Frequently Asked Questions about TMT Site Selection

TMT Science Advisory Committee

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Q: What is the status of TMT site selection?

The Maunakea 13N site is the preferred site for TMT. However, construction was stalled because some members of the state and local community, including many Native Hawaiians, do not think TMT should be built on Maunakea. The Roque de los Muchachos (ORM) on La Palma, Spain has been selected as the backup site for TMT. The timescale for either starting construction on Maunakea or for deciding to move to ORM is uncertain. The TMT project and the Science Advisory Committee believe that both sites are excellent. TMT in Hawaii or in La Palma, Spain would lead to amazing, breakthrough discoveries.

Q: Why is the backup TMT site in Spain and not in Chile?

The GMT and ESO's ELT are being built in Chile; a northern hemisphere site for TMT would ensure that observations with 30m-class telescopes can target objects anywhere on the celestial sphere. ORM also offers some longitudinal coverage for time-monitoring of transient events, such as follow-up of gravitational wave events, that would not be possible if all three telescopes were in Chile.

Full sky coverage for the set of ELTs is scientifically important, especially for targeting rare objects of which each example may be precious (e.g., nearby Earth-mass habitable-zone exoplanets for direct imaging and atmospheric spectroscopy; the most metal-poor stars; the most distant quasars) and for follow-up of important survey fields in each hemisphere (e.g., M31 in the north; LMC/SMC in the south). Space-based telescopes and ground-based gravitational wave detectors will discover unique and important objects in both hemispheres that will require follow-up studies with 30m-class telescopes. As a consequence, the US ELT Program that is being proposed to the Astro2020 decadal survey is predicated on the concept of bi-hemispheric coverage using TMT and GMT.

Q: Maunakea is a better site for astronomy than ORM. Wouldn't it be better to try to resolve the issues on Maunakea and delay TMT?

The preference of TMT partners is to build TMT on Maunakea in a way that supports and empowers the local community, with respect for the spiritual importance of Maunakea to native Hawaiians. While many members of the local community strongly support TMT on Maunakea, it is not clear whether the broad range of local perspectives will reach a unified consensus that TMT will be beneficial and acceptable for them. For the TMT project, every year of delay brings a considerable increase in the financial cost as well as a scientific cost by delaying the discoveries; an indefinite delay without prospects for a resolution threatens the viability of the project. Some astronomers within the TMT partnership further believe that respecting the local community means understanding that ongoing discussions and better acknowledgement of their perspectives might not lead to a situation where a broad consensus of the local community supports building TMT. On the other hand, many of the TMT partners have been involved in astronomy on Maunakea for decades and have long-established commitments to the community. As described below, ORM is an excellent site and is supported by a local community that broadly believes that the construction of TMT is beneficial for them and for science.

Q: Why didn't ESO choose ORM for E-ELT?

A site in Chile was always ESO's preferred option for the E-ELT. ESO site testing found that ORM provides excellent conditions for supporting AO observations and is the 2nd best astronomical site in the northern hemisphere, consistent with TMT's findings. Armazones offers a higher fraction of usable nights (86%) compared to ORM and Maunakea (72% for both), drier conditions than ORM and Maunakea, as well as scientific and financial synergies with existing ESO facilities in Chile.

Q: Do we really understand all the properties of the ORM site?

ORM is among the best-characterized astronomical sites in the world. The site properties have been studied for decades, and telescopes have operated there since 1985, with about 20 that are currently in operation, including the 10.4m GTC. Measurements of weather conditions, usable time fraction, seeing, atmospheric turbulence, extinction, atmospheric dust, and water vapor have been made over periods ranging from years to decades.

Some properties, such as the atmospheric turbulence profile, have not been measured at the specific site on ORM proposed for TMT, but have been inferred from data available from turbulence profiles and from nearby telescopes like the GTC and from simulations of fluid dynamics. The current estimates are conservative for AO performances, particularly regarding the strength of the free atmosphere turbulence. Several groups have recently worked to independently review the available site data and to compare results and have reached similar conclusions.

The document entitled *ORM Site Description* summarizes in detail the properties of ORM.

Q: How much forefront science is lost by going to ORM? Will we be able to observe the Galactic Center? Is exoplanet science compromised because of site differences in PWV and coherence time?

The core TMT science will be possible at either ORM or Maunakea. The three first light instruments for TMT are WFOS, a multi-object optical spectrograph, IRIS, an AO-fed near-IR imager and integral field spectrograph, and MODHIS, an AO-fed high-resolution near-IR spectrograph. None of the science capabilities with these three instruments are severely degraded at ORM versus Maunakea. The AO corrections by NFIRAOS should be very similar at ORM and Maunakea. Some very specific science goals will be compromised because ORM is located at 28.9° vs. 19.8° latitude for Maunakea. For example, the Galactic Center will be observable from ORM, but at lower elevations and for a shorter duration than from Maunakea.

Some capabilities of possible second generation instruments may be affected. The warmer temperatures will increase background emission in the thermal infrared, beyond about 2.2 microns. With respect to Maunakea, at the lower altitude of ORM, precipitable water vapor and atmospheric pressure are both higher, leading to broader telluric absorption lines. These effects will reduce performance at mid-infrared wavelengths at ORM compared to Maunakea, particularly at wavelengths longer than 14 microns.

Q: Isn't adaptive optics performance better at Maunakea than at ORM? How does AO at ORM compare to that at Armazones?

The expected AO corrections at ORM are very similar to Maunakea, based on end-to-end simulations of NFIRAOS performance that include atmospheric turbulence strength, isoplanatic angle, and turbulence coherence time. When viewing within 45 degrees of zenith, the AO performance at Maunakea, ORM and Armazones are very similar. ORM and MK13N perform better than Armazones at lower elevations because Armazones suffers more from higher turbulence at the jet stream level - see Figure 10 in *ORM Site Description* for relative performance of AO at all three sites).

Section 1.2.1 of *ORM Site Description* describes in detail the assessment of AO at ORM. The atmospheric turbulence profiles have been measured at ORM in a few long-term monitoring campaigns by the Instituto de Astrofísica de Canarias, ESO, and other groups. The turbulence in the upper atmosphere (higher than 1 km) at ORM is similar to that measured at Maunakea and is consistently weaker than at Armazones. The total boundary-layer turbulence below 1 km at ORM is stronger than at Maunakea and Armazones, and is dominated by the surface-layer component for which we do not have measurement at the exact candidate site at ORM. Computer fluid dynamics simulations, which have been validated with experiments at Keck and CFHT, indicate that the dome seeing, while minimized by the enclosure design, is still dominated by the dome rather than by turbulence from the outside environment entering the dome, and therefore is largely independent from the ground-layer strength of the site. Maunakea and ORM have larger isoplanatic angles and longer coherence times than Armazones because of the differences in turbulence strengths in the upper atmosphere and in wind altitude profiles.

ORM has a demonstrated record of success for AO, including on the Swedish Solar Telescope, which has operated since 1999 and achieved excellent corrections even under the most challenging conditions of daytime solar astronomy. The new European Solar Telescope will be built in the Canary Islands, possibly at ORM, because of the demonstrated success of AO corrections.

Q. Is the dust from the Sahara Desert from the Calima dust storms a serious problem at ORM for extinction and contamination of the telescope/instruments?

We expect 72% of all nights at ORM to be usable, the same percentage as for Maunakea. This number is based on operational statistics and already includes the nights that would be lost due to severe Sahara dust during Calima dust storms. Astronomers remember dust events because they are unusual for us, while being weathered out because of snow or thick clouds is common and not memorable in the same way. Our estimates are obtained from V-band extinction statistics and 30 years of monitoring at the Carlsberg Meridian Telescope. When we consider only the 72% of usable nights, the median extinction in the V-band of 0.13 mag at ORM is only slightly higher than the 0.11 mag at Maunakea.

The combined effect of dust and humidity to the mirror reflectivity degradation needs to be examined further, but the specified reflectivity would be maintained at ORM by adjusting the mirror maintenance schedule.

Section 1.2.4 of *ORM Site Description* describes the measurements of dust extinction, while Table 8 shows the distribution of dust concentration for five sites, including the fraction of time when dust levels rise to increased levels.

Q: What are the seasonal variations of weather on ORM? I have heard there is a correlation between good seeing and the Sahara dust events?

Due to the lower altitude of the ORM site, seasonal variations of temperature and water vapor at ORM are more significant than those at Maunakea. The Calima dust storms occur mainly during the summer. While statistics indicate that the seeing is better in summer than in winter, there are many summer nights with good seeing that are not affected by the Sahara dust; best seeing conditions last from May through November. Mid-IR astronomy at ORM will be best during the winter, when the PWV and summit temperatures are both at a minimum. Further details on seasonal variations are shown in Section 1.1.1 of *ORM Site Description*; Section 1.2.6 of *ORM Site Description* describes that no significant long-term trends due to climate change have been identified at either ORM or Maunakea.

Q: The multi-object spectrograph WFOS, expected to be a workhorse instrument, WFOS, will be operated under seeing-limited conditions. What is the expected seeing statistics at ORM compared to Maunakea and Armazones?

The relevant seeing is measured at 60 m above the ground, where light enters the telescope, plus dome seeing. Maunakea, ORM, and Armazones each have similar distributions in seeing, with medians of 0.50, 0.58, and 0.50 arcsec, respectively, excluding dome seeing.

The distribution of seeing measurements is described in Section 1.1.2 of *ORM Site Description*.

Q: If TMT is built on ORM, would that sacrifice mid-IR science?

Most of the mid-IR science planned for TMT could be done at either site, although with longer integrations at ORM. This assessment is based on the experience with the GTC's mid-IR CanariCam instrument and telluric absorption and emission models and long-term monitoring of the PWV. Significant discrepancies between different sources had led to confusion in the PWV of ORM (specifically the use of raw GPS data). The distribution of PWV used in the TMT study are obtained from two years of radiosonde balloon campaigns as well as recalibrated GPS data from IAC and are consistent with the experiences of the CanariCAM mid-IR instrument on the GTC.

Queue scheduling would be implemented at ORM so that mid-IR observations occur during the best 25% of conditions, when the PWV is less than 2.2 mm and predicted in advance. At L (3-4 microns) and N (7-15 microns) bands, in the 25% best conditions, typical exposure times would be 5-50% longer at ORM to achieve the same sensitivity, after accounting for higher PWV, warmer average temperatures, mirror emissivity, and the lower elevation of ORM. While most science cases would be feasible at either site, Q-band (16-24 micron) observations and measurements of water would require 25-100% increases in exposure time and would be challenging at ORM.

Section 1.2.2 of *ORM Site Description* describes the PWV measurements in detail, while Table 10 and Figure 13 describes the increase in exposure times that would be required at ORM, relative to the same sensitivity that would be achieved at Maunakea.

Q: Will the UV performance of TMT be compromised, if TMT is built at ORM?

Performance below 340 nm will be reduced, with lower sensitivity as observations approach the atmospheric cutoff. The reflective coatings that are currently baselined for TMT are not sensitive below 340 nm, so differences are negligible. If new developments facilitate a coating with better reflectivity in the UV, then this would provide TMT with a unique capability, even if the sensitivity is reduced at a lower-elevation site. The planned instrument suites for E-ELT reach only to 400nm in the blue due to the fiber feed to the instruments and more mirrors in the telescope optical train. The coatings currently planned for GMT would have sensitivity to 340 nm.

Section 1.2.3 of *ORM Site Description* describes the UV extinction curve at both Maunakea and ORM.

Q: How much longer will exposure times (as a function of wavelength) need to be at ORM?

A: Observations at visible wavelengths would typically require about 25% longer integrations at ORM than at Maunakea, given the differences in seeing distribution at 60 m and taking into account the telescope diffraction effects. At near-IR wavelengths, exposure times at ORM would need to be about 20% longer than at Maunakea due to a minor degradation in the AO correction, and higher background at K-band. In the thermal IR beyond 2.2 microns, the increase in exposure time less than 10% for most high-resolution spectroscopy but 10-50% imaging. Observations in the UV would require exposures that are about 20% longer at 350 nm and about 50% longer at 310 nm.

Table 10 in *ORM Site Description* describes the expected increases in exposure times, although precise numbers will always depend on the specific goals of the project.

Q: If TMT were to move to ORM, would that change the science and instrument planning? Would having an adaptive secondary mirror be more important at ORM?

A: The first-generation instruments and most second-generation instruments would be unaffected by a move to ORM. When prioritizing second-generation instruments, TMT will need to evaluate the efficiency and anticipated science from all instruments for the chosen site, including the degradation to thermal IR science. An adaptive secondary mirror brings some benefits to TMT at either site to correct for ground layer turbulence, especially during nights with bad seeing. Although evaluations to date have not identified an adaptive secondary as a priority, it could be considered alongside other future upgrades to the telescope/instrument system.

Q: If TMT decides to build at ORM, would that decision be a blow to Maunakea astronomy in particular and U.S. astronomy in general? What steps is the consortium taking to minimize the chances that TMT will act as a lightning rod for similar issues at the ORM site?

The majority of TMT's partners have observational facilities on Maunakea. Regardless of TMT's site outcome, these partners and the TIO are firmly committed to working with all parties to ensure the continuation of Maunakea astronomy, while respecting Maunakea's rich history and the spiritual beliefs of native Hawaiian culture.

The TMT project is sensitive to the ongoing struggles of indigenous people around the world and is also committed to a model of environmentally sustainable astronomy. As the project has done in Hawai'i, we have been participating in both public and private conversations with government and community leaders in Spain to ensure that any concerns are aired and addressed to our best ability.

Q: What are the impediments to building on ORM?

A: TMT and IAC have worked together to secure the relevant permits from the local and Spanish government. A very detailed environmental impact study has been submitted regarding the construction of the TMT. This study has been reviewed by the relevant authorities and was open to public comments, including from environmental organizations, before being approved in the summer of 2019. TMT recognizes the challenges of minimizing impact on biodiversity and sites of cultural or archeological significance and TMT approaches such concerns similarly for the La Palma and Hawaii sites, with the highest level of caution and care.

More information can be found at:
https://www.maunakeaandtmt.org/get-the-facts/tmt-supporting-environment.

Q: Maunakea is a better site than ORM. Shouldn't a telescope this expensive be built on the best site possible?

A: The key word in this question is "possible". It remains unclear whether TMT will be able to be built on Maunakea. If the members decide that Maunakea is not a possible site for TMT, then the next best possible site is ORM. The TMT and the Science Advisory Committee are confident that TMT will be a fantastic, uniquely capable telescope, regardless of whether it is built on Maunakea or ORM.