**NASA's Infrared Telescope Facility (IRTF)**
**Independent Review Panel Evaluation**

*All reports and reviews are proprietary and should be handled by the reviewer in a confidential manner.*

*Comments on this page may be transmitted to the IRTF staff.*

## I. PANEL EXECUTIVE SUMMARY

**Overall Score (mean): Excellent/Very Good**

Operating on the summit of Maunakea, the NASA Infrared Telescope Facility (IRTF) represents a unique asset in NASA's portfolio to provide both mission support capabilities and Near-Earth Object (NEO) characterization. The uniqueness of IRTF as a facility stems from the combination of 1) its location at a high-altitude, low humidity, stable atmosphere, and geographically positioned (both in the northern hemisphere and at far western latitude) site; 2) its suite of instrumentation including capabilities in the mid-infrared that are not available on any northern hemisphere telescope of similar or larger aperture; and 3) its operations capabilities including the ability to observe during daytime hours, providing extended monitoring capabilities for Solar System objects near the Sun, such as Venus, on the sky. IRTF remains a cost-effective and high-impact facility, and a very important asset in the NASA portfolio. We address individual aspects of the review below in the summary, and provide details in the panel evaluation.

*Support of NASA's Objectives*: IRTF is directly responsive to NASA's Strategic Objective 1.2: "Understand the Sun, solar system, and universe" by enabling observations that have led to key discoveries and advances in our understanding in both planetary science and astrophysics. Specifically, infrared observations made from the IRTF of primitive bodies, comets, planetary atmospheres, stars and brown dwarfs, protoplanetary disks and young stellar objects, exoplanets, the interstellar medium, and galactic and extragalactic transients have made significant contributions to our understanding of the solar system and the universe. Time domain observations with IRTF cover the range from milliseconds (occultations) to decades, enhanced by almost year-round observations of planets through daytime observing.

*Scientific Productivity:* The IRTF has continued to be a scientifically productive facility in both planetary science and astrophysics. Over the past decade (2012-2021) the number of refereed papers produced per year that make use of IRTF data has been approximately 100, including papers on planetary science, non-Solar System targets, and data libraries. This productivity typically exceeds other facilities of comparable size. Specifically, the IRTF publication rate and total impact for solar system papers alone from 2016-2020 is substantially higher than that of other telescopes of its class and is higher than all other ground-based telescopes, including those of much larger aperture.

*Effectiveness as a Near Earth Object (NEO) physical characterization asset:* The IRTF offers several capabilities that, when taken together, make it uniquely suited for the physical characterization of NEOs and potentially hazardous asteroids for the purposes of planetary defense. The combination of efficient visible and near infrared spectroscopy, visible photometry, and mid-infrared photometry enables both the determination of bulk densities and masses and the albedos and sizes of NEOs, which is completely unique. This information is critical for the physical characterization of these objects, needed for an accurate threat assessment, and is in direct support of Congressional mandates related to this characterization.

*Data archiving and management:* The IRTF has received only relatively modest funding for developing data analysis tools and data archiving. The data from the two main facility instruments, SpeX and iSHELL, are being archived and curated at the IPAC Infrared Science Archive (IRSA). This ensures long-term access to those data by other investigators. This is also moving towards consistency with new requirements from NASA concerning open access to data. The IRTF plans to make reduced legacy data available at IRSA after the dedicated open data pipelines are developed and released. This would significantly improve the scientific value of the IRTF. At this time, however, not all IRTF data are available at this archive, reduction of IRTF data is not automated, and data is not available in the archives in a science-ready form, although plans to address these shortcomings are addressed to varying degrees.

*Technical Capabilities:* IRTF has a dedicated instrument suite primed for planetary observations, through a mixture of facility and visitor instrumentation. IRTF offers an unmatched suite of imaging and spectroscopic capabilities for solar system studies, particularly beyond 2.5 µm. IRTF is the only ground-based facility that truly prioritizes this longer wavelength spectral region. Additionally, IRTF is the only major ground-based facility that conducts regular daytime observing, and the IRTF's relatively unique rapid tracking rate allows tracking on very close NEOs. IRTF has identified a new integral field spectrograph covering 0.4-4.2µm (SPECTRE) to add to its portfolio, but the overall cost funding plan for this instrument is uncertain, particularly in a challenging environment for instrumentation funding for ground-based facilities from the National Science Foundation.

*Enhanced Capabilities:* IRTF's heavy use of remote observing, having multiple instruments available and changeable each night, the inclusion of daytime observing, and allocation of fractional nights is a relatively unique set of technical strengths that have enabled high scientific output. With effective remote-enabled flexible telescope scheduling and short observing blocks, IRTF is well-suited to monitoring programs and fast follow-up, essential to dynamic planetary observations. The Target of Opportunity (ToO) and Director's Disctretionary Time (DDT) programs are a very powerful capability to meet transient and time-domain needs, but the policies regarding the use of one over the other need further exploration, clarity, and community input.

*Cost Reasonableness:* For its mission support and scientific returns, IRTF's operating costs are very reasonable and are about as low as possible for a facility of its type on Maunakea. It is remarkable that operating costs have not increased significantly above inflation in the past 25 years of operations despite the facility's increased productivity and the expense of maintaining its aging systems. The current level of effort is 25.5 FTEs, only about 2 – 3 FTE higher than 25 years ago, despite large increases in the number of observing programs and adding capabilities for remote observing, data reduction pipelines, and data backup and archiving. The IRTF cost per scientific publication is also competitive with typical NASA Planetary Science and Astrophysics Research and Analysis (R&A) programs.

*Community Input:* The IRTF has played a proactive role in seeking community feedback. Examples include having a booth at the American Astronomical Society and Division of Planetary Sciences meetings and organizing the "Future Directions Workshop" in 2018. The Director and IRTF staff are accessible and open to recommendations, in particular via the NASA IRTF-Keck Users Group (NIKUG), which is a prime medium for the community to provide operational feedback and guidelines to the observatory. IRTF staff meets with the NIKUG twice a year. However, stronger community input into strategic planning and a better articulation of how commmunity input has influenced decision making is needed.

*Facilities Operations:* IRTF uses a well-established set of methods to assess and mitigate technical risks to the facility. The structure of risk "ownership" and management is well organized, with the appointed risk owners being the Observatory Manager (the day crew lead), the Senior Engineer (Hilo) and the IRTF Director (Honolulu). Ultimately, the IRTF Director owns the top ten risks and continuously monitors them. IRTF is conscious of its carbon footprint, and is incorporating energy efficiency into facilities planning.

*Strategic Planning:* IRTF is likely to maintain its supremacy as a planetary facility. The IRTF's strategy to provide new instruments, offer large amounts of remote observing, provide rapid scheduling opportunities, maintain mid-IR capability, and continue daytime observing will keep it competitive as an astrophysics facility and as a NASA asset. Implementing planned telescope image quality improvements will increase the impact of most data from existing and will potentially improve the scientific value of data from future instrumentation like SPECTRE. The planned automation of data reduction is needed to improve the scientific output of the IRTF and to keep IRTF a leading asset for planetary science. At this time, IRTF does not have a clearly focused strategic planning document with input from both the community and NASA that covers the period from 2023-2032 to align with the recent planetary and astrophysics decadal surveys and other priorities.

*Contribution to the Maunakea Observatory's efforts:* The IRTF is engaged in a number of outreach activities despite having no budget for outreach or requirement to do so. Notably, the types of outreach activities conducted by the IRTF staff are varied, including visiting high schools, working with teachers, hosting students, and giving community presentations. The IRTF is active in training Univeristy of Hawaii undergraduate and graduate students and the NSF Research Experience for Undergraduates program. The addition of the Assistant Telescope Operator positions is an effective way of offering employment to local residents who may not have the technical training to be hired as telescope operators. This initiative is unique to the IRTF, unlike the other outreach activities in which they participate. There is, however, a lack of demonstrated emphasis on non-STEM outreach activities and how IRTF intends to move forward along with the other Maunakea Observatories with the newly established Maunakea Stweardship and Oversight Authority (MKSOA).

## II. PANEL EVALUATION

### (A) Relevance and responsiveness to NASA strategic goals and objectives (4 criteria)

**1. Degree to which the IRTF operations support and advance NASA's scientific objectives**
Assess the responsiveness of the IRTF to NASA goals as described in the latest Planetary and Astrophysics Decadal Surveys (including findings related to ground-based assets and planetary defense), and Strategic Objective 1.2 of the NASA 2022 Strategic Plan, "Understand the Sun, solar system, and universe."

**Strengths**
Major Strength: The IRTF is responsive to NASA's Strategic Objective 1.2 ("Understand the Sun, solar system, and universe.") by enabling observations that have led to key discoveries and advances in our understanding in both planetary science and astrophysics. Specifically, infrared observations made from the IRTF of primitive bodies, comets, planetary atmospheres, stars and brown dwarfs, protoplanetary disks and young stellar objects, exoplanets, the interstellar medium, and galactic and extragalactic transients have made significant contributions to our understanding of the solar system and the universe (and the Sun, to the extent that the study of space weather and its interaction with planetary atmospheres can teach us about the workings of the Sun). The IRTF's efforts and capabilities in characterizing NEOs are directly relevant to the 2023 – 2032 Planetary Decadal Survey.

Major Strength: IRTF recognizes the strategic importance of fast-turnaround and time-critical observations, and has operational capability to execute these observations. Examples include rapid follow-up observations and discoveries of threatening objects that may impact the Earth imminently or have a close flyby. For example, the timeline in Table 1 of the IRTF report demonstrates how the first detection by another telescope (Catalina Sky Survey) was followed by report of an observation by IRTF to the NASA Planetary Defense Coordination Office with very fast turnaround. Time domain observations with IRTF cover the range from milliseconds (occultations) to decades, enhanced by almost year-round observations of planets through daytime observing.

Major Strength: The IRTF has significantly advanced NASA's scientific objectives by regularly providing critical observations needed to maximize the scientific return of NASA's strategic and large PI planetary science missions. IRTF has supported practically all previous, current and planned future small body missions and many planetary missions to help with mission design and execution, maximizing their science return. This includes support to LCROSS, DART, Lucy and Psyche, among many others. For the Galileo mission, support was only possible with IRTF thanks to its unique daylight infrared observing capability, with IRTF images taken hours before the probe entry when Jupiter was only 9 degrees from the Sun. For Juno, IRTF imaging has been used to support and complement the optical and 4-5 micron imaging from spacecraft instruments, while IRTF imaging also provides valuable context for the Juno Microwave Radiometer (MWR) measurements made during the spacecraft's perijove passes. For New Horizons, the region to be studied during the 2015 flyby of Pluto was selected thanks to spatially resolved IRTF spectroscopy that identified $N_2$ and CO ice features on that hemisphere. IRTF's strengths also apply to comets, for which IRTF uniquely permits daytime investigations. Additionally, iSHELL offers superior image guider performance, critical for tracking a comet during daytime observations. IRTF has been essential in cometary campaigns to support NASA missions such as the Comet Shoemaker-Levy 9 Jupiter impact campaign in 1994, the Deep Impact mission observations of Comet 9P/Tempel 1 in 2005, Comet C/2012 S1 (ISON) in 2013, and Comet 46P/Wirtanen in 2018.

Major Strength: For Venus, IRTF is the only infrared facility able to provide observations with a wide range of solar elongation angles (i.e. daytime), which are essential for providing temporal cadence and extended seasonal coverage. IRTF's instrument suite, including a high spectral resolution capability, enables studies of kinematics and trace species in Venus' atmosphere. This capability is critical considering the current NASA mission portfolio with upcoming Venus missions such as DAVINCI.

Minor Strength: The distribution of IRTF observing time supports NASA's strategic objectives in understanding the Sun, solar system, and universe (Objective 1.2 of the 2022 NASA Strategic Plan), with half of all time going to planetary science and half going to astrophysics observations. The IRTF is also supporting the non-scientific objectives in NASA's and SMD's strategic plans by attracting and developing a diverse workforce, transforming mission support (e.g., a leader in remote observing), and training the next generation of explorers (i.e., students).

Minor Strength: The IRTF can be operated in creative observing modalities (e.g., daytime operations, or long-term monitoring campaigns) unlike larger ground-based telescopes or space-based assets. Examples of the importance of this capability include advances in our understanding of Venus' atmosphere, for which daytime observations are critical since the planet is only visible for an hour or two after sunset or before sunrise, and the temporal evolution of methane clouds of Titan, both of which were enabled through IRTF observations.

**Weaknesses**
Major Weaknesses: none

Minor Weaknesses: none

**2. IRTF scientific productivity in planetary science and astrophysics (i.e., performance metrics: papers, citations, etc.)**
Also, compare productivity from IRTF vs. comparable facilities if provided (e.g., Hubble, Keck, SOFIA, and ground-based observatories).

**Strengths**
Major Strength: The IRTF has continued to be a scientifically productive facility in both planetary science and astrophysics. As shown in Figure 54 of the IRTF report, over the past decade (2012-2021) the number of refereed papers produced per year that make use of IRTF data has been approximately 100 (with a peak in 2015), including papers on planetary science, non-Solar System targets, and data libraries.

Major Strength: The publication rate of the IRTF over the past 5 years, as shown in Figure 55 of the IRTF report, is comparable to or better than those of other 3-4m class ground-based telescopes with PI-led observing programs (e.g. SOAR, WIYN, ARC, SALT).

Major Strength: The IRTF has the highest number of refereed publications and the highest total impact in solar system science of any Earth-based observatory over the 2016 – 2022 period and is exceeded by only the Hubble Space Telescope.

**Weaknesses**
Major Weaknesses: None

Minor Weakness: The use of the IRTF for student PhD dissertations has noticeably declined over the past 5 years. Even if the data for the last couple of years are incomplete (as stated in the caption of Figure 57 of the IRTF report), there is still a decline. It is unclear what is causing this decline.

**3. Effectiveness of the IRTF as a primary Near-Earth Object (NEO) physical characterization asset for Planetary Defense**
Also, assess whether other similar assets may duplicate this role.

**Strengths**

Major Strength: There are no other assets that can duplicate the role of the IRTF as a tool for NEO physical characterization in terms of wavelength coverage, spectroscopic capabilities, telescope availability, and operational modes. This is demonstrated in Section 3.6 of the IRTF report, which describes the limitations of other facilities (spectral coverage, lack of simultaneity across a large wavelength range, higher telluric absorption due to lower site elevations, limitations on non-sidereal tracking, lack of northern hemisphere coverage).

Major Strength: The 0.7 – 2.5 µm prism mode in SpeX is useful and has been used widely for characterizing the compositions of NEOs by measuring the objects' solid-state absorption features. These data are also relatively unique and take good advantage of the IRTF's dry, high altitude Maunakea site. Compositions determined from these spectra are used to assess the impact hazards of the objects. The IRTF/SpeX MIT-Hawaii NEO Spectroscopic Survey is the largest publicly available NEO spectral database with over 1000 objects.

Major Strength: The IRTF's fast tracking ability (60"/s), new wide-field `Opihi camera, and flexible scheduling allows finding, observing and following NEOs efficiently even when they are close to Earth. The MIRSI/MOC and MORIS instruments form a unique capability for characterizing NEOs because together they can measure the objects' albedos and sizes. This yields object densities, which are also important for hazard assessment.

Major Strength: The IRTF is located on Maunakea in the middle of the Pacific Ocean, a unique location filling a gap in the time zone coverage needed for planetary defense. The IRTF has also participated in three planetary defense exercise campaigns that included assessing the potential damage from observed objects.

Major Strength: When assessing the risk posed by NEOs, knowledge of their size and density (mass), composition and material properties, shape and spin state are essential. For instance, NASA's NEO Surveyor will not provide any reflectance colors or spectroscopy needed for understanding the composition and material properties of the targets it observes, while IRTF/SpeX provides the needed spectral coverage, resolution to map their composition and to the long baselines to better understand their spin state.

Minor Strength: With the proposed new instrument, SPECTRE, spectral features would be recorded across the entire 0.4- 4.2 µm range in a single shot, removing uncertainties resulting from assembling spectra taken with different instruments at different epochs.

Minor Strength: Scheduled observing can be interrupted on very short timescales at the discretion of the IRTF Director following NEO alerts, and through programmatic requests by the PDCO.

**Weaknesses**
Major Weaknesses: None

Minor Weaknesses: None

**4. Data archiving and management, including proprietary data period, development of data reduction tools, etc.**
Also, assess how these strategies align with NASA and community expectations for open science.

**Strengths**
Major Strength: The data from the two main facility instruments, SpeX and iSHELL, are being archived and curated at the IPAC Infrared Science Archive (IRSA). This ensures long-term access to those data by other investigators. This is also moving towards consistency with current requirements from NASA concerning open access to data. The MIRSI data are to be included at IRSA soon, once the instrument is in its final recommissioned configuration.

Minor strength: The IRTF provides the Spextool data reduction pipeline for reducing SpeX and iSHELL data. The IRTF plans to make reduced legacy data available at IRSA after the license-free python version of the reduction software, pySpextool, is developed and released. This would significantly improve the scientific value of the IRTF.

**Weaknesses**
Major Weaknesses: None

Minor Weakness: Reduction of IRTF data is not yet automated. Archival data are not yet available in a science-ready form.

Minor Weakness: The timeline for full data archive establishing work effort, data storage, and future delivery is not yet fully developed.

## (B) Technical Capability and Cost Reasonableness (3 criteria)

### 1. IRTF's technical capabilities and systems status, including the current instrument suite, to achieve (2023–2032) Planetary and Astrophysics Decadal science

**Strengths**

Major Strength: The IRTF management team has identified creative solutions for modernizing its instrument suite in the face of a lack of a healthy and dedicated instrumentation budget. By converting guest instruments such as MIRSI and possibly also TEXES to facility instruments, the observatory has been able to keep pace with modern technologies without the substantial development costs. It also has enabled the facility to continue to offer the scientific community access to the longer IR wavelengths using state-of-the-art instruments.

Major Strength: The instrument suite is focused on providing high-quality IR spectroscopy and is relatively unique and well-suited for the telescope, site, and scientific utilization of the IRTF. The large simultaneous wavelength coverage of SpeX is useful for characterizing stars (including exoplanet hosts), brown dwarfs (giant planet analogs), and brighter astrophysical transients. iSHELL is useful for characterizing protoplanetary circumstellar disks, interstellar medium material, and exoplanets (all Astro2020 Decadal Survey topics). The current capabilities and instrument suite will also be useful for the Planetary + Astrobiology Decadal: MORIS/MOC + MIRSI for NEOs and planetary defense, SpeX for organic molecules on outer planets and ISM, iSHELL for characterizing Uranus (flagship mission), comets, exoplanets, and Mars's atmosphere. The IRTF has a long history of providing high-speed time-series imaging of lunar and planetary occultations for astrophysics (e.g., stellar multiplicity) and planetary science. Its MORIS CCD camera is optimized for high-speed imaging during occultations, and the IRTF's location on Maunakea in the middle of the Pacific Ocean allows access to shadow paths that cannot be observed by other Earth-based observatories.

Major Strength: The IRTF is one of very few (perhaps only) telescopes that also observes during the day in the IR. This provides an additional number of available days to observe, and increases the usage of the telescope - it can contribute to more programs or projects. IRTF has averaged about 200 hours of daytime observing per semester; this is ~10% of the nighttime scheduled hours per semester.

Major Strength: At longer wavelengths, MIRSI/MOC's main scientific use is for simultaneous visible and mid-infrared photometry of NEOs to measure albedos and estimate diameters for IRTF's planetary defense role. MIRSI is currently the only regularly available MIR camera in the northern hemisphere. IRTF is now the only telescope on Maunakea (and possibly the northern hemisphere) offering regular mid-infrared observing. As with iSHELL, TEXES provides high-resolution infrared spectroscopic capabilities not available with JWST nor any other space observatory.

**Weaknesses**

Major Weakness: The development of SPECTRE has been slow and the funding path for achieving completion of the instrument is unclear. The report does not contain a timeline of the development effort, including the design requirements that should flow down from the science users and their needs. It also does not contain a strategy for how the remaining budget required for the completion of the instrument, estimated at $4M and awaiting a higher fidelity cost estimate at preliminary design review, would be obtained other than seeking funds from NASA and NSF, or what efforts have been made thus far. NSF's MRI system historically does not fund instrumentation at levels beyond $2M, placing a SPECTRE proposal at a disadvantage, and the future of the NSF MSIP instrumentation funding schema is currently highly uncertain. The budget does not contain contingency, which for an instrument of this complexity could be at the $1M level, beyond the ability for operations funds to cover. This uncertainty in funding-constrained development is not unusual for other ground-based instruments at this stage.

Minor Weakness: The SpeX and iSHELL facility instruments have pixel scales and minimum slit widths that are too fine for the telescope's delivered image quality. This results in some loss of signal-to-noise and does not take full advantage of the full area of the instruments' detectors. This could be ameliorated by improving the delivered median image quality to the ~0.5" FWHM range. Further developments and improvements of the tip-tilt corrections, focusing, and an adaptive secondary mirror (ASM) would greatly benefit the capabilities of the observatory. This is a bigger issue for observations of faint point sources than for bright, extended sources like planetary disks.

## 2. Enhanced capabilities, including scheduling responsiveness, targets of opportunity programs, and time domain observations

**Strengths**

Major Strength: IRTF's heavy use of remote observing, having multiple instruments available and changeable each night, daytime observing, and allocation of fractional nights is a relatively unique technical strength that has enabled versatile usage and high scientific output.

Major Strength: The ToO and DDT programs are a very powerful capability to meet transient and time-domain needs. To limit the potential impact of these interrupts on classically scheduled observing programs, the time blocked out for ToO observations each semester is limited to 24 hours for the top-ranked Solar System and 24 hours for top-ranked non-Solar System programs, with each ToO interrupt being no longer than three hours. The telescope typically receives ten DDT requests per year, spanning a wide range of subjects across both Solar System studies and Astrophysics. A high percentage of the observations obtained under DDT have contributed to rapid publications.

Minor Strength: IRTF allows for fast (~15 minute) instrument switching allowing for multiple science programs or more robust capabilities for an individual science program.

**Weaknesses**

Minor Weakness: The DDT route seems to be more heavily used for time-domain and transient observation requests, leading to an apparent disincentive for the user community to propose via the Time Allocation Committee (TAC) for ToO's, since the duration for each interrupt is so limited. The IRTF report acknowledges that a change in scheduling and observing strategy may be required to accommodate more time domain and ToO programs, and the panel agrees, finding that a more detailed user community survey on the issue is warranted.

**3. Cost reasonableness, including general budget details and status, yearly operational costs, level of effort, travel costs, Maunakea support services, projected costs for future operation, etc.**

The Panel will not perform a detailed cost analysis of the IRTF report. However, the panels may assess in broad terms the science return of the facility relative to its overall costs.

**Strengths**

Major Strength: The science return of the facility is high relative to its overall costs. As noted in the IRTF report, return does not account for the added programmatic value that the IRTF brings to NASA through its mission support and planetary defense efforts. IRTF is extremely well managed, providing state-of-the-art astronomical capabilities at a fraction of the cost of other facilities.

Major Strength: The projected staff travel costs are under $2K / FTE per year in the 2020 – 2024 budget. This is about equal to only 1 domestic trip per employee, which is remarkably small given that regular interisland travel in Hawaii is required for the successful operation of the facility. This indicates that the IRTF is minimizing travel costs.

Minor Strength: The total budget for IRTF operations covering the current five-year contract (2019-2024) is $30.3M. The full staff (25.5 FTE) is diverse, specialized and highly well trained.

**Weaknesses**
Major Weaknesses: None

Minor Weaknesses: None

## (C) Management and Operations (4 criteria)

### 1. Community input, responsiveness to feedback, and strategies to stay competitive

**Strengths**
Major Strength: The Director and IRTF staff are accessible to the user community and open to recommendations, in particular via the NASA IRTF-Keck Users Group (NIKUG), which is a prime medium for the community to provide feedback and guidelines to the observatory.

Minor Strength: The IRTF has played a proactive role in seeking community feedback. Examples include having a booth at the AAS and DPS meetings and organizing the "Future Directions Workshop" in 2018.

**Weaknesses**
Major Weaknesses: None

Minor Weaknesses: It is not clear from the IRTF report how regular community input and observer feedback is considered, weighted, and implemented.

Minor Weakness: Additional community and financial support is needed to ensure capabilities such as SPECTRE moving forward. Community concerns on adaptive optics capabilities have yet to be adequately evaluated.

### 2. IRTF facility operations, including engineering risk matrix, carbon footprint, and plans to be more energy-efficient while exploring the nature of the universe

**Strengths**

Major Strength: IRTF has a defined set of methods to assess and mitigate technical risks to the IRTF facility. These are the same methods as those employed by the UK Astronomical Technology Centre (ATC) for Gemini and European Southern Observatory (ESO) instrumentation projects. Once identified and ranked, the objective of risk response planning is to implement cost effective risk reduction actions that reduce the probability and effect of the risk.

Major Strength: Previous studies show that the three main sources of greenhouse gases are air travel, gasoline vehicle use, and electricity. Assisting to reduce its carbon footprint, the IRTF has instituted primarily remote observing. The IRTF's carbon footprint is significantly lower than that of CFHT and Keck, two other Maunakea observatories.

Minor Strength: The Chlorine Monoxide (ClO) monitor that was originally housed at Caltech Submillimeter Observatory (CSO) has been moved to the IRTF bunker since CSO is being decommissioned. ClO is a proxy to estimate the destruction of ozone in the stratosphere. It is important that the monitor be sited at 4,200-m on Maunakea. IRTF offers a small amount of support, but NOAA will monitor it.

**Weaknesses**

Major Weaknesses: None.

Minor Weakness: Potential energy savings achieved by installing more efficient HVAC systems were not sufficiently quantified.

**3. IRTF's strategic plan for the future (2023–2032), e.g., planned new capabilities, future needs, etc.**

**Strengths**

Major Strength: The IRTF's future plans revolve around enhancing its role in planetary defense, adding capabilities for primitive body studies, and follow-up observations of transient objects discovered in all-sky surveys. These are all important strategic areas for NASA planetary science and astrophysics. The IRTF held a strategic workshop in 2018. IRTF staff collected significant community input that led to changes in the proposal process (DDT), endorsement of SPECTRE for planetary defense, and implementing MIRSI as a facility instrument.

Major Strength: The IRTF report discusses current and planned new capabilities of the IRTF, and ways in which they are working to be creative to schedule time efficiently, make improvements to the telescope (active guiding) and instrumentation, and cut their carbon footprint.

Major Strength: IRTF's most important future project is the development of the new 0.4-4.2 µm R=150 integral field spectrograph, SPECTRE, which will be a unique NEO instrument. In the 5-30 µm wavelength range, MIRSI's planned upgrades would provide an improvement in 10 µm sensitivity of 1-2 magnitudes. This region is key for solar system observations, yet it has been largely abandoned by other telescopes on Maunakea.

Minor Strength: The addition of an optical CCD channel enables MIRSI to directly measure asteroid albedos and sizes using their blackbody curves and improve the albedo-composition correlation for the NEO population. Estimates suggest that with the upgrades MIRSI will be able to measure the sizes of about 250 NEOs per year.

**Weaknesses**

Major Weakness: The IRTF does not have a clearly focused strategic planning document that covers the period from 2023-2032. Section 15 of the IRTF report addresses this topic and focused on the following areas: possible changes in schedule modes to accommodate an expected increase in time domain projects, improving the telescope image quality, continuing to develop new instrumentation (particularly SPECTRE), upgrading data analysis tools, and working to make its staff more diverse. However, given that the IRTF Future Directions Workshop was held in 2018, a documented outcome of that workshop with a prioritized list of planned improvements that was driven by the users, or a matrix that covers near-term vs. long-term, low cost/risk vs. high cost/risk was not presented. Long-term plans for new instruments or upgrades are not adequately defined, nor are their alignment with decadal objectives and user community input. Specific performance targets (i.e., image quality metrics) or schedules were not provided for the planned improvements.

**4. IRTF's contribution to the Maunakea Observatory's effort to reach out to, include, and respect the local community (e.g., professional development plan and community engagement, etc.)**

**Strengths**

Major Strength: The IRTF is active in training UH undergraduate and graduate students, participating in a UH-based NSF REU program, and allowing observers to have students participate in observations. Additionally, the new assistant telescope operator position appears to be an important gateway for local community members to gain work experience in Maunakea observatories without a technical degree.

Minor Strength: IRTF participates in the Maunakea Scholars program to give Hawaii public high school students observing opportunities on Maunakea telescopes. This participation includes IRTF staff working with students to plan, interpret, and document results. IRTF staff have also participated in local STEM outreach activities not funded by the IRTF (e.g. the Marine Advanced Technology Education Center).

Minor Strength: All Maunakea Observatories participate in the 'Kama'ãina Observatory Experience' (KOE). The KOE is a free monthly community event that provides residents with an opportunity to visit the summit (although KOE was suspended during COVID-19).

**Weaknesses**

Minor Weakness: Details on how the IRTF participates in bringing astronomy to the local community beyond traditional career training (e.g., hands-on small telescope viewing) were not provided. There was also no information on non-STEM local outreach. These activities could be beneficial for the future of the IRTF and other Maunakea observatories, but they are not in the statement of work and the IRTF is not funded to pursue them.