of 6.5 years from the receipt of funds to begin the project (assumed to be January 2019) until Day 1 (July 2025). The First Light of the telescope will be done with the f/5 Cassegrain configuration fully installed and with a commissioning instrument currently developed by IA-UNAM. Once the telescope itself is tested, the commissioning instrument will be dismounted and the scientific camera, MegaCam, will be installed in its place and commissioned. Day 1 is the date when MegaCam is ready for scientific operations. MMIRs will start to operate six months later. MegaCam and MMIRS will be the first generation of instruments operative at the TSPM, and are an in-kind contribution from SAO/UA. The second generation of instruments will be decided after a call that will be launched once the funds for construction are guaranteed. Figure 15

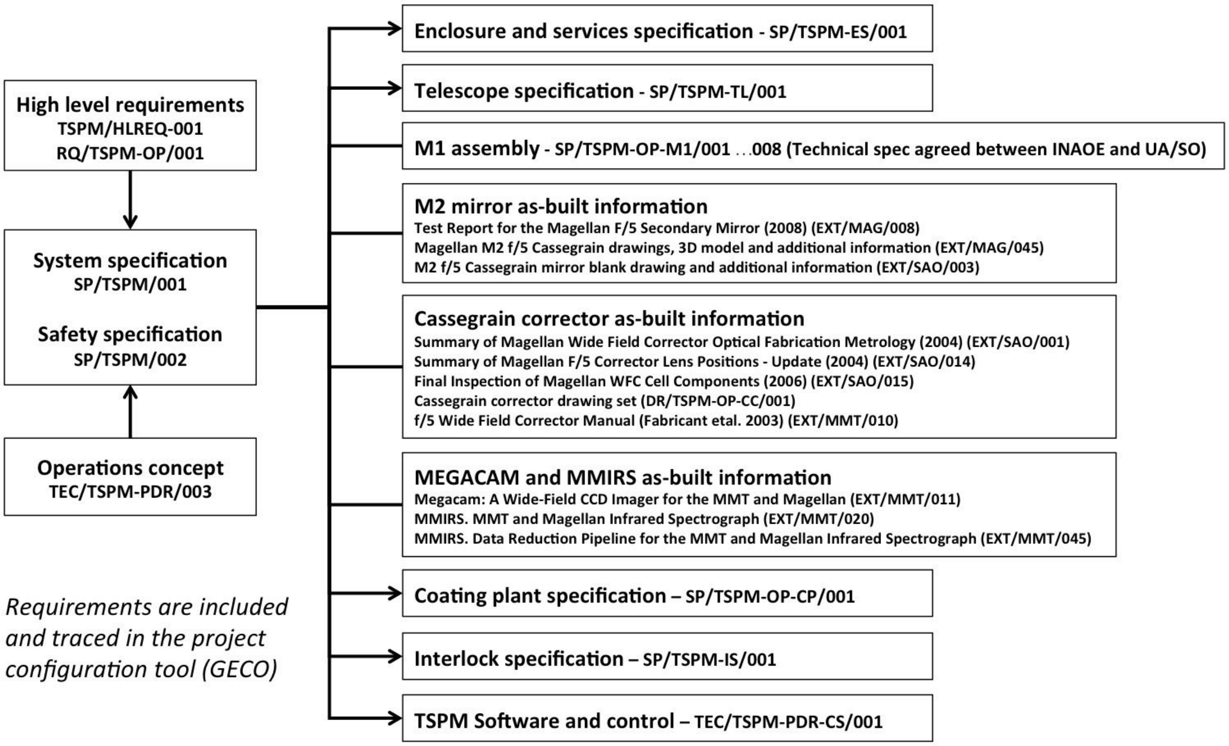
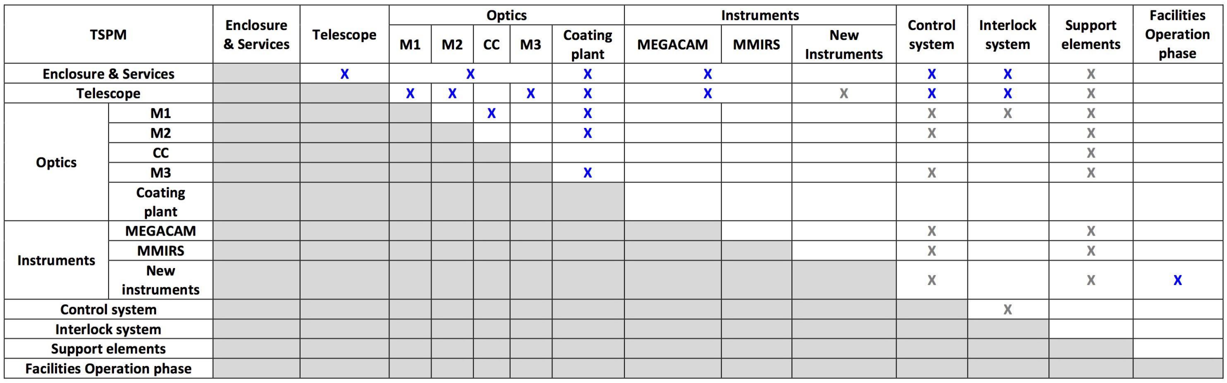


Figure 16. This table presents the subsystems interface definition table. We indicate the defined interfaces in blue while those that remain to be defined are in black.



TSPM		Enclosure & Services	Telescope	Optics					Instruments			Control system	Interlock system	Support elements	Facilities Operation phase
				M1	M2	CC	M3	Coating plant	MEGACAM	MMIRS	New Instruments				
Enclosure & Services			X	X				X	X			X	X	X	
Telescope				X	X		X	X	X		X	X	X	X	
Optics	M1					X		X				X	X	X	
	M2							X				X		X	
	CC													X	
	M3							X				X		X	
	Coating plant														
Instruments	MEGACAM											X		X	
	MMIRS											X		X	
	New instruments											X		X	X
Control system													X		
Interlock system															
Support elements															
Facilities Operation phase															

Figure 17. This table presents the subsystems interface definition table. We indicate the defined interfaces in blue while those that remain to be defined are in black.

presents a schematic calendar for the project.

The budget is composed of monetary and in-kind contributions. The latter are very important in this project, in terms of real hardware, such as the f/5 Cassegrain secondary mirror, the f/5 Cassegrain WFC, and the first generation of instrument, contribution from SAO/UA, the M1 assembly as a contribution from INAOE/UA, and the human resources at the different partner institutions. The monetary contribution for Day 1 is estimated at US$105 M.

Currently, the project's high level requirements and the interfaces between first level subsystems are fixed, as shown in Figure 16. A system-level specification has been developed taking into account high level requirements and constrains coming from the fixed optical components (i.e., the primary mirror contracted to Steward University and the secondary mirror and Cassegrain corrector delivered from Magellan). Then, requirements have been flowed down to main subsystem specifications, in particular, to the Enclosure specification and the Telescope specification. As-built information is being captured for definition of the interfaces with the already existing components to ensure their correct integration, operation and maintenance. The NxN interfaces diagram is provided in Figure 17. The system level error budgets for image quality, differential distortion, image background, pointing and tracking as well as technical budgets including mass, power and other services consumptions, heat dissipation and reliability budgets have been also generated and are being detailed as the design progresses. The verification matrices are being generated for the main subsystems to state how requirements shall be verified at the relevant milestones.

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