Resources and information on TMT and Maunakea

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Astronomy and Maunakea[1]

Observational astronomy is one of the most awe-inspiring of the sciences. Astronomers use large telescopes to gather light from unimaginably faint objects in the sky, to peer back in time, search for life on other planets, and learn about the origins of planets, stars and the Universe itself. The main tools we have are telescopes and, in general, physically larger telescopes are much more powerful, as they allow us to obtain sharper images of fainter objects. To take full advantage of the gain in sensitivity, however, requires exquisite observing conditions that are found at only a few places on Earth. Large telescopes are also highly sophisticated, expensive facilities that require international collaborations to construct and operate. They take decades to plan and build, and they operate productively for 50 years or more. Some more information on this, and the process taken in Canada to set priorities on such ambitious projects, is given in the Appendix.

Maunakea is an outstanding, unique location for astronomy. With an altitude of 4200m, located in the middle of the Pacific Ocean, the atmosphere above the summit is exceptionally dry, stable and thin. It is perfectly suited for natural seeing observations (frequently reaching <0.4 arcseconds in the optical, in a well-designed dome), and for adaptive optics observations in the near-infrared. It is the only site in the northern hemisphere, and one of the only sites in the world, where observations are possible from the atmospheric cutoff (320nm) to the mid-infrared (5-20 microns). For this reason it is the preferred location in the northern hemisphere for optical and infrared astronomy. Currently Maunakea houses 11 optical/IR/submm telescopes and two radio observatories or arrays.

Development of new astronomy facilities on Maunakea has become controversial. Much of the negative response to this use of the summit is rooted in historical and current social grievances with which many people, including astronomers, are likely to be sympathetic. From the beginning of the project, many of those involved in TMT have been keenly aware of these controversies, and have spent time developing a better understanding of astronomy's impact in the context of Maunakea's cultural significance. The TMT has tried not to repeat many of the mistakes of the past, by consulting broadly to ensure that decisions and procedures are not only fully compliant with the law, but also respectful of the diverse Native Hawaiian cultural resources and voices.

[1] We follow the findings of the Cultural Impact Assessment report (Appendix D of the Environmental Impact Statement), and use "Mauna Kea" for reference to official entities such as the Mauna Kea Science Reserve, and when citing other sources that have used that spelling. For all other instances we use the one word version, "Maunakea".

As an advisory committee, part of the mandate of CATAC is to inform and consult with the Canadian astronomy community about issues related to TMT. We have therefore written this document, to provide some facts and references about the TMT project and its history; we hope that it will be a useful foundation when discussing the current dispute over Maunakea. We also refer you to our report for the Canadian Long Range Plan for astronomy, which you can find at this link. Much of the information in the present document is drawn from the excellent resources at https://www.maunakeaandtmt.org/. Another good source of background information, from a different perspective, can be found at the Office of Hawaiian Affairs: see https://www.oha.org/maunakea/. Finally, for those who would like to learn more about some of the underlying issues that animate the current situation, we recommend the book *Shoal of Time: A history of the Hawaiian Islands* by Gavan Daws. Additional references and supporting documents are provided in the final section.

Recent history: The Keck Outriggers, and how most astronomers learned there was a problem

The TMT project began against a backdrop of growing concerns over the management of Maunakea. A 1998 state audit concluded that UH had failed to properly manage a number of aspects of access to the summit and protection of natural resources. As a result, a new Mauna Kea Science Reserve Master Plan was developed in 2000. This Master Plan created the Office of Mauna Kea Management (OMKM) along with the Kahu Ku Mauna Council, a Native Hawaiian advisory council on summit management. It also identified a single new site (13N) on the mountain, away from the summit, for a possible future, large optical telescope. The site was deliberately chosen because of its lack of archaeological, cultural or biological impact, and is not as good for astronomy as the summit sites. Any other development would have to reuse established sites.

The two 10-m Keck telescopes on Maunakea are among the world's most scientifically productive ground-based telescopes (Crabtree 2019). They were originally designed to work together as a powerful optical interferometer, using four 1.8m telescopes linked to the main telescopes. A 2012 article in Sky and Telescope describes how construction of these crucial (for interferometry) 'outrigger' telescopes was halted by protests, in a situation that has many parallels to what is happening today with TMT . The article can be recommended not only for describing the original concept behind the Keck design, but also because the comments below the article provide a foreshadowing of the discourse seen when proponents and opponents of the TMT try to communicate via social media.

NASA, who were funding the outrigger development, undertook an environmental assessment of the project in the hope of receiving a "no significant impact" ruling, which would circumvent the need for a full Environmental Impact Statement (EIS)[2]. However, in 2003 the Office Hawaiian Affairs[3] (OHA), representing a broad range of Native Hawaiian groups, successfully argued in federal court that an EIS, addressing both environmental and cultural impacts, should be conducted for the new telescopes. NASA agreed to begin the EIS in December 2003, and publicly admitted it had been deficient in addressing cultural aspects of the outrigger project. The full EIS took almost a year to complete. During its preparation the Conservation District Use Permit (CDUP) necessary for development was granted, with the proviso that if any unexpected findings appeared in the EIS the permit could be revoked. This decision was immediately appealed, with opponents noting it would take the summit beyond the limit of thirteen telescopes specified in the Master Plan.

Against a reality of increasing concern over development on Maunakea, and significant unhappiness about how the project had moved forward, in the end the Outrigger project was ended by NASA budget cuts that removed funding for the project in 2006. This decision came ahead of an August 2006 announcement that the CDUP for the Outrigger project had been revoked, subject to the creation of a Comprehensive Management Plan (CMP) for Maunakea[4]. The CMP was developed and released in 2010.

The Outrigger project provided a very clear lesson for astronomy on Maunakea. Development on the mountain must be approached in new ways; in particular, OHA approval must be sought for any new project, and both cultural and environmental concerns must be fully addressed. One positive outcome of the failure of this project was that it helped raise

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[2] EIS "include detailed information about plants and animals, historical background of the site, and cultural information [...] The general process is that a draft EIS or plan is posted online, made available by an agency, and/or deposited in libraries for a public comment period. The public comments are incorporated into the final EIS or other plan. The governing agency issues a decision about whether or not the environmental impacts are significant. If significant impacts are anticipated, the project may be halted, or a mitigation plan may be required." From https://guides.library.manoa.hawaii.edu/c.php?g=433877&p=2958826.

[3] The OHA was established in 1978 when the State Constitution was revised. "*The Office of Hawaiian Affairs is a public agency with a high degree of autonomy. OHA is responsible for improving the well-being of Native Hawaiians. OHA is governed by a Board of Trustees made up of nine members who are elected statewide to serve four-year terms setting policy for the agency. OHA is administered by a Chief Executive Officer (Ka Pouhana) who is appointed by the Board of Trustees to oversee a staff of about 170 people.*" https://www.oha.org/about/

[4] Among other things, the CMP includes a more thorough report about the prospective site, 13-N, and concluded that there is minimal evidence that it has specific cultural significance.

awareness in the astronomical community of the contentious nature of development at this very special place.

What TMT did about it and how it sought consent

Prior to making a decision about where to site the telescope, the Moore foundation commissioned an independent report by the Keystone Center to help it better understand concerns in Hawaii and how it could improve community consultations. The Keystone review clearly highlighted the failure of previous projects to adequately consult with Hawaiians – both Native and non-Native communities. One of its key recommendations was that TMT would need to "Undertake both broad and deep consultations with Native Hawaiians," although the challenge of identifying who to speak with was acknowledged: "However, there is no broad agreement on exactly who can speak for the community or how best to understand overall community sentiment." The modest returns of astronomy benefits to the local community were also highlighted. While the OMKM received some praise for bringing a better consultation process to management of Maunakea, at the same time it was criticized for having no real authority to enact policy change.

On the basis of this advice the TMT collaboration began an earnest campaign of discussion with the Hawaiian community, including Native Hawaiian groups. However, despite the Keystone report stating that "TMT has a chance to model a new kind of dialogue with Native Hawaiians" it was clear from the very beginning of consultations that there were likely to be some people that would remain firmly opposed to the project. It was believed that approval from OHA represented consent from the broad Native Hawaiian community because that is the constituency to whom OHA is responsible.

Many of the details about the consultation process can be found in the TMT Final Environmental Impact Statement (FEIS). This includes (in Volume 3) a thorough Cultural Impact Statement, with clear acknowledgement of rituals and practices on the mauna, and an acknowledgement that Maunakea is a sacred space. An independent academic review (Swanner, 2013) found that the TMT consultation process went well beyond what was expected or required. Not only were more public meetings held than required, but cultural practices were acknowledged as the starting point for each meeting, with invited kupuna giving an opening greeting to all those attending. In addition to public meetings, over 300 "talk story" sessions were held in the community. The TMT FEIS was approved in May 2010 after a two-year public review and input process. This statement was not challenged following approval.

Throughout the process, feedback forms were completed at the public consultations. Typically, these showed about a 50/50 split in those supporting or opposing development. Yet it was clear that viewpoints were diverse, and not aligned in a simple way with other characteristics of the population. For example, it was not true that all business-oriented people supported the project, nor that all Native Hawaiians or environmental groups objected. Many Native Hawaiians were seen to support TMT selecting Maunakea in a June 2009 rally.

The following month, and after hearing two hours of testimony, the Office of Hawaiian Affairs Board of Trustees adopted a motion that supported the selection of Maunakea 13-N as the site for TMT.

"*In consideration of various cultural and economic factors, the OHA Board of Trustees resolves to support the selection of Maunakea, Hawai'i as the site for the proposed Thirty Meter Telescope Project*"

For many supporters of the project this was viewed as the key endorsement, the indication that consent from Native Hawaiians had been obtained. This expectation arose, in part, because OHA had effectively represented the views of so many Native Hawaiian groups during the Keck Outrigger discussions.

Giving back to the community

One of the objections raised by Hawaiians to new astronomy development has been that the presence of astronomy has not provided sufficient "return" to the community in an impactful way; this was highlighted, for example, in the Keystone report. While this has been true in the past, TMT tried to set a new standard for community engagement, through several initiatives:

- TMT launched The Hawai'i Island New Knowledge (THINK) Fund in 2014 to better prepare Hawai'i Island students to master STEM subjects and to become the workforce for higher paying science and technology jobs in Hawaii's 21st century economy. For a school system that was deprived of major funding, a significant investment in STEM education was seen as having a strong influence on local outcomes. At the time, for many Native Hawaiians, this was seen as a practical step and in their view something worth supporting. TMT makes an annual contribution of US$1 million to the Fund, which is administered by the Hawai'i Community Foundation and Pauahi Foundation. The fund has had an impact on tens of thousands of Hawaiian residents; this report to the Hawai'i Board of Land and Natural Resources (BLNR) gives an overview of how effective it has been.
- TMT has also initiated a Workforce Pipeline Program, working with the State Department of Education, University of Hawaii Hilo, Hawaii Community College, Hawaii County government, and nonprofit organizations to strengthen STEM skills infrastructure at UH Hilo, HCC and K-12 education organizations serving low income and first-generation college

attending populations. More than US$2.5 million has been disbursed to the community in Hawai'i as part of this program, including $30k to sponsor a camp (Camp Laniakea) in 2018 to allow children in the Puna Emergency Shelters affected by the Kilauea eruption to learn more about STEM disciplines. When fully operational, TMT is committed to continue and expand the Workforce Pipeline Program.

- Since 2010, TMT has been the cornerstone funder of the Akamai Workforce Initiative, aimed at advancing STEM disciplines among Native Hawaiians, women, and other groups underrepresented in STEM. Over 300 students, of which 25% are Native Hawaiians, have been awarded Akamai Internships. Over 80% of these students have pursued degrees and careers in STEM disciplines.
- TMT pays a lease rent, starting at $300,000 per year and ramping up to $1M per year once the telescope is operational. This will be the first telescope on the mountain to pay significant rent, and 80% of this money will go directly to the support and stewardship of Maunakea.

In total, TMT has already invested over $8M in the Hawaiian community through these initiatives. However, none of these efforts could address the concerns of people who fundamentally objected to constructing a large building on land that is known to be considered sacred by many Native Hawaiians.

The legal process

An excellent summary of the process TMT underwent to acquire the legal right to build on Maunakea is given at http://www.maunakeaandtmt.org/tmt-process/#legal-process. A short timeline summary of the activity between selection of Maunakea as the telescope site, and the protests in 2014, is provided here for reference.

May 2010	State of Hawaii Governor Approves TMT Environmental Impact Statement (EIS)
Sept 2010	Maunakea Management Board Approves Conservation District Use Permit (CDUP) Application, which is accepted by the State of Hawaii Land Board
Feb 2011	The State Land Board Considers the CDUP application and authorizes a Contested Case
Aug 2011	Five TMT CDUP Contested Case Hearings (public) are held

Nov 2012	Hearings Officer Paul Aoki issues a 124-page ruling concluding that TMT should be granted its CDUP
April 2013	State of Hawaii Board of Land and Natural Resources (BLNR) issues CDUP
Dec 2013	Judge Nakamura, Third Circuit Court, holds hearing on the opponents' appeal of the CDUP
May 2014	Judge Nakamura issues Final Judgment upholding the decision to grant the CDUP.

Construction protests

2014 protests

The disruption of the ground-breaking ceremony in October 2014 was unexpected. Many of the protest leaders were Hawaiian Sovereignty advocates, who reject not only TMT but the entire civil structure of the State of Hawaii. Most of their grievances were directed at the University of Hawai'i and their management of the mountain, rather than at any particular action or inaction on the part of TMT.

Shortly afterward, Governor Ige issued a "10 point action plan" to the University of Hawai'i, for the stewardship of Maunakea. This includes several important and ambitious items, among them to:

- Formally and legally bind itself to the commitment that this is the last area on the mountain where a telescope project will be contemplated or sought.
- Decommission – beginning immediately – as many telescopes as possible with at least 25 percent of all telescopes gone by the time TMT is ready for operation.
- Voluntarily return all lands not specifically needed for astronomy (over 10,000 acres) to the full jurisdiction of the Department of Land and National Resources (DLNR).

Progress is being made on all ten points. In particular, two telescopes - the Caltech Submillimetre Observatory (CSO) and the UH Hilo Hoku Kea telescope - have already ceased operations, and the third (UKIRT) is slated for decommissioning prior to TMT operation. Five telescopes in total will be decommissioned before 2033. Some other information on progress that has been made on these points is available at https://www.hawaii.edu/news/2016/05/25/uh-reports-progress-on-governors-10-point-plan-fo

r-maunakea/, though this is from 2016 and quite out of date. More recent information on CSO decommissioning can be found here and here.

On Dec 3, 2015, the Hawai'i Supreme Court revoked the construction permit, on the grounds that due process had not been followed by the State's Department of Land and Natural Resources. A second, lengthy contested case hearing was launched. Ultimately, in July 2017 the hearing officer decided that the permit should be granted, under a number of conditions. The subsequent approval by the BLNR was appealed directly to the Hawai'i Supreme Court (HSC). The HSC also ruled in favour of TMT, with a 4-1 decision, at the end of October 2018. More detail about the legal process and court challenges during this time can be found at this link and in the CATAC report to the 2020 LRP panel.

2019 protests

Much has been made of the arrests that occurred shortly after the latest protests began, following the restart of construction on June 20, 2019. Law enforcement is not under the control of the TMT project, and the project is not always informed of all police activity. However, everyone was pleased to see that the police have taken a non-violence approach, and did not attempt to break the blockade.

During the first few days after the blockade was set up, police met peacefully with protestors each morning to discuss what was going to happen. At times this included police and protestors praying together. Several citations ("tickets") were issued on the mountain; the protestors were then allowed to return to the protest site, and many of them did[5]. The first hearing was held recently; all pleaded not guilty to the charge of Obstruction.

The number of people at the protest site swelled to over a thousand at one point. The weather at the protest site can be inclement; to ensure the safety and well-being of the protestors the site is equipped with a medical tent and free food is available. The site attracted many locals and families, who spent time there.

An important point is that no attempt has been made to restart construction. At no time has the project tried to intimidate, or force its way up the mountain. No one associated with the project has expressed a desire to proceed in the present climate. CATAC has been disappointed to see letters from Canadians expressing "shame" that their institutions are

[5] There is an interesting parallel, in a dispute in Oahu over the Waimanalo Bay Beach Park (aka Sherwood Forest). There, 28 protestors who had blocked the road to prevent construction vehicles to enter were all cited for obstruction. The police moved in swiftly but non-violently to clear the road.

associated with TMT, or calling for a moratorium on construction. All evidence is that the project followed procedures that were believed to be appropriate for obtaining consent from Hawaiians, and that construction halted in the face of protests. We see nothing shameful in trying to find a peaceful solution for a project that has been nearly twenty years in development, and that promises economic benefits to Hawaiians and scientific benefit to the world.

Can TMT be built elsewhere?

Prior to making a site selection, TMT spent five years measuring the atmospheric properties of five candidate mountains (Schoeck et al. 2009): Cerros Tolar, Armazones and Tolonchar in northern Chile; San Pedro Martir in Mexico and the 13N site on Maunakea. These sites were preselected using satellite data to identify acceptable candidates based on cloud cover and precipitable water vapour (PWV). All the measurements gathered are available at the TMT Site Testing Database. Schoeck et al. (2009) concluded that all five candidate sites are excellent, and that no single site stood out among the others in all respects. Taking into consideration other factors (financial, accessibility, health and well-being of staff, and cultural/environmental impact), Maunakea was ultimately selected by the TMT Board. When construction was halted in 2014, TMT considered two additional sites: Cerro Honar in northern Chile, and Observatorio del Roque de Los Muchachos (ORM), in the Canary Islands (Spain); ORM was selected by the Board as the alternative in 2017.

In 2017, CATAC wrote a report which, among other things, considered the scientific capability of the TMT on ORM. It concluded that the TMT would still be a powerful facility, able to conduct transformational science, and that therefore ORM is an acceptable alternative to Maunakea.

In light of the continuing protests on Maunakea, the question of why delay a move to the alternative site is a good one. There are several important reasons, including:

- ORM greatly compromises observations at mid-infrared and extreme blue wavelengths. This impacts a relatively small number of science cases, but they are compelling, and include the search for biosignatures on exoplanets. Searching for life on other planets is one of the most exciting things we can do as a human race, and it is something that no other planned large telescope will be able to do as well as TMT on Maunakea.
- Observations in the near-infrared are also impacted, with integration times that are 20-40% times longer at ORM than on Maunakea. The near-infrared is the part of the spectrum where TMT offers the very best spatial resolution; it is critical to many of the core science objectives.

- Canadian participation in the CFHT and Gemini telescopes on Maunakea offers scientific and operational synergies with TMT that contribute to a preference for this site.

Many of the reservations expressed about the scientific quality of ORM apply to the other low altitude sites considered by TMT: Cerro Tolar and San Pedro Martir. Cerro Armazones is now the site of the European ELT. Only the high altitude sites – Cerro Tolonchar and Cerro Honar – have conditions that make them comparable to, or even better than, Maunakea. Scientifically, they are certainly compelling sites. However, the other two large telescopes, ELT and GMT, are also being built in Chile, and this would leave the very unsatisfactory situation of no large telescope in the north. As undeveloped, very high altitude sites, a telescope at Tolonchar or Honar would be more expensive to construct and to operate. Schoeck et al. also noted that Tolonchar has "significance to the local people and communities", and structures of cultural significance were found at the summit.

Voices of Support

Some of the protestors' concerns have resonated worldwide, and this has resulted in many letters and social media postings from around the world, suggesting, requesting or demanding that TMT immediately withdraw from Maunakea. While even mainstream media can present a biased view, social media platforms, by their very nature, tend to reflect the viewpoints of those most active about an issue. This may not accurately depict broader local sentiment or discussions. In the case of TMT, we must be careful to not rely solely on these media to gauge the level of support/opposition to the project. Many Hawaiian residents, including on the Big Island, support TMT construction, and many young Native Hawaiians have spoken out to say that they consider TMT to be critical for their future. A collection of some of these voices can be found here: http://www.maunakeaandtmt.org/tmt-and-the-community/.

Independent polls show a mix of results, although they invariably suffer from small number statistics, especially when restricted to the Native Hawaiian populations. Polls from 2017 and earlier showed that the majority of people, both statewide and among Native Hawaiians, supported the project. An August 2019 poll indicated a Native Hawaiian population almost equally divided between support and opposition, while opposition among registered voters was 31%. The most recent poll seems to indicate declining support for the project among Native Hawaiians, while statewide support remains steady. These polls demonstrate that the Native Hawaiian community is strongly divided on the issue, and that the voices of the protestors are not representative of the entire Native community in Hawaii.

Beyond the numbers, several of the letters and postings from Native Hawaiian TMT supporters have been particularly thoughtful and raise some important points worth quoting here:

- A letter (July 28, 2019) to the Hawaii Tribune Herald by a student named Hokunani Sanchez, states:

"*The opportunities from CFHT and Keck helped me get accepted into college, internships and especially with a job at W. M. Keck Observatory in their finance office during my college summer break. The job the observatory offered me helps me and my family, given that money is not easy to come by…*

I believe it's my kuleana (responsibility) to become a teacher, teach young keiki to always show aloha, and never stop wondering and learning about the beautiful universe we live in. My passion for the beautiful stars will never cease, my heart will always be at my roots in Hawaii, and maybe someday in the future, I can give back to the people who made me who I am today."

- Malia Martin and Samuel Wilder King II represent a group of TMT supporters (https://www.imuatmt.org/), and in a letter dated Aug 26, 2019 they state that:

"*We at Imua TMT have heard that this false narrative has spread to our indigenous brothers and sisters in Canada, and we want it to stop. The idea that TMT and astronomy on Mauna Kea tramples on Native Hawaiian rights is far from the truth. The legacy of stargazing and astronomy honors our Pacific voyaging heritage. TMT's involvement with our community places indigenous peoples in a unique position to inform the global STEM community about our native methods of conservation and sustainability, which are disappearing in today's modern world.*"

- In a powerful letter to Honolulu Civil Beat Community Voices (July 18, 2019), Kauionalani Onodera states

"Mauna Kea is our piko, that which connects our land and sky, and TMT opponents claim that telescope construction is desecration. But I think telescopes maintain the sanctity of the mauna, worshipping the sky through observation and servicing a goal of bringing humankind closer to understanding creation of life in the universe. It isn't traditional but neither were the ahu erected on the mauna, which didn't diminish their sanctity to those who built it…

For my opinions I may be criticized and attacked, but I cannot stay silent and must also fight for what I believe in. I don't want to be afraid to say "Imua TMT" and want everyone to proceed with respect, on the common ground that we want what is best for

Hawaii's future. It isn't Hawaiians versus desecration. It isn't a war on culture and science. It isn't an issue where only Native Hawaiians get to have a say because we are no longer the only ones who live here."

- A longtime TMT supporter, Chad Kalepa Baybayan, is quoted in an interview for the Hawaii Star Advertiser (Aug 20, 2019):

"*There is more than enough room on the mauna for everyone to have their own space to conduct cultural practice and scientific research. There just needs to be the collective will to make that happen. We must be a better community by all of us learning how to share the mauna.*"

- In a letter to the University of Victoria student newspaper, Native Hawaiian and Big Island resident Michael Kealoha Stevens writes:

There is no single, unified native Hawaiian viewpoint. The vast majority of native Hawaiians do NOT practice the old Kapu religion, abolished by the Hawaiian monarchy almost 200 years ago.

Developing ideas based on ALL relevant data is important. Supporting Indigenous peoples is a fine sentiment, but requires some nuanced research, without which, Hawaiians like myself and the silent majority end up being unfairly disregarded.

What is particularly important about these comments is that they demonstrate that a decision to *not* build TMT on Maunakea will itself have an impact on Native Hawaiians. There is not a simple decision that can defuse the situation.

Looking ahead

Despite the work that has been done by TMT to "do things differently", it has proven difficult to rebuild trust in a future that respects both cultural and scientific goals on Maunakea. This is clear in the OHA Board resolution of July 25, 2019, authorizing OHA to provide support for the protestors, where the list of grievances does not include any activity by TMT itself.

However, a negotiated solution is proving difficult. Some of the protest leaders have made it clear that they will accept no solution that involves TMT construction. And there remains the difficulty (identified in the Keystone report of 2009) of knowing whom to speak to in the community.

A letter titled "Beyond the Standoff" was circulated broadly in August. It was written by Peter Adler, a lead author of the 2009 Keystone report, and it provides 36 suggestions for how both sides might be able to move forward together. In our opinion this shows, at least, that there are ideas out there that have not yet been tried. We highlight the closing statement in this letter:

> The current standoff is a "win-lose" moment. We cannot become a model for the rest of the world if that is the only face we choose to display. Time for something different. In a fractious world full of angry disputes, we must find ways to coexist. If not, we self-destruct.

What is clear is that Hawaiians will need to decide how they are going to share the land between themselves; how disputes will be resolved; how laws are made and enforced. Only then can an outside organization like TMT have certainty that it is following a process that is respected, and that will result in a fair outcome. Intentionally or not, the present controversy and dispute has been created in part by astronomers and those who support us. We cannot roll back the past; but we must also recognize that at this point any decision made by TMT will have an impact on Hawaiians. As Canadians we must all resist the urge to proclaim what we believe to be "best for Hawaiians", and to condemn or vilify those who disagree. As an astronomy community we must do a better job of listening, and of supporting those communities with which we wish to partner.

Recommended for further reading

1. General information and overviews
    - https://www.maunakeaandtmt.org/
    - https://www.oha.org/maunakea/
2. Science and Long Range Planning
    - TMT Detailed Science Case 2015
    - Canada's Long Range Planning Process
        - LRP 2000: The Origins of Structure in the Universe
        - LRP 2000: 2005 Mid-term Review
        - LRP 2010: Unveiling the Cosmos: A Vision for Canadian Astronomy
        - LRP 2010: 2016 Mid-term Review
        - LRP 2020 Process
            - CATAC report to the 2020 LRP panel
            - Indigenizing the next decade of astronomy in Canada, by H. Neilson et al.

- Canadian Astronomy on Maunakea: On Respecting Indigenous Rights, by H. Neilson et al.

3. Selected consultation and legal documents
    - Mauna Kea Science Reserve Master Plan
    - Comprehensive Management Plan
    - Final Environmental Impact Statement
    - Keystone report: Assessment of the risks for siting the TMT on Mauna Kea
    - Mountains of Controversy: Narrative and the Making of Contested Landscapes in Postwar American Astronomy, Swanner, L 2013.
4. Solutions and paths forward
    - Harry Kim Vision for Maunakea (March 1, 2019)
    - Finding a way forward on Mauna Kea, TMT by Governor Ige
    - Editorial in the Hawaii Star-Advertiser, by Kalepa Baybayan
    - Beyond the Standoff, by Peter Adler
    - The Heart of Aloha, by Mayor Harry Him
5. TMT-specific resources
    - Site testing
    - BLNR report on TMT THINK fund disbursements, Jan 26, 2018
6. Hawaii
    - *Shoal of Time: A history of the Hawaiian Islands* by Gavan Daws
    - Census summary from DBEDT (March 2018)

Appendix: Large Telescopes, Long Range Planning, and TMT

The core activity of astronomy is based on observations of the night sky at a range of wavelengths. Canada has a long history of leadership in this field, especially at visible and near-IR wavelengths, thanks in part to construction of the Canada-France-Hawaii Telescope (CFHT) in 1979. At the time CFHT was one of the largest telescopes in the world (with a 3.6m primary mirror), at a location with exquisite observing conditions, and Canadians had access to a significant fraction of the time (~50%). With this privileged access, Canada built up a very strong reputation in observational astronomy (Crabtree 2019).

Telescopes differentiate themselves in many different ways, but one of the most important is the diameter of the primary mirror, D. The light-gathering power of a telescope increases as D^2. The size of a point source decreases as D^2, if atmospheric turbulence can be well-corrected

using sophisticated adaptive optics systems. Together this means the point source sensitivity of a telescope scales like D^4: increasing mirror diameter by a factor of 3 increases sensitivity by a factor 81. There are other important factors, (e.g. at near-infrared wavelengths the background depends on the properties of the telescope, and for survey telescopes the field of view is a huge consideration), but, in general, bigger telescopes are better telescopes, and history shows that having access to large telescopes is key to being at the forefront of observational astrophysics. There are other paradigms for doing forefront investigations (e.g. survey facilities, which tend to be based on smaller telescopes), but even in this case breakthroughs require access to larger telescopes 'fed' by the survey telescopes.

In the 1990s construction began on a generation of 6.5-10m class telescopes, two to three times larger than the 3-4m class telescopes of the 1980s. Over the span of about a decade, 17 of these were built: 4 on Maunakea, 7 in Chile, 4 in the continental US, 1 on the Canary Islands, and 1 in South Africa. These are still the largest optical telescopes available today, twenty years later, and are still highly productive (Crabtree 2019).

Already in the era of 8m class telescopes it became apparent that it was increasingly difficult for individual institutions, or even nations, to construct and operate their own telescopes. In 2000 Canada launched its first Long Range Plan, with the objective of identifying and ranking projects of national import that required significant funding. Central to this plan was engagement in a Very Large Optical Telescope, of diameter 20m or more. After considerable study and investigation[6] of alternatives, in 2003 ACURA, in collaboration with NRC-HIA, joined a partnership with Caltech and the University of California, who were planning a 30-m telescope called CELT (California Extremely Large Telescope). This concept evolved into TMT with an expanded partnership including India, Japan, and China. This project has remained a top priority in Canada through the 2010 decadal plan, and the midterm reviews of those plans in 2005 and 2015 (see links at https://casca.ca/?page_id=75).

Planning and significant funding for the TMT project thus dates back twenty years, and first light is still a decade away. Attitudes, among many other things, can evolve considerably over such a period. International projects of this scale necessarily move more slowly. If consent can be "rescinded and changed", as argued in a recent submission to the LRP, we need a new model to make such ambitious projects viable.

[6] This included two important peer-reviewed funding awards, from NSERC and CFI, during the early stages of the project. A later NSERC Special Research Opportunities grant enabled development of the enclosure and telescope structure concepts. When Canada joined the TMT International Observatory in 2015, the preconstruction expenditures were split nearly equally between NRC and ACURA (i.e. government and academia).

TMT, with a mirror three times larger than the biggest ground-based optical telescopes today, will therefore be nearly 100 times more powerful than the largest optical telescopes today. It was recognized that by building the telescope on the best site in the northern hemisphere – Maunakea – it would be the most powerful telescope in the world in many areas. Only two other telescopes of similar size are currently being designed or built. The Giant Magellan Telescope (GMT) is a 20-m telescope built by a consortium of primarily Universities and institutes. The Extremely Large Telescope (ELT) is a 39-m telescope being built by ESO. Because of the enormous cost and complexity of these facilities, it is unlikely that many more than these three will ever be built. This is in stark contrast to the 8-m era, where the 17 telescopes making new discoveries every day are still heavily oversubscribed. There is an enormous amount that can be learned about the Universe from this next generation of telescopes, and with only three of them available, competition for time will be fierce for decades.

The science capabilities of TMT are well described in the detailed science case (Skidmore et al. 2015). In general it is impossible to predict what the most impactful and exciting discoveries will be, more than a decade from now. New science will be enabled through key technologies and capabilities, including:

- High spatial resolution imaging, using adaptive optics in the near-infrared to reach an angular resolution ten times better than the Hubble Space Telescope;
- Access to the widest possible wavelength range from the ground, including the ultraviolet (320nm) and midinfrared (up to 20 microns). This generally requires access to a high site (>4000m elevation).
- Rapid response, to follow up time variable phenomena

Among the many questions TMT will address, some of the most compelling are:

1. Are we alone? TMT will enable the direct detection of exoplanets, including candidates for “Earth 2.0”. Crucially, with transit spectroscopy TMT will allow us to search for “biomarkers” – chemical abundance patterns in the atmospheres of these planets that indicate the possibility of life.
2. How did the Universe begin? By observing fainter galaxies and quasars, we can see the Universe at earlier and earlier times. We will learn about the formation of the first galaxies and stars, that ended the so-called “Dark Ages” and reionized the Universe. By finding and mapping the oldest stars in our own Galaxy, we will learn about how it was assembled at these very early times.
3. How did the Solar System form? Detection and spectral characterization of faint objects in the Kuiper belt allows us to study the building blocks of the solar system.

There are many other important goals, including tests of General Relativity, an improved understanding of the nature of dark matter and dark energy, and the role of supermassive black holes in the formation of galaxies.