Keck 2035:
The W. M. Keck Observatory Strategic Plan

Photo credit: Andrew Richard Hara

W. M. KECK OBSERVATORY

WHY WE EXIST

We exist to advance the frontiers of astronomy and share our discoveries, inspiring the imagination of all.

WHAT WE ENVISION

We envision a world in which all humankind is inspired and united by the pursuit of knowledge of the infinite variety and richness of the Universe.

Photo by Andrew Hara

CONTENTS

W. M. KECK OBSERVATORY

Ho'okahi ka 'ilau like 'ana

(Wield the paddles together)

Over the last three decades, W. M. Keck Observatory (WMKO) has transitioned from 'the impossible machine' to the premiere facility for discovery on the ground today.

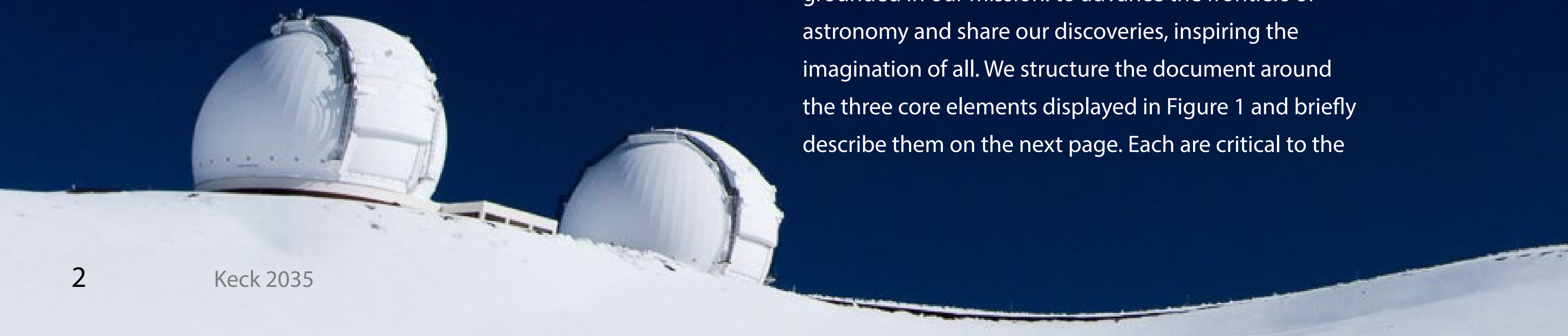
Astronomers using Keck have made fundamental and transformational discoveries across every aspect of the discipline, from the first few minutes of the universe to planets orbiting other stars. WMKO science remains the most impactful in the ground-based optical and infrared (OIR), with hundreds of highly-cited papers per year, national and international public interest, and critical contributions to two Nobel Prize-winning studies. Our leadership is a direct result of a scientific community that believes strongly that WMKO is their observatory, not just a tool.

Our staff provide nimble, world-class support and service, and WMKO is a strong member of the local community.

Nevertheless, each aspect of the environment the Observatory operates in has evolved since operations began. The facility is entering middle age, the world of work has changed, and our role in the community must evolve.

We present in this document, Keck 2035: The W. M. Keck Observatory Strategic Plan. The year 2035 to scope the plan is chosen for many reasons. First, by 2035, a new lease for the observatory to operate on Maunakea will need to have been successfully negotiated. Second, on this timescale, significant changes in WMKO staffing across the Observatory will have occurred at every level. Finally, by 2035, the landscape of astronomical capabilities will be radically different both on the ground and in space.

Although this is a forward looking document, it remains grounded in our mission: to advance the frontiers of astronomy and share our discoveries, inspiring the imagination of all. We structure the document around the three core elements displayed in Figure 1 and briefly describe them on the next page. Each are critical to the



successful execution of our mission, and none of these elements exists alone. They are deeply intertwined and interdependent, and as we implement the plans laid out in this document in both the coming years and over decades, we allocate our resources under the guiding principle that our future success requires deliberate consideration of each theme. We build the document outwards towards the end goals of our mission, beginning with our organization and staff, growing to discuss our relationships in Hawaiʻ i, and finishing with our plan to continue to enable strong leadership science. Across the document, we remain both ambitious and grounded in reality. Implementation of the recommendations in this plan requires varying combinations of significant new investment, new thinking, dedication, and resolve, but none are beyond our abilities to execute.

Figure 1: The three core elements of the Keck 2035 Strategic Plan

ORGANIZATIONAL HEALTH

WMKO's core asset is its people. Investing in our staff, where and how they work, and creating opportunities for professional growth drive our organizational strategic thinking. To help meet our mission, this plan sets four organizational goals:

1) Positioning WMKO as an employer of choice
2) Achieving best in class organizational health
3) Ensuring sustainable operations
4) Building tomorrow's workforce.

To achieve our position as an employer of choice amongst U.S. astronomical observatories and within our community, we strive to provide competitive compensation and benefits. We also seek to expand career growth and development opportunities, and to assist our staff in balancing personal and professional lives through flexible work options.

Best in class organizational health will require a focus on diversity, equity, inclusion, and accessibility (DEIA) and effective communication throughout the organization. Further, we must invest in our staff through training, mentoring, and building leadership capabilities. Our organizational health will also improve through the elimination or reduction of barriers that prevent our staff from working as effectively as possible.

Sustainable long-term operations require a model in which we deploy our resources in an efficient manner that enhances our overall effectiveness. We seek to ensure sustainable, long-term operations through focus on economic, technical, and environmental sustainability. Economic sustainability will require aligning our staffing with our core mission and competencies within our financial means. Technical sustainability necessitates a comprehensive review of facility and staff succession planning needs. Finally, environmental sustainability recognizes our responsibility to our staff, community, and beyond to ensure our operations are aligned with environmental best practices for long term stability.

Lastly, in conjunction with our community strategy, we must build a strong workforce in our areas of critical need. Our efforts will include strengthening partnerships with Hawai'i educational institutions, enhancing our internship and apprenticeship opportunities, and reaching out to Hawai'i's youth to ensure they know their opportunities at home to pursue STEM careers.

Photo by Andrew Hara

HAWAI'I COMMUNITY RELATIONS

Astronomy in Hawaiʻi stands at a turning point, with its vibrancy and legitimacy on the line. In our plans for community relations in Hawaiʻi, we discuss how WMKO must evolve its leadership as an agent for positive change within the astronomical community, and critically, how it becomes a strong reciprocal partner in the place we live and work. Recent years have offered significant challenges, but have set the stage for a transformation in how we approach our place in the community, and how we can thrive in and with it.

We begin by discussing how we have arrived at our position in time today, and how we can transition our mindset from a hierarchical to one, to one grounded in networks. We expand our concept of community beyond our walls or immediate geography to all of those who connect with us. We build on our strengths in outreach in STEM, and use the input from our staff and others to chart how we can move from a transactional community relationship to a lasting reciprocal one.

With this backdrop framework established, we define six strategic foundations: *Reciprocal Relationships*, *Maunakea Governance*, *Environmental Stewardship*, *Hawai'i-Grounded*, *Leadership*, and *Science Engagement*.These foundations then thematically flow into multiple, often interconnected, initiatives in the near term (and with some already underway) that each play an impactful role in our evolution as a community partner. Each initiative carries with it a commitment that must be resourced, but not always monetarily. We must invest in our community success to both enable our mission of scientific discovery and also our collective responsibility to Hawaiʻi as stewards, partners, and friends.

SCIENCE

While many of the core questions in astronomy will remain the same, the way we will explore them will undergo significant evolution in the coming decades. Transformative new capabilities are slated to come online on the ground with the onset of the ~30-meter aperture era, the rise of robust multi-messenger facilities, and large aperture synoptic capabilities yielding millions of transient events per night along with massive increases in statistical grasp across every type of astronomical object. Likewise, a new multi wavelength fleet of space missions from cubesats to flagships will arrive, offering powerful new capabilities to change and refine our view of the universe. Finally, the data tsunami is arriving, and along with it, new community expectations around how it is produced, used, and shared. Each of these changes represent immense opportunities for WMKO to continue to lead, should it rise to the challenge.

With this backdrop in mind, the science strategic plan is thematically anchored in three main themes. In the first theme, *Leveraging the Current and Future Landscape*, we explore how WMKO stands ready to augment its current capabilities with near-term additions to the instrument suite, powerful enhancements to existing instrumentation and adaptive optics, and a transformation in how data is created, managed, and archived. In the second theme, *Growing Scientific Leadership*, we describe the need for WMKO's suite of instrumentation to become faster, wider, deeper, and smarter, and how to evolve our capabilities into ecosystems of instrumentation where the impact is greater and more efficient than the sum of its parts. In the third theme, *Harvesting Innovation*, we motivate an evolution in how WMKO can partner across the astronomical landscape to mature and benefit from new technologies, and how to drive and resource innovation to meet our scientific goals and increase productivity.

The strategic themes then map onto 6 key strategic goals, from which we present a suite of instrumentation and adaptive optics capabilities that meet these goals and serve to maintain WMKO's status as a premier observatory and partner. These capabilities bring not only new tools, but also significant increases in efficiency, with many capabilities being unmatched, even by the telescopes on the horizon. This portfolio is ambitious, but realizable with the appropriate investments and partnerships, and the continued deep shared sense of ownership across our scientific community.

Artist's rendition of SN 2020EYJ, a white dwarf star that went supernova after pulling material from a helium companion star.

Credit: W. M. Keck Observatory/Adam Makarenko

THE STRATEGIC PLAN FOR ORGANIZATIONAL HEALTH

An Inspiring Place to Work

W. M Keck Observatory's (WMKO or Observatory) mission is to advance the frontiers of astronomy and share our discoveries, inspiring the imagination of all. To meet our mission we must work to ensure that WMKO is an inspiring place to work. We will achieve this by meeting four organizational strategic goals:

- First, we will position WMKO as an employer of choice amongst U.S. astronomical observatories. We define being an employer of choice as achieving a competitive position where WMKO is a primary choice amongst talent seeking to work for a U.S. astronomical observatory.
- Second, a healthy organization has "minimal politics and confusion, high degrees of morale and productivity, and very low turnover among good employees." (Lencioni, 2012). Therefore, we seek to achieve best in class organizational health.
- Third, we will ensure a sustainable operations model through a focus on economic, technical, and environmental sustainability.
- Finally, we will build tomorrow's WMKO workforce through close collaboration with our Hawai'i and continental partners.

Goal 1 - Be an Employer of Choice

For WMKO to flourish into 2035, we must retain our highly skilled, innovative staff and recruit the best talent from Hawai'i and beyond. Specifically, we strive to be an "employer of choice" amongst U.S. astronomical observatories. To achieve employer of choice status, we commit to the following initiatives:

- Competitive compensation and benefits, including additional support for our Hawai'i Island based staff so they may effectively balance their personal and professional lives.
- Career growth and development for all staff, including a preference for promotion from within.
- Flexible work opportunities, including hybrid and fully remote opportunities.

Compensation and Benefits

We will continue to provide competitive compensation and benefits that support our staff's ability to carry out our mission on Hawai'i Island. Further, through our best practices based compensation program, we seek to attract, motivate, and retain the talented employees needed to drive our success.

Compensation

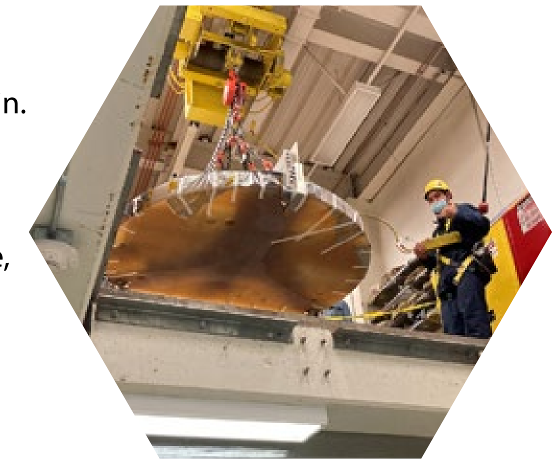
Our compensation will continue to target an above-midpoint percentile of market compensation of the relevant labor markets for each Observatory position. When determining the appropriate market level target for our compensation, we strive to meet or exceed levels set by similarly situated Hawai'i or Southern California employers.

Benefits

We will provide generous and competitive benefits meeting or exceeding benefits provided by other U.S. astronomical observatories. Further, for our Hawai'i Island based staff, we will provide additional support to assist with balance of personal and professional lives.

- Maintain competitive benefit package.
- Explore ways to reduce the housing cost burden for full-time staff residing on Hawai'i Island.
- Work with our observatory and community partners to explore providing staff residing on Hawai'i Island with access to high-quality, affordable childcare.

Career Growth and Development



To ensure we are an employer of choice, we will prioritize career growth and development for all staff through growth plans, training, mentoring, professional/industry/trade organizations, and hiring from within. The development of staff spans the full duration of a career at WMKO.

- Supervisors will work with Human Resources to create goal-based career growth plans for all staff. The growth plans will include development in areas of both technical mastery and personnel management, with an emphasis on one path or the other based on aptitude, individual preference, and business need.
- We commit to providing professional development (both funds and time) for all staff through a combination of on-site, off-site, and web-based training.
- We prioritize developing talent from within. To the extent feasible, we strive to recruit internally.

Flexible Work Opportunities

In the three years preceding this strategic plan, we have learned much regarding the benefits and challenges of flexible work. We seek to assist our staff in balancing personal and professional lives while preserving the benefits that come from close collaboration. In this spirit, we will offer a range of flexible work opportunities.

- We will continue to evolve our comprehensive flexible work policy with the goal of providing flexibility in working location, schedule, and hours.
- Certain positions may be eligible for full remote work (i.e., the staff member does not reside on Hawai'i Island). To balance our work needs and community commitment, we expect that no more than 20% of our total workforce will reside outside the State of Hawai'i.
- We will continue to provide flexibility on an as needed basis (i.e., temporarily shifting work location/days/hours to allow for short duration medical and other personal needs).
- To help ensure staff have access to a broad housing market, we will explore opportunities for office and meeting space in Hilo.

THE STRATEGIC PLAN FOR ORGANIZATIONAL HEALTH

Goal 2 - Be a Leader in Organizational Health

Fostering a healthy organization is vitally important to ensuring WMKO's position as an inspiring place to work. WMKO is a mission-focused organization with clear and lived values that shape the organization we aspire to be.

We create a healthy organization by focusing on Diversity, Equity, Inclusion, and Accessibility (DEIA); effective communication throughout the organization; cultivating and preparing our future leaders; training our managers and supervisors in effective supervisory methodologies; empowering staff at all levels of the organization; and reducing/eliminating unnecessary barriers to accomplishing our work efficiently.

DEIA

DEIA has been defined as follows:

- **D**iversity is the practice of including many communities, identities, races, ethnicities, backgrounds, abilities, cultures and beli
- **E**quity is the consistent and systematic, fair, just and impartial treatment of all individuals.
- **I**nclusion is the recognition, appreciation, and use of the talents and skills of employees of all backgrounds.
- **A**ccessibility is the design, construction, development and maintenance of facilities, information and communication technology, programs and services so that all people, including people with disabilities, can fully and independently use them.[1]

WMKO seeks to develop a culture where we embody DEIA best practices at all staff levels and in all organizational processes. We will support and advance DEIA at WMKO by:

- Creating and assigning staff to champion DEIA at WMKO.
- Adequately funding DEIA, including staff efforts to champion DEIA.
- Ensuring staff have the the authority to advance DEIA at WMKO.
- Committing to creating a workforce inclusive and supportive of staff from communities traditionally underrepresented in Hawai'i astronomy.
- Tailoring our DEIA practices to the place in which we live and work.

[1](Floore, 2022, https://blog.dol.gov/2022/02/22/diversity-equity-inclusion-and-accessibility-a-foundation-for-meaningful-change#:~:text=DEIA%20is%20a%20new%20way,and%20contributions%20of%20all%20workers.)

Communication

Effective, transparent communication throughout the organization provides the foundation for organizational health. This foundation allows for greater trust and connection amongst staff at all levels of the organization. We will take the following measures to ensure effective internal communication:

- Assigning staff to the role of internal communications. This role will champion effective communication throughout the organization.
- Adequately resourcing the internal communications role, including providing suitable tools (and staff training on those tools) for effective cross-Observatory communication.
- Ensuring that the role has the authority to advance internal communications at WMKO.

Supervisory Training and Mentoring

Managers and supervisors must be fully competent and committed to carry out their roles. They must emphasize and demonstrate our values, including the ability to foster teamwork. Training is essential for ensuring our supervisors (both new and established) are equipped with the tools for success.

We are committed to providing supervisory training and will ensure that all managers/supervisors, regardless of tenure, receive training that is aligned with our values and human resources best practices. Refresher training will occur on a schedule aligned with best practices and business need.

To further augment the development of our new supervisors, we will create mentorship pairings with established, effective managers/supervisors.

Building Leadership Capacity

Building leadership capacity starts with identifying leadership potential across the Observatory. With potential identified, we will will seek to develop and elevate effective leaders at all levels of an organization. Effective leadership is empathetic, decisive, and servant-modeled with a major focus on effective communication. To develop the leaders we wish to see, we will provide formal training opportunities. Beyond the formal training, we will provide our leaders with informal opportunities to develop and strengthen their leadership capacity. Additionally, we will encourage supervisors to provide leadership opportunities to all staff, regardless of their position in the organization.

Elimating / Reducing Barriers

Unnecessary or poorly defined barriers frustrate staff and reduce organizational effectiveness. We strive to eliminate or reduce barriers that prevent staff from working as effectively as possible. We will regularly review our processes and eliminate/restructure those that no longer serve an appropriate compliance or risk-reduction purpose or are not needed to carry out our core mission. We will be attentive to and reduce administrative and technical barriers that impede efficient workflow. Further, through formal and informal means, we will encourage all staff to identify processes and procedures that negatively impact their work.

THE STRATEGIC PLAN FOR ORGANIZATIONAL HEALTH

Goal 3 - Sustainable Operations Model

WMKO operates in a budget-conscious environment and works to maximize the efficiency of our resources. However, efficiency must not compromise the mission, nor the ability to attract new funding and new talent. Therefore, we seek to ensure sustainable, long-term operations through focus on economic, technical, and environmental sustainability.

Economic Sustainability

WMKO anticipates that its current, flat operations funding model will continue through the life of this strategic plan. Accordingly, we are not anticipating significant new operations funding. Therefore, to maintain economic sustainability while ensuring we provide the necessary level of compensation and benefits, we must align our hiring with our core mission and competencies.

To meet additional needs and to ensure long-term economic sustainability, we will:

- Build shared services models with our Maunakea Observatories partners. The shared services may stretch across administrative and technical functions.
- Build a network of trusted collaborators and contractors to fill skill gaps as they arise.
- Regularly evaluate and implement outsourcing in areas outside core competencies.

Technical Sustainability

Within our anticipated, flat operations funding model, we are confident that facility renewal and technical sustainability are possible. Although WMKO is a mature Observatory, we strive to operate at peak performance well beyond 2035. To accomplish this, we must address comprehensive facility needs, including the following:

- Modernize the Observatory to maintain its full operational status well beyond the life of this strategic plan.
- Ensure sufficient allocation of funds and staff for effective day/night operations, preventative and predictive maintenance, and infrastructure renewal.
- Improve efficiency of existing operations systems.
- Ensure that new capabilities are effectively deployed and operational on delivery, including documentation, adequate spares, and staff training.
- Improve our Observatory planning processes with the goal of creating better and more predictable outcomes.
- Decommission instrumentation and other systems.

To ensure technical sustainability, we must also address our staff succession planning through:

- Maintaining clear, easy to locate documentation for systems, policies, and procedures across the Observatory’s technical functions.
- Fostering a healthy spread of early-, mid-, and late-career staff across the Observatory. This requires attention to the needs of each position, along with a commitment to develop earlier-career talent. Where appropriate, we envision an approach like the following:
    - Wherever practicable, develop talent from within.
    - Hire talent residing in Hawai’i, or with strong connections to Hawai’i, to foster stability of staff and to help meet our community connection goals.
    - For certain positions, recruit talent regardless of location, to ensure we have the expertise needed to operate and develop one of the world’s premier observatories.

Environmental Sustainability - Green Initiative

“[T]he future of astronomy, like the future of so much of the world to which it is bound, will depend on the development and implementation of more sustainable practices and partnerships with the global community, commercial ventures, and Earth.”[2] We have a responsibility to our staff, community, and beyond to ensure our operations are environmentally sustainable. To ensure the success of our “Green Initiative,” we commit to the following:

Climate Action

- Net-zero scope 1 and scope 2 carbon emissions by 2035.
- Early and significant reduction of Scopes 1 and 2 carbon emissions, aspiring for net-zero by 2030 by decarbonizing the WMKO vehicle fleet and implementing energy efficiency improvements.
- Strive towards net zero scope 3 indirect emissions by 2035, by researching ways to account for and minimize emissions from sources not owned or controlled by the observatory but which occur as a consequence of observatory activities, such as air travel.
- Success may include the need for carbon offsets, which we will strive to do in partnership with entities on Hawai‘i Island first, followed by entities throughout the State of Hawai‘i and then beyond. Any carbon offset program will be scrutinized to ensure effectiveness for sustainable, genuine carbon reduction.

Other Environmental Initiatives

- We will address other potential environmental concerns as they are identified, with a focus on protecting our environment.
- We will continue to work with partners across Hawai‘i to care for Maunakea holistically, including cultural and environmental considerations.

[2] “Astro2020” (National Academies of Sciences, Engineering, and Medicine. 2021. Pathways to Discovery in Astronomy and Astrophysics for the 2020s. Washington, DC: The National Academies Press. https://doi.org/10.17226/26141.)

THE STRATEGIC PLAN FOR ORGANIZATIONAL HEALTH

Goal 4 - Build Our Workforce

To ensure success in 2035, we must build a strong workforce in our areas of critical need. These efforts coincide with our desire to be a Hawai'i-centered organization. To address these needs, we will:

- Strengthen partnerships with Hawai'i based institutions of higher learning, including community colleges.
- Collaborate with the University of Hawai'i system to help ensure a direct workforce pipeline into open WMKO positions.
- Continue our internship programs (e.g., Akamai and Keck Visiting Scholars) and enhance hands-on training opportunities for trade and technical positions.
- Collaborate with our local education community to assist with building STEM curricula that align with our workforce needs.
- Inspire Hawai'i's youth to pursue STEM careers, through our science and engineering outreach programs.

Conclusion

We are dedicated to creating an extraordinary and inspiring work environment at WMKO. We understand the pivotal role of attracting and retaining exceptional talent to propel the continued success of the Observatory and its prolific scientific production. To achieve this, we prioritize positioning our Observatory as the preferred employer among U.S. astronomical observatories through providing competitive compensation and benefits, career growth and professional development opportunities, and providing flexible work options that prioritize a harmonious work-life balance, aligning with the evolving needs and aspirations of our current and future workforce.

We place great emphasis on fostering organizational health through our steadfast commitment to diversity, equity, inclusion, and accessibility (DEIA). By actively cultivating an environment that values and celebrates diverse communities, backgrounds, and abilities, we create an inclusive workplace that harnesses the talents and skills of all our employees. Effective communication, comprehensive supervisory training, mentorship programs, and leadership development initiatives form the bedrock of our efforts to empower staff at every level and eliminate barriers that hinder their success.

In our pursuit of excellence, we also recognize the importance of sustainable operations—economic, technical, and environmental. While operating within a budget-conscious landscape, we remain resolute in optimizing our resources' efficiency without compromising our mission or impeding our ability to attract new funding and talent. Through collaborative shared services with our Maunakea Observatories partners, strategic partnerships with trusted collaborators and contractors, and regular evaluations of outsourcing opportunities, we ensure the long-term economic sustainability of WMKO.

By implementing these comprehensive strategies, we will continue to push the boundaries of astronomical research, while inspiring and motivating our exceptional team of staff members. We remain committed to creating an environment that fosters innovation, collaboration, and unparalleled discoveries, making us an extraordinary place to work.

THE STRATEGIC PLAN FOR HAWAI'I COMMUNITY RELATIONS

A New Future for WMKO in Hawai'i - a Big Shift

W. M. Keck Observatory (WMKO) has been very successful in meeting, and often exceeding, our scientific and technological innovation objectives on Maunakea for over three decades. Our operation has matured, and we have hit our stride in delivering world-leading scientific impact with exciting scientific opportunities on the horizon. During this same period, the socio-political environment in which WMKO operates in Hawai'i has changed dramatically. Deep divisions formed in our local community over the acceptance of astronomy on Maunakea, punctuated by intense native Hawaiian-led protests against the construction of the Thirty-Meter Telescope (TMT) in 2015 and 2019. We at WMKO were not fully aware of how the community truly felt, and found ourselves unprepared to navigate the emotion and complexities of the situation. The hard truth is that we came to realize we are disconnected from parts of the Hawai'i community who care about Maunakea and are impacted by astronomy.

THE STRATEGIC PLAN FOR HAWAIʻI COMMUNITY RELATIONS

Since then, we have put significant effort into expanding relationships across Hawaiʻi and have made promising progress with much work remaining. As we look forward, it is essential that we continue to broaden and deepen relationships in Hawaiʻi, especially with those who have different perspectives and lived experiences than us, continually sensing the social field in which we conduct our work. We must strive for interconnection and not allow ourselves to slip back into disconnection again in the future.

For us to look forward, we must make sense of how we got to this point in time. Appendix A provides a contextual summary of changes WMKO experienced in the astronomy ecosystem in Hawaiʻi.

At the apex of the TMT protests in 2019, with hundreds and sometimes thousands standing in protest of the construction of TMT on the Maunakea Access Road, it became clear that maintaining the status quo of Maunakea astronomy would not lead to a successful future for WMKO. We are now navigating major systems change. One visible aspect is the state's adoption of a new Maunakea stewardship authority that is based on a community-based mutual stewardship model with a lineal descendant, a native Hawaiian cultural practitioner, and representatives of other interests in decision-making positions instead of just advisory roles.

WMKO's adaptation to this big shift requires new approaches and mindsets. The Observatory successfully advanced its scientific and technology innovation objectives by tapping the collective expertise and creativity of a network across multiple organizations. Going forward, our Hawaiʻi community relations approach must be equally innovative and adaptive in order to successfully navigate socio-political change facing astronomy in Hawaiʻi, in which we do not have full control of our destiny, nor are there readily apparent solutions.

The "Network Mindset" in Table 2 captures the essence of WMKO's approach to Hawaiʻi Community Relations in which we see ourselves as an integral part of the Hawaiʻi community (the Network) and seek to participate in and support it, rather than transact with it. Based on our experiences engaging with the Hawaiʻi community, we believe this approach will be beneficial, not only for WMKO, but for the Maunakea Observatories (MKO) as a collective. WMKO can be a positive and supportive influence for moving in this direction.

Hierarchical Mindset	Network Mindset
Mechanistic worldview	**Living systems worldview**
System seen as a hierarchical pyramid	**System seen as a web of interactions**
Organization at the center of focus	**Purpose at the center of focus**
Top-down, directive leadership	**Distributed, servant leadership**
Centralized decision-making	**Collective decision-making**
Impulse to command and control	**Impulse to connect and collaborate**
Information restricted	**Information shared**
Task oriented	**Relationship oriented**
Bias toward deliberate strategy	**Embrace of emergent strategy**

Table 1: The Network Mindset

While WMKO's mission of scientific discovery remains steadfast and clear, we must, with open minds, hearts and will, adapt HOW we conduct the mission incorporating what we have learned about our place in Hawaiʻi and in our community. This document presents a values-based approach for building and sustaining healthy, thriving, reciprocal relationships with our Hawaiʻi Island community and *ʻāina* (natural environment) we exist within.

WMKO's Hawaiʻi Community Relations Strategic Plan

This plan is an essential component of WMKO's overall 2035 strategic plan that will steer our organization for the next decade-plus. It guides our interactions in Hawaiʻi i while recognizing the impact of WMKO's presence on places and communities.

In this plan, we define community as everyone in Hawaiʻi who cares about or is touched in some way, big or small, directly or indirectly, by what WMKO and the observatories do. We acknowledge that many people in Hawaiʻi do not make a distinction between WMKO and the other MKOs, so our approach needs to be co-created and enacted with the MKOs. It is also important to remember our staff is an integral part of the community.

This Hawaiʻi Community Relations Strategic Plan provides guidance for everyone associated with WMKO, e. g., staff, leadership, governance, partners, funders, contractors, and consultants. It informs Hawaiʻi astronomy stakeholders and collaborators about the direction we are headed in. More broadly for the community – the people, partners, and organizations we live among in Hawaiʻi – this document shares who we are, our intentions, and values.

Our strategic vision for community relations builds upon WMKO's three decades of community work in STEM educational outreach, career pathways, and community citizenship, as well as numerous relationships built over time. It incorporates what we've learned, including what we have heard from our valued staff members. Their voices affirm that strengthening our community connections is key to our future and a priority for our employees, and must be done in a meaningful way that harmonizes with the perspectives of the local and native Hawaiian community.

Examples of Staff Feedback, All-Staff Meeting, January 2020

"Seek opportunities to do more listening, show the community we are listening, and perhaps respond with support where we can."

"Make Keck 'cool.' I mean, I love astronomy, but let's face it, the 61% who are struggling economically to just get by may not be as interested."

"We need to spend more time contributing in ways that have nothing to do with astronomy…we need to work shoulder-to-shoulder with people to address their needs."

Many recent conversations with community members refined our community relations approach to one based on deep listening rather than simply hearing, genuine relationship building as opposed to transactional engagement, and adopting a mindset that we and the community are "in it together." For WMKO to thrive, we need to help our community thrive, not in a transactional way, but built on lasting commitments and reciprocal relationships.

WMKO will continue to evolve, grounding our approach in humility, respect, and appreciation for this place and community we work and live in.

Our Aspirations for Hawai'i Community Relations

We aspire to excel at our mission of uncovering new knowledge about the universe to enrich all of humanity, while being fully aware of and responsible for our impact on ʻāina and the community. It is in this context that WMKO has developed an aspiration for our Hawai'i Community Relations.

WMKO prioritizes reciprocal relationships with our community, generously receiving and sharing knowledge, resources, and opportunities to earn and uphold our place as ethical, respectful and humble community partners. We lean in alongside community members to mutually-steward Maunakea and contribute to the well-being of the ʻāina and communities we live and work in.

Examples of Community Feedback

"We love astronomy!"

"Astronomy jobs are not for us."
"You (observatories) are so arrogant - you don't acknowledge the knowledge and wisdom that comes from Hawai'i."

"We hear all about economic benefits of astronomy but I don't see how it makes my life better."

"You are the first person I've met who works at an observatory."

The ʻupena (Hawaiian throw net) is a metaphor that grounds and centers our intention. The fisherman casts the ʻupena to catch fish to eat, feeding the ʻohana (family) and community. An ʻupena in disrepair doesn't do the job. In this metaphor, the knots symbolize relationships in the community (picture a knot as the connection between two people holding hands). In a well maintained ʻupena, all the knots hold fast and function collectively, with a mutual purpose. Community relations is all about taking good care of relationships and ʻāina, and we, too, will be cared for in return. Mutuality, or a sense of "we're all in it together," is how we – astronomy and the local community – will thrive together into the future.

Widening our view plane, there are numerous weighty environmental, social and political challenges facing us in Hawai'i, nationally, and globally in increasingly divisive contexts. We feel a continued responsibility to conduct our mission and share our amazing discoveries in a pono (good, ethical, upright, moral, equitable) way - not only because we must meet our mission, but simply because we believe it is the right way to conduct ourselves as humans.

It will not be easy – fulfilling challenging aspirations rarely is. We will engage in uncomfortable spaces and difficult conversations. We will take calculated risks and act courageously. We will strive for the collective good with an eye to a positive long-term future. WMKO's staff and leaders of tomorrow will continue the work we embark on today. We will strive to co-create this future, not in a silo, but in synergy and cooperation with the other MKOs and the community.

Six Strategic Foundations

There are six strategic themes that will lead us to meeting our aspirations. The first strategic foundation, *Reciprocal Relationships,* is the base upon which the other themes are built.

Reciprocal Relationships: We build authentic relationships with our community. Learning each other's history and perspectives is invaluable and cannot be rushed. Mutual understanding leads to supporting collective, rather than narrow, interests. Staying connected to community, including those whose perspectives don't necessarily align with ours, keeps us in tune with our community so that we may adapt continuously over time. Going beyond the comfort of our silos may be uncomfortable, but is essential and we need to develop the mindset and skillset to do this effectively.

Because we live on an island, we are "in it together" and integrally connected with our community – and we nurture our relationships accordingly. We are generous with what we offer that is within our means, and without a transactional expectation for return. We develop collaborations and partnerships, working side-by-side with community organizations to make our community stronger.

When it comes to relationships with native Hawaiians, it is important that we listen and acknowledge their history of dispossession from lands and lifeways, and the resulting impacts over generations. While we may not be able to repair injustices of the past, we can and should listen with open hearts and interrupt inequitable systems and practices to change them for the better.

Maunakea Governance: We embrace community-based management in collaboration with the local and Hawaiian community. We work proactively and collaboratively with the new Maunakea authority to develop a fair and sustainable land authorization beyond the end of our current lease (2033).

We communicate, strategize, collaborate and share resources among our fellow Maunakea Observatories, University of Hawaiʻi, ʻImiloa, and community partners to be good stewards of Maunakea, to be good stewards of our scientific assets, and to deliver the greatest positive impact to our local community.

Environmental Stewardship: We engage in direct environmental stewardship going above and beyond compliance requirements to care for the mauna holistically, putting into practice the idea that if we take care of ʻāina, it will take care of us. Engaging in caring for the land and natural resources demonstrates our long-term commitment to Hawaiʻi and the people of this place.

Foundations	Themes	Initiatives (1-3 years)
Reciprocal Relationships:	Relationship-building Community-citizenship; volunteerism Community partnering	• "Talk story" discussions with community members* • Involve staff: 2% Community Engagement Program* • Community engagement initiatives; Nā Hōkū Huihui; Food Truck Fridays * • Community well-being initiatives – Food security, COVID health initiatives, Diaper Bank* • Waimea Middle School mentoring program*
Maunakea Governance:	New Maunakea authority MKO/UH governance Lease negotiations	• Actively support new stewardship authority transition* • Develop community kuleana (responsibility/benefits) terms* • Strengthen the MKO/UH alliance* • Lease negotiations
Environmental Stewardship:	Caring for the land	• Maunakea Forest Restoration Project* • Center for Maunakea Stewardship invasive weed pull* • Zero-waste facility upgrade
Hawai'i-Grounded:	Kamaʻāina and native Hawaiian employees Incorporate Hawaiian and local culture at WMKO	• Hiring and Astronomy career pathways for kamaʻāina and native Hawaiians* • Akamai Workforce Initiative* • Electrician Apprenticeship Program* • High School Student Employment Program* • Kalihiao – cultural and history education for employees* • Halau ʻŌhiʻa – cultural stewardship training of staff • Land acknowledgement statement
Leadership:	MKO Leadership Collaboration Leadership capacity Tell our stories	• Kamaʻāina Connections Program* • Share WMKO community relations approach with MKOs* • Government, Civic and Business Relations* • Community leadership, board service* • Professional development: Theory U, Futures Thinking, Impact Networks* • Articles, Op-Eds, Presentations, Panel Discussions*
Science Engagement:	Education outreach Connect science and culture Promote scientific literacy in schools	• Maunakea Astronomy Outreach Committee – Journey through the Universe, AstroDay, Solar System Walk, etc.* • Keck community astronomy talks* • Maunakea Scholars* • A Hua He Inoa - ʻImiloa-led Hawaiian naming of celestial objects* • Partner with ʻImiloa, Dept of Education, Hawaiian immersion schools, UH to develop curriculum

Table 2: Community Relations into Action
(* indicates initiatives that are in progress

Hawaiʻi-Grounded: We conduct our work in a way that embraces and shows respect to Hawaiian and local culture and values. We strive for the Observatory's demographics to reflect the surrounding community, with kamaʻāina (Hawaiʻi-born) and native Hawaiians in leadership positions. We orient new members of our observatory to feel a sense of belonging at WMKO and in Hawaiʻi. To operate effectively in harmony in Hawaiʻi, our organization must be grounded in Hawaiʻi.

Leadership: We are human-centered, systems-thinking, adaptive leaders who create opportunities for new possibilities to emerge. The stories we share enable positive change. We collaborate and co-create change initiatives with the Maunakea Observatories and the community, and we develop future leaders who embody these attributes. Going beyond Hawaiʻi astronomy, we share and exchange lessons learned about community relations across multiple disciplines in Hawaiʻi, the US and the world, fostering positive systems change. We choose to be in the vanguard and a significant contributor to the big shift of mindset and practice of astronomy that is happening in Hawaiʻi.

Science Engagement: We share WMKO's passion for science with local community members, especially Hawaiʻi's children and youth who represent our future. By showing respect of and integrating traditional knowledge systems and connecting our science to Hawaiian culture and sense of place, we dismantle the regrettable and unnecessary division of science "VERSUS" culture.

Putting the Strategy Into Action

Table 2 summarizes the six strategic foundations and describes initiatives for the next 1-3 years - many of which are in process to some degree (denoted by asterisks). We believe the foundations and themes should be resilient up through our 2035 horizon, with occasional course corrections. The initiatives, on the other hand, will need to be updated annually as we make progress and learn what works and what doesn't.

The table does not represent an implementation plan – that still needs to be developed so that clear near term objectives, scope, deliverables, budgets, schedules and metrics can be developed. Rather, Table 2, provides tangible examples of how the strategy is or may manifest.

Particular initiatives may span multiple themes, but for simplicity, they only show up in one cell of the table. The next step will be to create an implementation plan.

Conclusion

We are at a pivotal point of both immense challenge and immense opportunity to bridge the deep divides and polarization in Hawaiʻi regarding astronomy on Maunakea.

The vision of a bright and fulfilling future is compelling – a vision in which WMKO is in tune with and widely embraced by our community, our employees and scientific community feel truly welcomed, our science is inspiring to our community and is nspired by Hawaiian culture, and we are all united in mutuality with aloha for one another and for majestic Maunakea.

Let us be bold, confident, courageous, and innovative, while conducting ourselves with humility, openness, commitment, and passion to realize this vision!

THE STRATEGIC PLAN FOR SCIENCE

Since first light nearly three decades ago, data from WMKO has led the world in astronomical discovery from the ground and has been a powerful partner to facilities in space. To date, astronomers using WMKO have published over 6,500 refereed publications, with over 12,000 unique authors, garnering nearly half a million citations.

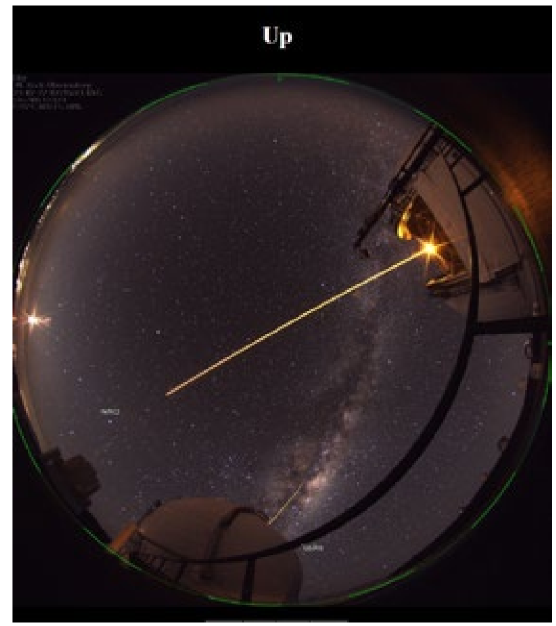
W. M. KECK OBSERVATORY

The foundations of WMKO's success in maintaining leadership lie in three main areas:

1. the collecting area and spatial resolution of the telescope and its leveraging of the pristine viewing conditions of Maunakea;
2. the power and versatility of the WMKO's instrumentation and Adaptive Optics (AO) combined with the nimbleness and efficiency of WMKO operations; and
3. the strength, creativity, and innovation of the WMKO community of astronomers, instrument builders, staff, and supporters.

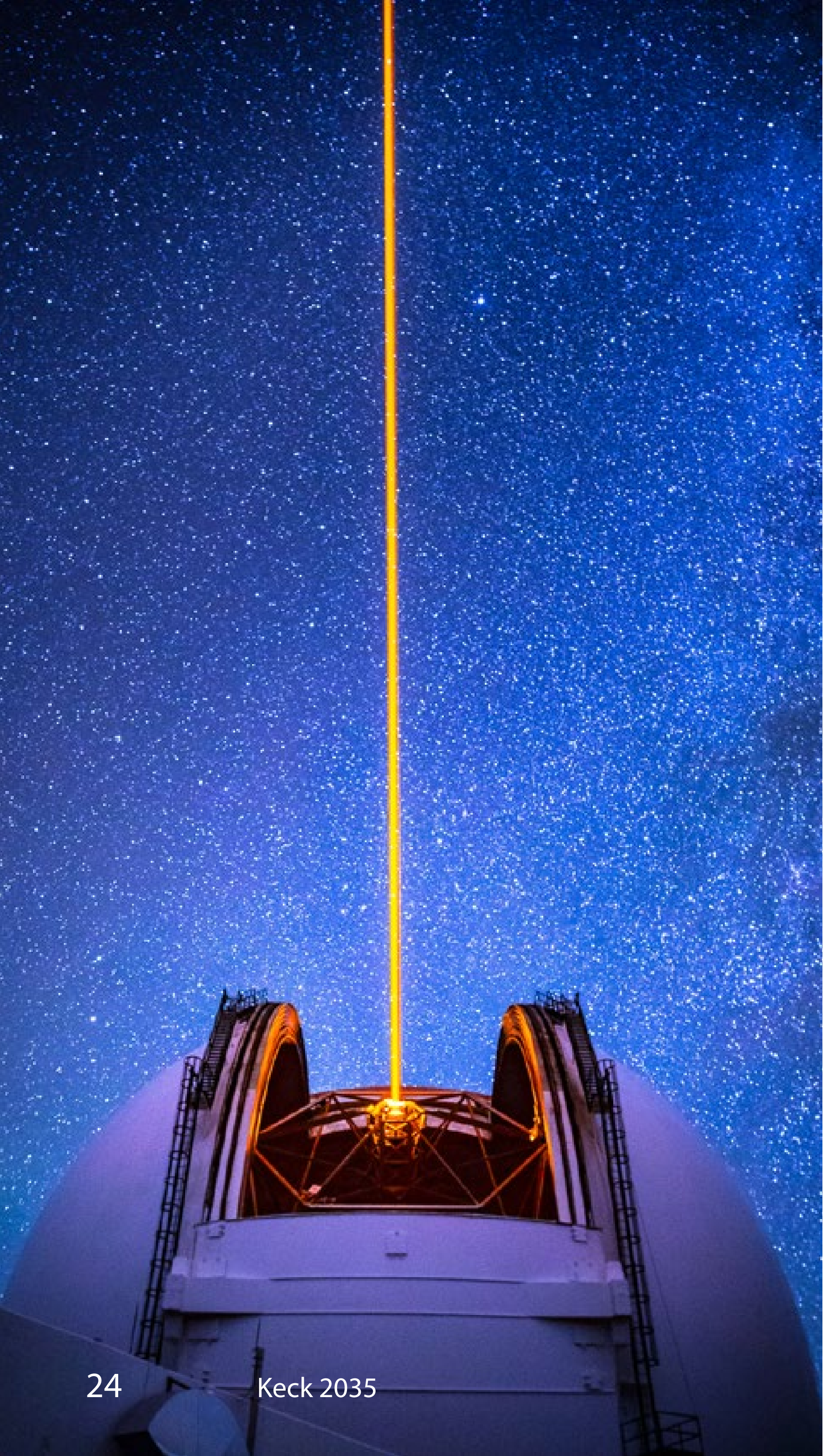
These foundations remain at the core of the strategies that WMKO will implement as it enters the ELT era and beyond to maintain and grow its leadership.

The Keck 2035 Science strategy is grounded in three main motivational themes: *Leveraging the Current and Future Landscape*, *Growing Scientific Leadership*, and *Harvesting innovation*. These themes emerged from nearly two years of input from the Keck community as detailed in the Supporting Materials. The themes then flow into six strategic goals, and a set of recommendations on new and upgraded capabilities to meet those goals. The recommendations in this document represent the consensus view of the Keck Science Steering Committee (SSC) and WMKO leadership, and are endorsed by the CARA Board.



Leveraging the Current and Future Landscape

The next fifteen years will see a transformative change in capability across astronomy. Powerful new facilities will come online on the ground and in space, dramatically altering our ability to both survey the sky and look ever deeper into it. More and more, non-electromagnetic observations will join with traditional ones to probe the most extreme environments in the cosmos. Exoplanet studies will continue to transition from discovery to characterization, to deep exploration as new high-contrast capabilities emerge, and the search for life in the universe becomes viable. Figure 2 shows many of these new facilities, and their notional first light dates; here we note a few key examples. Already, JWST is providing its first exciting results, some of which potentially challenge the established models of galaxy formation and evolution. Every image from JWST will effectively be a deep field, requiring significant follow-up capabilities to reach their full potential. If the early science is any indication, JWST will be an immensely powerful new asset in the fleet of great space observatories for the next two decades. By mid-decade, the Roman and Rubin observatories will bring immense new capacity to wide field imaging surveys. Rubin will usher in the era of millions of transients per night, while Roman will provide Hubble quality images with 100 times the field of view. Both facilities will need an efficient and powerful partner on the ground to realize their full potential. Gravitational wave facilities will continue to increase in sensitivity and localization accuracy, opening up significant opportunities for new follow-up science. And finally, to close out the decade and start the next, the new era of large-aperture telescopes at the ~30-meter ELT scale will begin, providing the deepest looks ever from the ground, and promising to create new avenues for science that cannot be realized today.



How does WMKO best leverage its position within this landscape prior to the onset of operations of the ELTs? In the coming years, significant capabilities are already planned and underway to become available to maintain scientific excellence. For exoplanet science, a powerful trifecta of new instrumentation—KPF, plus SCALES and HISPEC coupled with HAKA's high order AO —will significantly expand WMKO's capabilities and build upon the foundations set by HIRES, NIRC2, and NIRSPEC. KAPA will provide significant improvements to AO capabilities on Keck I with OSIRIS. KCWI, with the integration of KCRM will offer full optical wavelength coverage to this premier integral field spectrograph, significantly increasing its utility for extragalactic science, and making it a powerful tool for transient follow-up. Finally, the Data Services Initiative will have transformed the endto end process of how data flows at WMKO, culminating in DRP-processed data available to astronomers for each instrument in near real-time.

Looking further forward, WMKO has significant opportunities to expand scientific leadership up to and through the start of the ELT era. These opportunities will be most successful when they maximize scientific productivity through the combination of new instrumentation and increases in efficiency. For example, a replacement of the workhorse LRIS instrument yields greater throughput when it is designed from the start to be compatible with an adaptive secondary mirror (ASM) and ground layer adaptive optics (GLAO). Likewise, MOSFIRE can be upgraded to benefit from the ASM + GLAO. Another example is KPF, which when expanded to include a second fiber feed from Keck II and operated via cadence scheduled observing can make significant gains in efficiency over its current baseline. Even current instrumentation can see large gains in efficiency through software that more effectively plans a sequence of observations and configures and calibrates the instrument faster and more reliably with each state change, while maintaining the classical nature of observing. Finally, expanding and optimizing the suite of instrumentation that is always available for rapid response to transient phenomena, coupled with fast, reliable DRPs allows WMKO to be first and best to target.

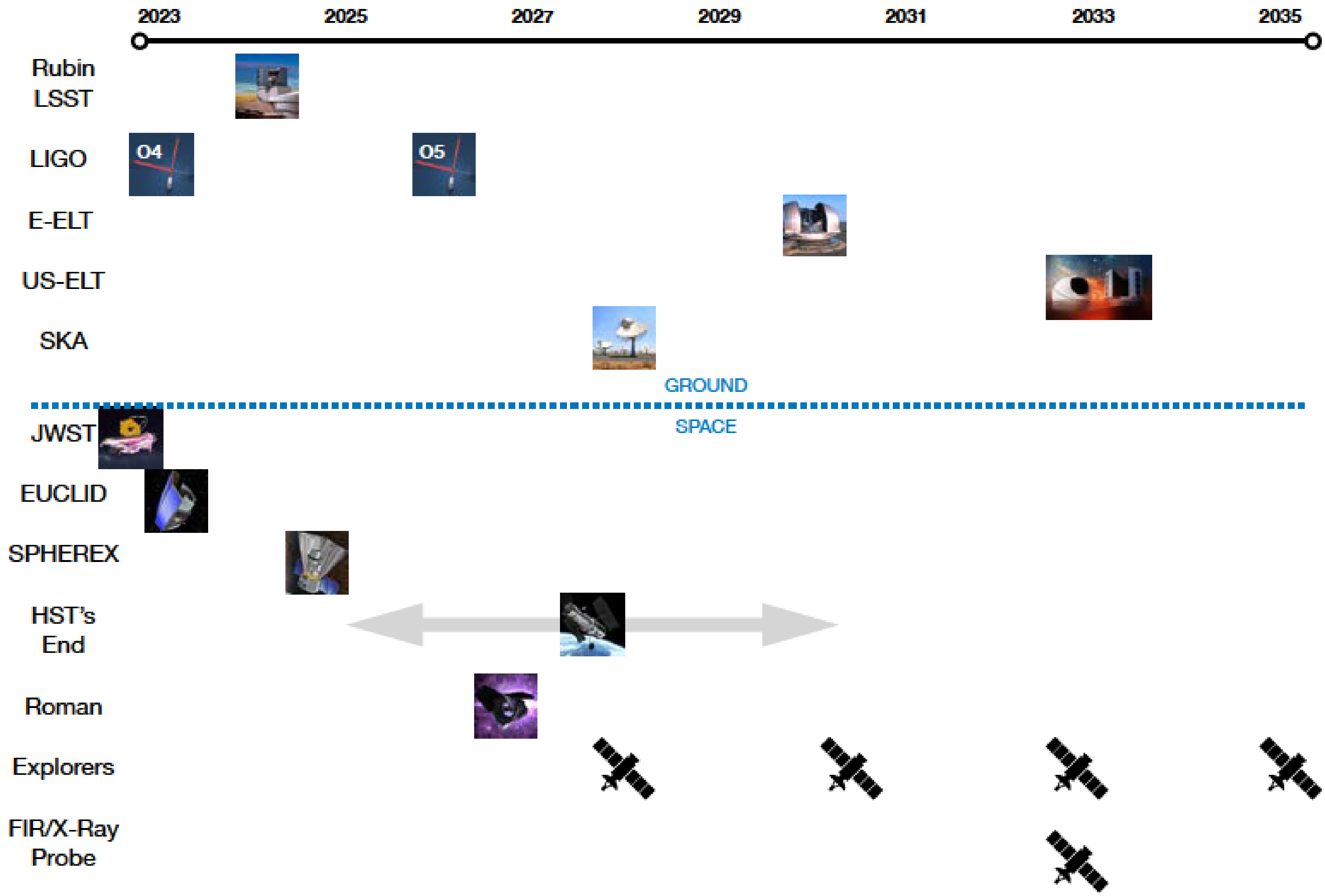


Figure 2: The Facilities landscape through 2035

Growing Scientific Leadership

In the 2030s, WMKO will continue to evolve as it enters the ELT era as a powerful partner and counterpart. This same period of time will see a new probe-class mission come online in space, and the architecture and capabilities of the next flagship space observatory after Roman defined and construction underway. This new environment represents a critical change: aperture superiority for WMKO will be no longer. To maintain and grow leadership, WMKO must evolve its core strengths and create new ones to create a facility which is faster, wider, deeper, and smarter on the sky than it is today:

Faster: WMKO can make significant strides in yielding science as fast as the transient universe demands. These include developing and deploying extremely efficient instrumentation coupled with swift, robust data processing and the ability to be always available during the night. Additionally, intelligent algorithms can assess the full facility (telescope, dome, instrument, AO, data processing, atmospheric conditions) to minimize losses and get faster and more robustly and fullyconfigured on target.

Wider: To best partner with Rubin, Roman, and poorly localized, faint transient events, WMKO will take one of its core capabilities, faint and multi-object spectroscopy, to the next level by increasing both the instantaneous field of view, and the number of targets accessible within that field. In parallel, WMKO will create a new strength: wide field, high throughput imaging. Both of these capabilities will maximize coverage of the bluest wavelengths with the uniqueness of the Maunakea site, providing a capability no current or planned facility on the ground can rival.

Deeper: While the ELTs will dominate studies of individual faint objects in the 2030s, they will do so typically at the expense of total wavelength coverage and field of view. By deploying powerful instrumentation that uses GLAO and the unique site characteristics of Maunakea, WMKO can be deeper in grasp for many science investigations than facilities of similar or larger size, especially in the first decade of their operation. Furthermore, WMKO will be a critical partner to the ELTs as it localizes and discriminates amongst faint transient sources for further study, a capability that cannot occur with today's 1-4m class facilities.

Smarter: As the science requires, WMKO will evolve not just the instrumentation, but the entire process of observation to yield the best science. Cadence observation can extend beyond exoplanet radial velocity surveys with KPF to other instruments and science challenges. Target of Opportunity observations will evolve to incorporate event brokering and other algorithms to deal with the onslaught of transients beginning with the start of Rubin and Roman observations and the continued evolution of multi-messenger observations. Data platforms at WMKO and in the cloud can yield not only scienceready data faster, but also analyze that data to inform rapid decision making, and in some cases, algorithmic target selection
and instrument reconfiguration.

Beyond individual new capabilities, WMKO can compete and lead by developing connected ecosystems of instrumentation. For example, deep imaging, intelligent targeting algorithms, and rapidly configurable multi-object spectroscopy can be combined to execute science programs in a single night which previously would have taken multiple observing cycles, if not years. Extending the ecosystem further, when the imaging capabilities are wide field, and the spectroscopic capabilities highly multiplexed, the targeting algorithm can select objects to serve the science needs of multiple independent investigators at the same time, providing a tremendous gain in efficiency for the Observatory. Similar ecosystem linkages can apply to exoplanet and transient/multi-messenger instrumentation. Likewise, WMKO data itself can be an ecosystem whereby well characterized and calibrated archival data from the Keck Observatory Archive (KOA) can serve as inputs into algorithmic targeting systems, or as parts of a discoverable whole across multiple archives from multiple observatories.

With the end of Hubble's mission likely within this decade, and with the next OIR space flagship of a size in the 6+ meter range nearly two decades away, the push towards the bluest wavelengths for near diffraction limited and diffraction limited capabilities via optical wavelength AO represents an immense opportunity for WMKO science and leadership. New instrumentation will need to match new AO capabilities, focused on imaging and integral field spectroscopy. Moving towards optical AO represents a substantial investment for WMKO, and will require a staged path of evolution in capabilities, with decision points along the way based on resources, the science needs of the community, technological innovations, and the external landscape. To shepherd the movement down this path, WMKO will continue to rely on and invest in the AO Future Studies Group as we advance this key strategic priority, beginning with the deployment of the ASMs, HAKA, and technologies stemming from the ORbiting Configurable Artificial Star (ORCAS) partnership between WMKO and NASA Goddard Spaceflight Center.

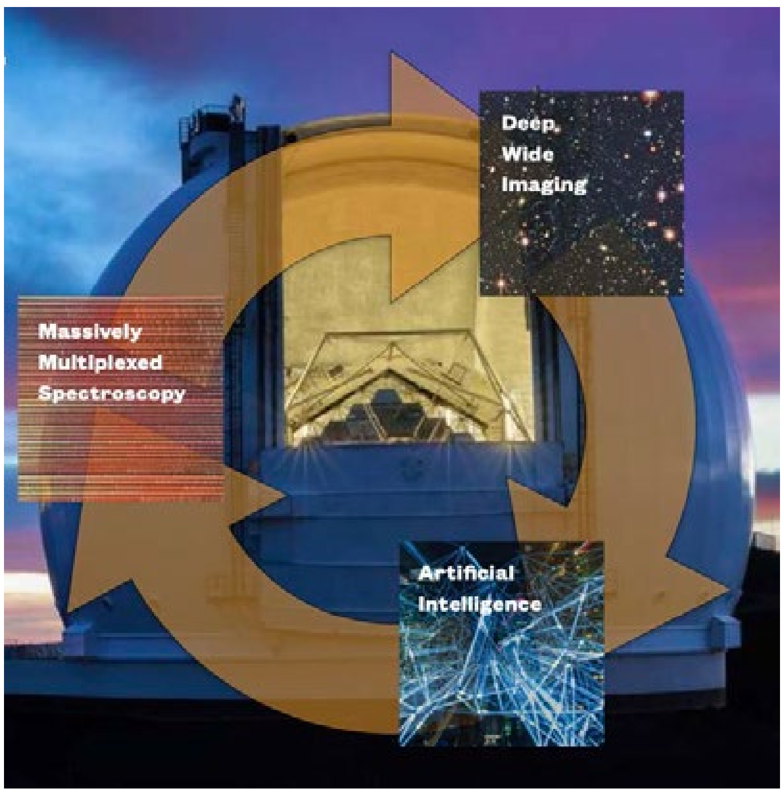


Figure 3: Example of an instrument ecosystem: imaging, spectroscopy, and algorithmic target selection combined

As WMKO develops and deploys new instrumentation and capabilities, it will continue to pursue an instrument development program guided by its community, and grounded in a balance between highly capable multi-purpose instrumentation and smaller, more focused instruments that meet more specific science needs. It is this balance that will continue to enable WMKO to powerfully engage the science that is known today, and the as of yet unknown science of tomorrow.

Harevesting innovation

How WMKO maintains continued scientific excellence throughout the next two decades depends critically on its community's ability to maintain, expand, and harvest innovation.

For AO, significant opportunities arise by developing and deploying a new bench. This new development bench will include multiple ports for both instrumentation and technology maturation experiments. By providing this new facility, nightly scheduled AO science operations become decoupled from development, increasing operational stability, and minimizing the time required to switch to and recover from development activities. As Nasmyth deck space is limited, deploying this new bench will require retirement of some existing capabilities, as discussed below.

A major strategic push in innovation will be expanding WMKOs partnership with NASA. This expansion can take multiple roles. First, WMKO can act as a key testbed facility for new technologies and science methodologies to advance and inform architectures for future NASA strategic missions. In particular, Astro2020's recommendation of a new flagship capable of surveying dozens of Earth-like candidates around Sun-like stars will require significant advances in large, segmented-aperture wavefront control and coronagraph development, and new detector technologies. Many of these advances can be proven at WMKO, simultaneously adding new science capabilities. Additionally, future flagship and probe-class architectures can be informed by dedicated precursor science programs at WMKO. Second, new opportunities like the partnership with the ORCASmission concept can open up significant new capabilities in the push towards optical wavelength adaptive optics, both by providing a new, configurable on the sky guide star capability and by advancing key components of the AO bench. Third, missions selected in the next decade to advance time-domain and multi-messenger astronomy will require new innovations on the ground for rapid, robust response to meet the prime mission goals. Fourth, the next generation of Solar System missions envisioned by the 2022 Planetary Decadal survey can drive innovations in observing modes like cadence, twilight, and daytime observing at WMKO to provide a constant eye on the Jovian, Saturnian, Ice Giant, and small body systems to both inform mission architectures and planning in the nearer term, and in-mission support once they fly. Finally, the increase in capabilities and breadth of NASA mission archives will motivate a commensurate increase for KOA to make the data maximally discoverable and useful in the heavily intertwined future ground/space ecosystem.

The volume and complexity of WMKO data will continue to increase, along with the interconnectedness between instruments and AO. These new complexities open the door for innovation in intelligent algorithms (Artificial Intelligence and Machine Learning) to analyze and optimize the processes of target selection, observing, data reduction, and verification of scientific viability of a data set to inform future observations. WMKO will assess then deploy those intelligent algorithms that meet our strategic needs of increasing efficiency and scientific yield. These algorithms will also play a key role in continuous monitoring of our instrumentation and facilities to optimize preventative maintenance and to highlight issues before they rise to the level where they require major servicing missions.

Palomar and Lick have been critical partners in developing technologies for WMKO through their strategic plans and the CARA partnership. As the ELT era approaches, WMKO will position itself in a similar fashion to support development of technologies in partnership with the ELTs, while simultaneously advancing our community's scientific interests. Many of the instruments in our future portfolio such as Liger and HISPEC already serve this purpose, retiring significant risks for the IRIS and MODHIS instruments at TMT, respectively. Additional ports and development facilities at WMKO will be made available to advance critical technologies.

Finally, and critically, new innovations in instrumentation and other capabilities will require significant, sustained monetary investment to match pace with facilities like ESO/VLT that plan significant resource allocations to instrumentation and technology in the coming decade. The portfolio envisioned for WMKO, both in cost and in timing relative to the astronomical ecosystem, cannot be achieved without growth in investment in our instrument and AO development programs. Many, if not most of the instruments in the coming years have notional budgets that exceed the ability for individual grants from federal or philanthropic partners to meet. The pressure is additionally acute given the annual uncertainty in the federal budgetary cycle and the volatility inherit in the stock market and other investments. As such, the stability of an instrument development program, both for the Observatory and for its community of developers is of equal importance to its funding top line. Based on history and lessons learned from other facilities and industries, WMKO adopts a value of 10-15% of the total cost of an instrument or AO capability needed to advance that project to a level where the cost, schedule, and contingency can be set with some confidence, usually coincident with the project's preliminary design review (PDR). With the envisioned portfolio of instruments and AO capabilities, we estimate a need of a stable \$3M/yr (\$2M for instrumentation, \$1M for AO) to advance projects from initial concept through to PDR, and to maintain the project teams across the uncertainty-laden periods of obtaining full-scale development funding across the spectrum of federal investment and philanthropy. These investments represent a significant increase in both the amount and funding stability WMKO has today.

(Background image: A googly-eyed KCWI, posing as Thomas the Train's lookalike and getting ready to return to the Keck II Telescope after having KCRM installed in it. Credit: C. Martin, Caltech

The Strategic Goals

With the thematic motivation for how WMKO moves into the 2030s established, a core set of strategic goals emerge. These goals are outlined in Table 3, and set the parameters for the portfolio of new and upgraded capabilities between now and 2035, along with their prioritization. We discuss the individual goals and how they flow down to recommendations. Descriptions of each instrument or new capability are given in the supplemental materials. For brevity, we describe a new initiative only once in the discussion that follows, even though those initiatives span multiple strategic goals.

The Scientific Strategic Goals

Strategic Goal	Description
1	Continue to support a broad OIR science portfolio with a diverse set of highly sensitive imaging, spectroscopy, and high spatial resolution capabilities
2	Enhance the WMKO community's competitive advantages in cadence, time domain, and large sample programs for precision spectroscopy, astrometry, and photometry
3	Sharpen our view of the universe with near diffraction-limited capabilities at visible wavelengths
4	Make maximal use of the unique capabilities of the Maunakea observing site including excellent seeing, UV sensitivity, and northern hemisphere access
5	Provide cutting edge science opportunities to the Keck community by hosting technology demonstrations for ELTs and space missions
6	Increase science yield with improved efficiency from instrument upgrades, state of the art seeing management, innovative operations improvements, excellent instrument calibration and characterization, and data reduction pipelines

Table 3: The main scientific strategic goals

Goal 1: Support a broad OIR science portfolio

Keck will remain one of the largest-aperture OIR telescopes until the onset of ELT operations, and will continue to be in high demand for many decades to come. As a result, WMKO will continue to provide state of the art instrumentation with a broad range of capabilities. In advance of and in parallel to the ELTs, WMKO will remain a scientific leader in the areas of planetary science, exoplanets, stellar astrophysics, galaxy evolution, and time-domain astrophysics, among many other fields. To maintain WMKO's core capabilities, new highly efficient instrumentation must replace the aging workhorse portfolio including:

* **LRIS-2 + GLAO** for blue-sensitive, single-object and multi-object spectroscopy
* **Liger** for near-infrared, AO-fed integral field spectroscopy and imaging.
* Investigate a **high-resolution spectrometer operating over (at least) the L- and M-bands** with long-slit capability for observations of extended objects.
* Develop a new capability with **FOBOS** for massively multiplexed, UV-sensitive spectroscopy over a wild field.
* Develop a world-leading wide-field imager with high UV sensitivity with **KWFI**
* Explore science cases and conceptual design for a new **highly-multiplexed near-IR spectrometer**
* Establish an **annual instrument development fund** of at least $2 million per year focused on bringing instruments to principal design review level, and enabling successful proposals for full funding.

Goal 2: Enhance the WMKO community's competitive advantages

As new facilities enter the landscape, WMKO's advantages will shift to those scientific endeavors that require more extensive telescope access. These would include large programs that require many repeat observations to sample time-domain phenomena (e.g. EPRV observations for exoplanets or astrometry for black hole orbits), fast response to rapid phenomena (e.g. follow up of high importance supernovae or gravitational wave events), or large samples of objects (e.g. spectroscopy of populations of stars or galaxies). While cadence work will occur on facilities like JWST or the ELTs, it will likely be very limited in the early years of operations. Fast response will always be difficult for JWST, and a challenge for ELTs in their early years. WMKO will continue to be suited for large samples over large areas or at higher spectral resolution than will be available in space or in first-generation ELT instrumentation. With these advantages in mind, the following capabilities rise to the fore:

* Support of **flexible observing modes** to enable rapid follow-up of targets of opportunity, cadence observing for multiple
* Develop an **"always ready" capability for optical and near-IR spectroscopic observations** of transit and time-variable sources. This can involve new instrumentation, augmentation of current instrumentation and software, or both.
* **A KPF fiber injection unit on Keck II** to provide better cadence opportunities and balance demand across the facility.

Goal 3: Sharpen our view of the universe

WMKO can remain competitive into the ELT era by delivering high spatial resolution at optical wavelengths using AO. Optical AO systems are easier and more cost-effective to build at smaller apertures, delaying their development on the ELT scale until later generations of instrumentation on those facilities. The ELTs will focus on near infrared AO capabilities in their first generation instrumentation. WMKO can be unique on the ground at the bluest wavelengths, providing ~15 milli-arcsecond resolution at optical wavelengths to complement the IR observations at similar spatial resolution to the ELTs. With the end of the Hubble Space Telescope mission on the horizon, the need for this capability becomes acute. Realizing these capabilities will require:

* Development of a **visible and IR AO capability** with high (40%) sky coverage and high (< 15 milli-arcseconds at 500nm) spatial resolution over 30 to 60 arc second diameter fields of view.
* Development of **high Strehl (>0.8) visible AO** at high resolution(< 15 milli-arcseconds at 500nm) over 1 arc second fields of view.
* Development of **AO-fed imaging and integral field spectroscopy** to take advantage of diffraction-limited resolution at visible wavelengths.
* Establish an annual adaptive optics development fund of at least $1 million per year focused on bringing instruments to principal design review level, and enabling successful proposals for full funding.

Goal 4: Make maximal use of the unique capabilities of the Maunakea site

WMKO operates its facilities on one of the best astronomical sites in the world. In particular, Maunakea provides an environment of exceptionally good seeing, located mostly at the ground layer, which can lead to excellent adaptive optics correction. Maunakea's high altitude, cold ambient temperature, and low precipitable water vapor provide unparalleled UV and IR atmospheric transmission and lower thermal background compared to any other developed site for large telescopes. As mentioned previously, instruments like FOBOS and KWFI are highly optimized to maximally leverage the superior conditions on Maunakea. Development of adaptive optics systems that best leverage the site conditions are also recommended (see in particular Goal #6), along with exploration of how the stable seeing for the hours following sunrise may allow for AO operations into daytime.

Goal 5: Host technologies for the ELTs and space missions

Looking forward to the ELT era, certain high-impact science cases are best performed with those facilities to leverage their significantly larger apertures. For example, in high-contrast imaging of exoplanets, the planet detectability scales as the diameter to the fourth power. High-contrast instrumentation for the ELTs will be expensive and challenging to develop. In this and other fields, WMKO will likely shift to become an on-sky test bed for state of the art technologies needed for next generation ELT instrumentation. As the demand for WMKO time will remain highly competitive for the next decade and beyond, technology demonstrations must be chosen strategically to deliver both novel instrumentation for future facilities and impactful science at WMKO in the present. A similar situation arises in space, where large, segmented aperture telescopes such as the Habitable Worlds Explorer will need to mature high-contrast capabilities to search for Earth-Sun exoplanetary system analogues, and WMKO can serve to advance these and other technologies in partnership with NASA and industry. Potential technologies include novel wavefront sensing and control systems, sensors based on innovative low-noise fast-read detectors, hybrid wavefront sensors and high contrast science focal planes, coronagraphs, injection into photonics devices, and many others.

Goal 6: Increase science yield through enhanced efficiency

WMKO will continue to deliver excellent science return for its investments in instrumentation and other capabilities to maintain scientific leadership. An extremely impactful way to increase scientific return is through instrument and facility upgrades to improve efficiency. These upgrades must be weighed against priorities for long term projects and the increased risk and maintenance cost of older hardware. In the coming decade, a key capability for WMKO to increase efficiency is to improve seeing for a suite of instruments through ground-layer adaptive optics upgrades and adaptive secondary mirrors on both telescopes. Technological improvements and risk reductions in ASMs make this a timely investment that can improve sensitivity by factors of two to three. Specific initiatives to increase efficiency include:

* Development of an **ASM to implement GLAO on Keck I** to provide enhanced seeing for LRIS-2, and an upgraded MOSFIRE, followed by an **ASM for Keck II** for high-contrast and other AO initiatives, along with enhanced seeing capabilities for FOBOS.
* Enabling efficient pathways from observations to science by supporting data reduction pipelines for all facility-class instruments and efficient data discovery and accessibility through KOA, along with observer tools for observation planning and execution that are user-friendly, flexible, and maximize the utility of archival data through the **Data Services Initiative.**
* Enable efficient communications and information flow between WMKO and the user community.
* Deploy systems for real-time monitoring of sky conditions such as seeing, sky brightness, atmospheric extinction, water vapor, and satellite trails.
* Develop a process (led by WMKO and the SSC) to review the instrument portfolio and make recommendations for instrument decommissioning.

Prioritization of the Recommendations

The top priorities for new and upgraded capabilities, as determined by the SSC, are grouped into three categories set by the scale of the investments. The Large scale initiatives are those with a notional cost of $15 million or greater and are presented in Table 4. The Medium scale initiatives are those with notional costs in the $5 to $15 million dollar range, and are presented in Table 5. The Small scale initiatives are those with a notional cost at $5 million dollars or less, and are presented in Table 6. In each category, we map how the recommendations enable the set of strategic goals from Table 3. The cost and schedule estimates for these initiatives are at different levels of fidelity, with some projects at the conceptual phase, and others, such as LIGER, able to begin immediate construction.

Large Scale Projects

Priority	Name	Strategic Goal Mapping
A	Keck 1 ASM for GLAO & Visible MCAO	1,2,3,4,5,6
	Liger	1,2,3
B	FOBOS	1,2,4
	GLAO on K1 for LRIS & MOSFIRE	1,2,4
	KWFI	1,2,4
	Visible AO on K1	1,3,4,5
C	GLAO on K2	1,3,4
	K2 ASM	1,4,5,6
	Visible AO IFU for K1	1,3,4

Table 4: Recommendations for large-scale projects. Projects are unranked within each priority and are listed alphabetically.

The Medium and Large scale priorities are likely only to be realized through a combination of philanthropic and federal funding. These projects will also benefit the most from the Instrument and Adaptive optics development funding lines, which are essential to bringing these projects to the design fidelity needed before making a full construction funding proposal. In the case of the Medium and Large scale projects, bringing a project to preliminary design level will require up to millions of dollars and multiple years of work.

In Figure 4 we present notional schedules for development of the proposed portfolio, assuming that the recommendations in Tables 4, 5, and 6 are realized. Smaller initiatives are not shown on the figure for simplicity. The visible wavelength AO-fed instrumentation are grouped in the adaptive optics timeline.

Medium Scale Projects

Priority	Name	Strategic Goal Mapping
A	HISPEC	1,2,3,4,5
	Instrumentation Development Fund	1,2,3,4,6
	LRIS2	1,2,4
B	Visible AO imager	1,3,4

Table 5: Recommendations for medium-scale projects. Projects are unranked within each priority and are listed alphabetically.

Small Scale Projects

Priority	Name	Strategic Goal Mapping
A	AO Development Fund	1,3,4,5,6
	DEIMOS+	1,2,6
	HAKA	1,3,4,5
	KPF K2 FIU	1,2,4,5
B	High Contrast Technology Development	1,5
	MOSFIRE + GLAO	1,2,4,6

Table 6: Recommendations for small-scale projects. Projects are unranked within each priority and are listed alphabetically

These timelines should be viewed in the context of two key elements: the larger portfolio of facilities coming online prior to 2035, and the specific notional first light dates for the European ELT and US-ELT as identified by Astro2020, as shown previously in Figure 2. In total, this portfolio represents over $300 million in new investments if realized in full between now and 2035.

In addition to the portfolio of recommendations above, a number of initiatives have been identified for further exploration and development up to a conceptual design level.

These include:

* A "NIRSPEC 2" long-slit spectrograph, optimized for L and M band spectroscopy, with a focus on solar system observations
* A highly-multiplexed spectrograph with FOBOS-like capabilities but in the infrared
* A "Time Domain Astronomy Machine" spectrograph providing moderate resolution, always-on capability across the OIR
* The next generation of the Data Services Initiative, including deep archive interoperability, AI and ML assisted target selection, and science platforms.

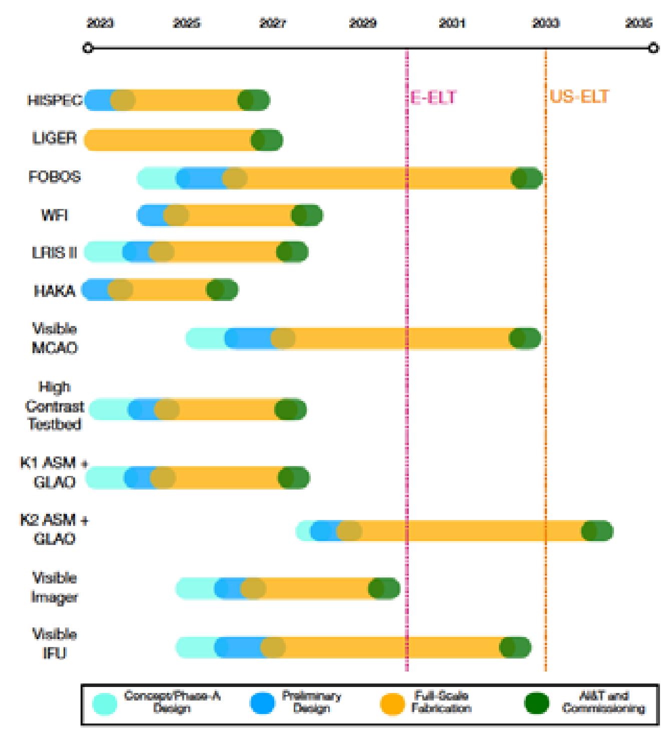


Figure 4: Instrumentation and AO timeline

Appendix A: Hawaiʻi Community Relations

The Context of WMKO in Hawaiʻi

The context in which we operate is complex, multi-layered and constantly evolving. We provide a high-level summary in this appendix to aid in understanding; however, we encourage the reader to dive deeper on their own and to also use the endnote references to gain a deeper, more nuanced understanding. Furthermore, this document is a snapshot in time – WMKO must continually evaluate our environment and make course adjustments as the context shifts over time.

The Cultural and Historical Significance of Maunakea

We must begin with an acknowledgement of our immense and humble privilege to pursue our mission atop the tallest mountain in the world as measured from its base on the sea floor to its summit, and the highest peak in the Pacific Ocean, Maunakea. Maunakea is also known as Mauna Kea, Mauna a Wākea and Mauna a Kea and is a significant landscape spiritually, culturally, historically, and ecologically.

> *Mauna a Wākea is "ka makahiapo kapu na Wakea," the sacred firstborn of the union of Papahānaumoku, She who is the foundation birthing islands, and Wākea, He who is the wide expanse of the heavens (Poepoe, 1906)...The mauna is the piko or summit where the earth meets the sky. The mauna is also the elder sibling of both the kalo plant and the Kānaka, the people, all fathered by Wākea.* [3]
> *..., and water on Mauna a Wākea is most sacred because it is the highest source of water that flows to the aquifer to feed the island (Nā Maka o ka ʻĀina, n.d.). This water from Kāneikawaiola, Kāne of the life-giving waters, comes from the hau, the snow, and the lilinoe, the mists that gently meander over the mauna."* [2]

Maunakea: Premier Site for Astronomy

In addition to the spiritual, cultural, historical, and ecological importance of Maunakea, there is no better place in the Northern Hemisphere or perhaps the world for ground-based astronomy due to Maunakea's unique physical characteristics - high, dry, clear, and dark - as well as the incredible collection of telescopes sited there, including WMKO's twin telescopes. Unprecedented discoveries, Nobel prizes in 2011 and 2020, and unmatched scientific impact are notable outcomes of astronomy on Maunakea. We will only be able to continue making these amazing discoveries on Maunakea as long as there is broad, sustained acceptance and support from our community for our presence.

Modern History of Astronomy Development on Maunakea

The modern era of astronomy on Maunakea began in the 1960s on former Hawaiian Kingdom Crown Lands, which are part of the one-million-plus acres seized from the native Hawaiian people and currently held in trust by the state. Astronomy development over the next half century ran in parallel with an awakening of knowledge about the complex, troubled history of the denationalization of Hawaiʻi and the struggle to restore Hawaiian language, culture, and education.

Astronomy on Maunakea has more than fulfilled its scientific promise, revolutionizing humankind's understanding of the universe. At the same time, some in our island community felt the development of astronomy on Maunakea ignored their views about the mauna's (mountain's) spiritual, cultural, and ecological significance. Development on Maunakea fit a pattern of broader dispossession of Kanaka Maoli (indigenous native Hawaiians) from their ancestral lands and ways of life.

This was punctuated by a critical 1998 legislative audit that found the University of Hawaiʻi (UH) Institute for Astronomy and the Department of Land and Natural Resources (DLNR), during their 30-year management of the Maunakea Science Reserve, had "failed to develop and implement adequate controls to balance the environmental concerns with astronomy development."[4] In 2020, an independent review conducted by Kuiʻwalu Consulting for DLNR found that UH "has made progress" and "is effectively[3] managing the activities and uses on Mauna Kea to better protect the natural and cultural resources" but that consultation with the native Hawaiian community about cultural and resource issues was lacking.[5]

In the broader social framework, the history and pattern of unresolved injustices to native Hawaiians have manifested into stark disparities in health, education, housing, economic opportunity, and the struggle to re-establish and maintain a cultural identity experienced by many who we live side-by-side within our community today. From the perspective of those community members who have experienced these injustices and disparities, astronomy development on Maunakea fits the pattern of outsiders utilizing and often degrading land and natural resources with the benefits primarily going to the outsiders or a privileged few, ignoring the impacts and perspectives of the local community. Because astronomy fits this pattern, there is a built in deficit of trust with some sectors of the community.

The planned construction of the Thirty-Meter Telescope has been a lightning rod that divided Hawaiʻi into those who support astronomy and astronomy development, those who stand for protection of Maunakea and believe “enough is enough” regarding astronomy development, and a relatively quiet middle who can see both “sides” and are looking for win-win.

Stewardship of Maunakea

In 2022, a new law was enacted6 to shift the governance and management of Maunakea from the University of Hawaiʻi’s (UH) responsibility to a new authority, the Mauna Kea Stewardship and Oversight Authority (MKSOA) emphasizing a “mutual stewardship paradigm in which ecology, the environment, natural resources, cultural practices, education, and science are in balance and synergy.” In the mutual stewarship paradigm, astronomy is important, and in fact the law declares “astronomy is a policy of the state,” but astronomy does not supersede other perpectives and interests. For the first time, lineal descendants and cultural practitioners are explicitly represented in decision-making roles, alongside a
representative of the observatories, among others, in the stewardship of Maunakea.

The establishment of the MKSOA is a massive shift that will require open minds, hearts, and wills, as well as leadership, engagement, and commitment. We are at a game-changing turning point for Hawaiʻi astronomy and WMKO will engage in sincere efforts to make it successful.

Assuring Astronomy’s Future on Maunakea

The MKSOA will decide whether to authorize WMKO’s continued operation on Maunakea beyond our current lease which expires in 2033. Our lease renewal, as well as other MKO leases, are part of a larger conversation in Hawaiʻi about land use, with leases ending and potentially being returned into Hawaiʻi hands e.g. military leases in Mākua Valley and Pohakuloa Training Area.

The Authority will be established no later than 2023, there will be five years to transition responsibility from UH to the MKSOA, and in 2028 the MKSOA will have full responsibility and authority. WMKO will have from 2028-2033 to seek and be granted a long-term lease beyond 2033. It is expected that part of the agreement for a new lease will be a set of commitments the observatories make to the well-being of the community (coarsely, a “community benefits package”), lease rent (a portion of which may be expected to fulfill the public land trust obligation, and will help pay for stewardship), contributions to shared infrastructure capital costs, and telescope observing time to UH to be used in part for providing telescope access for Hawaiʻi researchers and students.

For WMKO to pursue its scientific discovery mission, it must secure a new lease that extends land authorization beyond 2033 with terms that are reasonable and sustainable for WMKO, and fair in the eyes of the community. The definition of these terms provides a significant opportunity to work more transparently and collaboratively with the community in a spirit of reciprocity.

Clashing Knowledge Systems

The community divide over astronomy development has been characterized as “science vs. culture” – an unfortunate false narrative that needlessly foments conflict. This construct
highlights a disconnect in our community.[7]

One of the ways this divide has manifested among some members of the local/native Hawaiian community is a reluctance to show, share, or explore their curiosity for and/or interest in astronomy.

Astronomers do not intentionally seek to be anti-Hawaiian culture - they want to practice contemporary astronomy without harming anyone. Kiaʻi Mauna (protectors of Maunakea) are not anti-science – they rightly point out that Kanaka Maoli are, by tradition, keen and incisive observers of nature - they want to exercise their kuleana (responsibility) as guardians of a preeminently important spiritual, cultural, and ecological space.

What possibilities exist for shifting the oppositional dynamic of "science vs. culture" to a dynamic of mutual respect in which contemporary astronomy and traditional indigenous knowledge informs, complements and enriches the other? The naming of celestial bodies in ʻōlelo Hawaiʻi (Hawaiian language)8 and the side-by-side examination of the Kumulipo (Hawaiian creation chant) and the Big Bang[9] points to the potential for this synergistic shift.

<u>Socio-Economics in Hawaiʻi</u>

On a more practical note, it is important to recognize the realities of life in Hawaiʻi and particularly on rural Hawaiʻi Island where WMKO operates. If we are to establish strong, reciprocal relationships within our own community, our eyes must be wide open to the socio-economic realities of our community.

Data shows the Big Island of Hawaiʻi has the highest levels of poverty, the highest percentage (45%) of Asset Limited, Income Constrained, Employed (ALICE) households, and the highest unemployment rate in the state.10 With the high cost of living and housing overpowering wages, it's not uncommon for Hawaiʻi residents to work two jobs to make ends meet, and more local residents are moving out of Hawaiʻi to seek better opportunities – separating themselves from their birthlands.

Lived-experience data reveal that many community members experience resilience due to positive social connections and natural resources, e.g., deep connections to community, strong support system of family and friends, access to beaches, etc.11. However, economic, health, and educational challenges are often brought up in community conversations.

The observatories have created considerable educational and workforce opportunities and Hawaiʻi astronomy adds over $200M annually to Hawaiʻi's economy.12 Yet many in the community, especially those in economically-challenged circumstances, do not directly see or feel this positive impact. There is an opportunity to broaden our reach and impact in the community.

<u>Shifts in Astronomy Nationally and Internationally</u>

As we extend our gaze beyond Hawaiʻi's shores, we see synergy between the Hawaiʻi context and the desires of the U.S. astronomical community for how astronomy should be conducted in indigenous and local communities, as expressed in Astro2020[13]:

> "...(astronomy organizations) work to build partnerships with Indigenous and local communities that are more functional and sustained through a Community Astronomy approach, and by increasing the modes of engagement and funding for: (i) meaningful, mutually beneficial partnerships with Indigenous and local communities, (ii) culturally supported pathways for the inclusion of Indigenous members within the profession, and (iii) true sustainability, preservation, and restoration of sites."

Maunakea Astronomy as a whole, and WMKO in particular, can play a leading role not only in Hawaiʻi, but nationally and internationally in shifting to a more functional, equitable, and ethical way of conducting science, helping to assure a more sustainable future for astronomy and the communities in which astronomy is conducted.

[3] "Mapping Abundance on Mauna a Wākea as a Practice of Ea" by Candace Fujikane: https://kamehamehapublishing.org/wp-content/uploads/sites/38/2020/09/Hulili_Vol11_2.pdf

[4] Audit of the Management of Mauna Kea and the Mauna Kea Science Reserve: https://dlnr.hawaii.gov/mk/files/2016/10/B-17-e-1998-Legislative-Auditof-UH-Mauna-Kea.pdf

[5] Independent Evaluation of the Implementation of the Mauna Kea Comprehensive Management Plan, prepared for DLNR by Kuʻiwalu: https://evaluatethecmp.com/wp-content/uploads/2020/12/REPORT-CMP-Independent-Evaluation-Dec-2020.pdf

[6] Act 255 Relating to Mauna Kea: https://www.capitol.hawaii.gov/session2022/Bills/GM1358_.PDF

[7] "Is Native Science Science?" The Native American Academy, https://static1.squarespace.com/static/5bf5edb125bf020cc1502790/t/5c2ea79288251bade4acb42b/1546561427185/2014_Is+Native+Science+Science.pdf

[8] A Hua He Inoa, ʻImiloa Astronomy Center, https://imiloahawaii.org/a-hua-he-inoa

[9] The Physics of Pō and the Pō of Physics at ʻImiloa Astronomy Center, https://imiloahawaii.org/news/science-culture

[10] ALICE Report: Hawaiʻi County Profile: https://www.auw.org/sites/default/files/pictures/18UW_ALICE_Report_COUNTY_HI_Final_10.25.18.pdf

[11] Vibrant Hawaiʻi Lived Experience Data: "We Don't Feel Poor," https://www.hawaiidata.org/news/2020/10/13/we-dont-feel-poor-vibrant-hawaii-livedexperience-data-shaping-community-understanding-decisions

[12] UHERO Economic Impact of Astronomy in Hawaiʻi: 2019 Update, https://uhero.hawaii.edu/economic-impact-of-astronomy-in-hawaii-2019-update

Appendix B: Science

Description of Instrumentation, AO, and Initiatives

Instrumentation

DEIMOS+: Upgrade to increase the throughput of the DEIMOS instrument via new CCDs with better QE in both blue/visual and red, along with a new flexure compensation system implemented using a hexapod-mounted detector cryostat.

FOBOS: Fiber Optic Broadband Optical Spectrograph. Multi-object fiber fed spectrograph flexible acquisition system that will position 1800 individual fibers or 45 fiber-bundle IFUs over a 20-arcminute diameter FOV, full optical band (0.31-1 µm), moderate spectral resolution (R = 3500). The current scope involves 3 spectrographs, each serving 600 fibers; each spectrograph is divided into 3 wavelength channels.

HIghly-Multiplexed NIR spectrograph: Placeholder for possible massively multiplexed (architecture TBD) near-IR (0.9-2.4 micron) spectroscopy. In the near term, there is a need for a feasibility/trade study of possible options and development of basic science requirements.

HISPEC: High-resolution near-Infrared SPectrograph optimized for forefront Exoplanet atmospheric Characterization. Single object near-IR (0.9-2.4 microns simultaneously) AO Fiber fed high resolution (R>100,000) spectrograph optimized for precision radial velocity (< 30 cm/s) and high-contrast high-resolution spectroscopy. Instrument Development Fund: A proposed fund, incremented by ~$2M/yr, intended for use in advancing the design of facility instrument concepts to the PDR level, thereby allowing the early phases of instrument development to proceed on a much shorter timescale. The source of these funds is TBD, but would likely involve a new partner or increased share for an existing partner in exchange for new funds.

KPF: Keck Planet Finder. Fiber-fed, single object, high-resolution (R = 90,000) optical spectrometer covering 445-870 nm and is specifically designed to measure precise radial velocities (RVs) with a precision of 50 cm/s or better.

KWFI: Keck Wide Field Imager. Prime focus, 1 degree field of view imager covering 300-1000 nm, highly optimized for UV and blue. Deployable secondary mirror (DM2) as part of the design to enable multiple instrument operations in a night and to allow permanent mounting of the instrument with no need for top-end changes.

Liger: Second Generation IR integral field spectrograph, intended to replace OSIRIS. Configurable spectral resolutions (R=4000-10000) and a variety of IFU plate scales/sampling: 0.4-90 square arcseconds FOV using lenset arrays for fine scales and slicers for larger plate scales, wavelength coverage from the optical through the near infrared (0.84-2.4 µm). Simultaneous imaging with a FoV of 20”.

LRIS-2: Second generation Low Resolution Imaging Spectrometer, with improved throughput, stability, and image quality. Maintains LRIS broad range of core capabilities (imaging, long slit spectroscopy, multi-object spectroscopy, FoV 10’ x 5’ on-axis, , 2 wavelength-optimized channels. 310-1050 nm, R~1000-5000) with technological advances that optimize its use with the GLAO system enabled by the Keck 1 ASM.

MOSFIRE + GLAO: Once the K1 ASM+GLAO system is realized, MOSFIRE (mounted at the Keck 1 Cass focus when LRIS-2 is not) can be optimized to take advantage of significant improvements in image quality over the full 6.1’ x 6.1’ FoV for imaging or multi-object spectroscopy in the 0.95-2.40 micron range, allowing significant reductions in slit widths, providing higher spectral resolution and, by virtue of the reduced background, improved sensitivity. The upgrade may involve replacement of the current H2RG detector with a H4RG with smaller pixels (0.1” spatial sampling rather than 0.18”), providing spectral resolving power up to R~10,000.

NIRSPEC 2 (or high-resolution mid-IR spectrograph): Placeholder for Long-slit (>15”) , high-resolution (R>30,000) infrared spectrograph with focus on mid-IR (3-5 micron) capabilities. Long slit to enable observations of solar system targets. Intended as a replacement for NIRSPEC (TBD).

SCALES : Santa Cruz Array of Lenslets for Exoplanet Spectroscopy. Integral field spectrograph and imager, wavelengths 2−5 µm, configurable 0.13-4.5 square arcsecond FOV and resolutions (R=50--7000). Imaging 13 arcsecond FOV.

TDA Machine: Placeholder for a Target of Opportunity dedicated instrument or combination of instruments that would be available on any observing night for simultaneous UV/

optical/NIR spectroscopy of single targets over the range 310-1000 nm or 310-2400 nm, with resolving power R~2000-4000 (all TBD).

Visible AO Imager Imager (possibly multi-channel) paired with an adaptive optics system optimized for shorter wavelengths. (500nm-1 µm). Field of view from a few to a few tens of arcsec (TBD). The proposed VIPER concept is a candidate for this capability.

Visible AO Integral Field Spectrograph Placeholder spectrograph with contiguous field of view of TBD arcseconds, behind Visible AO, optimized for 500-1000 nm, R~1000-10000 (TBD).

AO Capabilities

AO Development Fund: A proposed fund, incremented with ~$1M/yr, to fund design, development, and upgrades of facility AO systems. The source of funds is not yet identified, but possibilities are a) trade of observing nights for additional funding from current or new partners b) similar arrangement with federal funding agencies c) foundations or individual donors.

GLAO (Ground-Layer Adaptive Optics): Use of multiple wavefront sensing systems over a wide (~10') FoV, to correct low-lying turbulence, leading to significantly enhanced image quality over large fields, and thus "enhanced seeing" for all OIR instruments. An ASM will provide the wavefront correction.

HAKA (High-Order All Sky Keck Adaptive optics): High order deformable mirror system (~3000 actuator DM) and associated upgrades for Keck II adaptive optics enabled instrumentation (e.g, NIRC2, NIRSPEC-AO, and, eventually, SCALES and HISPEC)

KAPA (Keck All-sky Precision Adaptive-optics): (in progress) Upgrades the KI LGSAO system with a new laser divided into three laser guide stars for more complete atmospheric correction, upgraded hardware for real-time wavefront corrections, and the camera that measures the atmospheric turbulence. Improves performance for OSIRIS in the near term, and possibly Liger and VisAO in the future.

Keck 1 ASM: Adaptive Secondary Mirror, a facility upgrade that would become part of a facility GLAO system, and that will work as an integral component of future facility diffraction-limited AO systems such as Visible MCAO. Envisioned as a replacement for current fixed secondary, enabling throughput and sensitivity improvements for all current and future instruments at Cass or Nasmyth locations.

Keck 2 ASM: The requirements for a Keck 2 ASM may include being deployable, in order to allow for switching between a prime focus instrument (i.e., KWFI) and instruments requiring the f/15 secondary. As on K1, a K2 ASM would be a replacement for a fixed secondary, and would facilitate GLAO and possibly future diffractionlimited AO systems, with emphasis on "extreme AO" at IR wavelengths.

Visible MCAO: Visible wavelength multi-conjugate adaptive optics combining multiple high-performance deformable mirrors (high actuator density and rapidity) and multiple high-power laser beacons on the sky. The Keck 1 ASM may be a major component of the system.

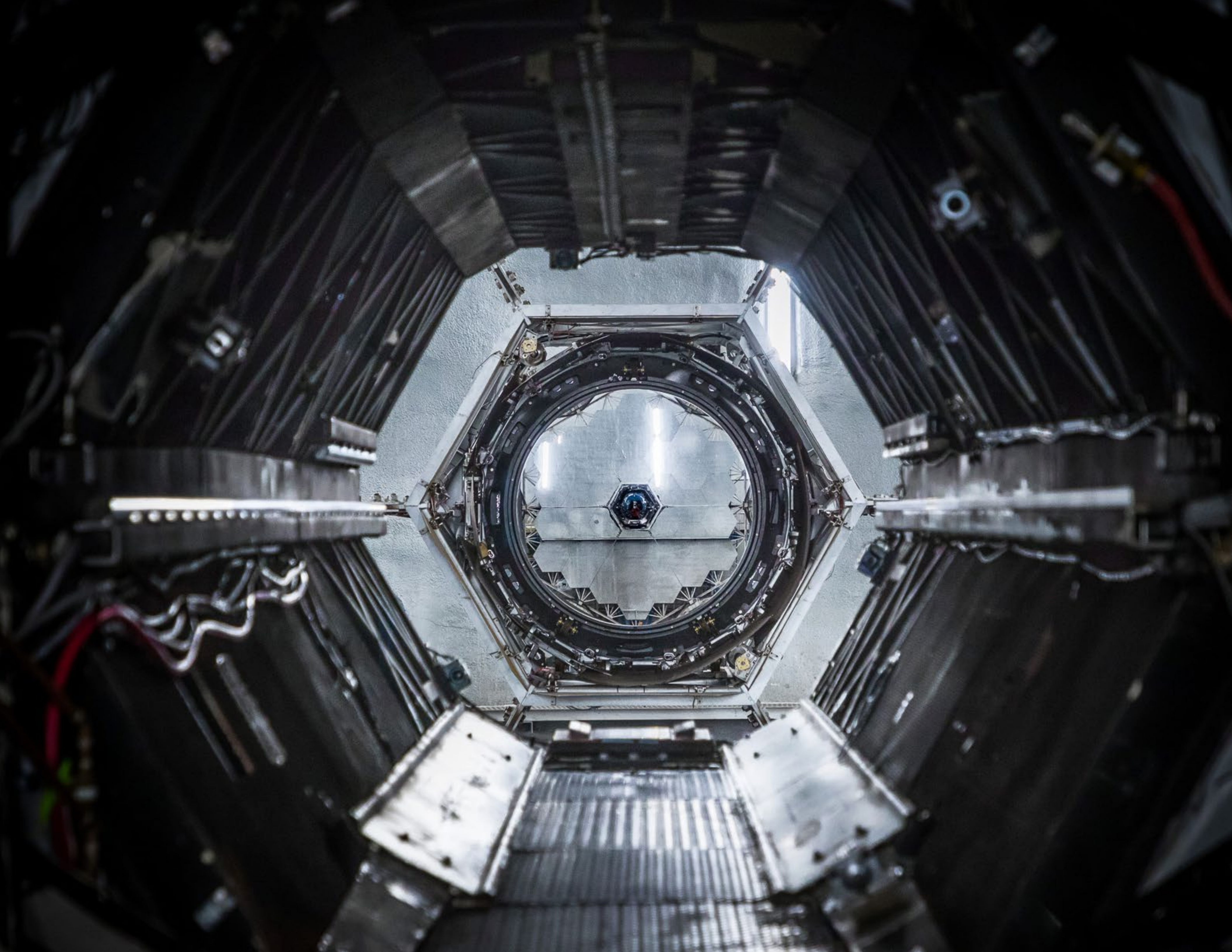
Other Capabilities and Initiatives

The Data Services Initiative (DSI): Refinement of the end-to-end processing of data at Keck, inclusive of observation planning and execution, data reduction pipelines, and archiving.

DSI 2.0 (AI & ML): Extension of DSI to include opportunities enabled by AI and ML (artificial intelligence and machine learning) techniques to enhance telescope scheduling, instrument operations, target selection, and data analysis, potentially withcomponents in the cloud.

ORCAS: A collaboration with NASA-Goddard to launch an ORbiting Configurable Artificial Star to be used as the guide star for science observations with Keck AO. ORCAS is intended to support AO correction at visible wavelengths when combined with appropriate Keck AO upgrades (e.g. HAKA).

Real-time monitoring of sky conditions: Concept proposed in a strategic planning white paper to implement systems for continuous monitoring of sky brightness, atmospheric extinction, seeing, precipitable water vapor, and satellite trails in the sky region that each telescope is pointed toward. Full implementation would likely require a small telescope co-mounted with each Keck telescope.



W. M. Keck Observatory
65-1120 Mamalahoa Hwy, Kamuela, HI 96743
keckobservatory.org