How we completed major maintenance and new installations at Las Cumbres Observatory during the COVID-19 Pandemic

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ABSTRACT

Las Cumbres Observatory (LCOGT) operates a network of more than 25 telescopes that are globally distributed over seven sites. Despite the COVID-19 pandemic restricting travel to most of those sites since March 2020, LCOGT achieved several significant operational milestones: (i) We deployed a new multi-channel imager (MuSCAT3) at Haleakala Observatory. (ii) We installed two new 1-meter telescopes at Teide Observatory. (iii) We performed essential maintenance with local staff at the sites. The latter included opening two of the NRES spectrograph's thermal and pressure enclosures - a task traditionally executed by trained LCOGT personnel only.

We discuss the evolution of LCOGT's paradigm for maintenance. Sustaining observatory operations increasingly relied on local observatory staff, of various skill levels and capabilities, to execute the highest priority work with remote support. We made this possible with extensive planning, being sensitive to local conditions, and bringing in expertise to support and guide in real-time via extended Zoom sessions.

Keywords: Observatory operations, commissioning, quality control

1. LCOGT'S PRE-COVID-19 SUPPORT MODEL: THE STATUS QUO

LCOGT operates a network of more than 25 telescopes[1] at seven sites across the globe. The sites are: Haleakalā in Hawaii, USA; McDonald Observatory, Texas, USA; Teide Observatory at Tenerife, Spain; Wise Observatory in Israel; Cerro Tololo Inter-American Observatory (CTIO) in Chile; The Sutherland site of the South African Astronomical Observatory (SAAO), South Africa; and the Siding Springs Observatory (SSO), Australia. The telescopes of each aperture class (two 2-meters, twelve 1-meter, and ten 40-centimeters) are all equipped with identically designed instrumentation. The Wise 1-meter telescope is equipped with an NRES spectrograph only. In addition, LCOGT hosts the ASAS-SN network of five telescopes[*] at our sites. The longitudinal distribution, especially of the 1-meter telescopes, enables – weather permitting – continuous monitoring capability of celestial objects in both hemispheres, making LCOGT an ideal platform for time-domain astronomy.

All telescopes are equipped with optical imaging cameras, and in the case of the 2-meter and 1-meter telescopes the cameras have cryostat / cooling infrastructure; the two 2-meter telescopes also host a low-resolution spectrograph (Floyds), and at four sites we operate nodes of the *Network of Robotic Echelle Spectrographs* (NRES)[2] that provide precision radial velocity measurement capability for the study of exoplanets. The sites and their telescopes are summarized in Figure 1.

All telescopes and instruments are scheduled via software and operate autonomously without local staff present. Supervisory monitoring and control of the telescope operation is provided by a department of four, globally distributed LCOGT staff members who can intervene remotely. In case of issues that are not software-resolvable, such as a telescope being stuck in a hardware stop, a help request is sent to the support staff

[*]https://www.astronomy.ohio-state.edu/asassn/index.shtml

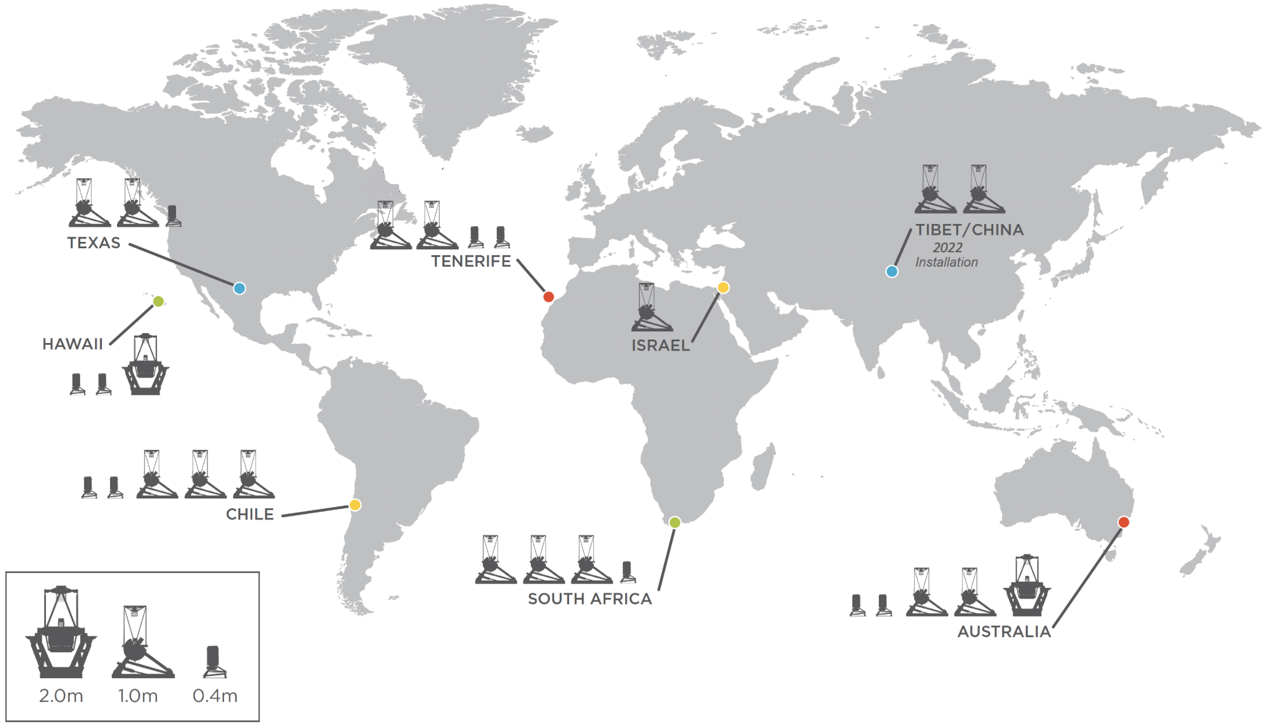

Figure 1. Map of the current LCOGT telescope network. The sites in Chile, South Africa, Texas, and Israel also host a NRES fiber-fed high resolution spectrograph.

of the hosting observatory site. Major repairs, comprehensive preventative maintenance, and new capability installations were handled by an engineering team traveling to a site and completing a list of tasks - about every 18 months for a general overhaul, and with additional trips scheduled as needed. We already had a history of asking observatory staff to execute routine tasks or minor repairs on-site, but for more invasive interventions we always sent an engineering team to our telescopes.

In 2018, with most of the initial telescope and instrument deployments completed, LCOGT focused on operational stability and ongoing refurbishments of the facility as it starts to age. At the beginning of the Pandemic, the telescope network was in an overall robust state.

2. MARCH 2020: WORLDWIDE COVID-19 SHUTDOWNS

The signs of the larger impact of the COVID-19 pandemic became apparent in the U.S.A. in January / February 2020, and already in February did we begin to scale back from international visits and suspended planned site trip activities. On March 16th 2020, LCOGT's headquarter in Santa Barbara, CA shut down all in-office operations, as did most of the world at that time in response to the emerging COVID-19 pandemic. LCOGT staff at first worked entirely from home. Most observatory sites went through some sort of shutdown or rescinded to a very limited operational model aimed at preserving the facilities, but not scientific productivity. CTIO shutdown on March 18th and SAAO on March 26th 2020. We ceased operations at McDonald Observatory on March 25th and at Teide Observatory March 29th 2020. The Wise Observatory in Israel continued to operate as they have only a small staff contingent living in close proximity to the observatory. At our sites on Haleakalā and at SSO we employ only one locally residing staff member, and those sites could continue to operate without a shutdown.

Our first action during the initial shutdown phase was to swiftly create mothballing instructions for the closing sites in Texas, Chile, and South Africa. After warming up instruments and shutting down the IT infrastructure via remote control, we asked site staff to turn off power switches, close gas supply valves, and power down UPS units - all tasks that need a real hand on site.

While most of the observatory world was shutting down, since we do not rely on local staff or a visiting observer to execute or oversee the operations of the telescope, we could maintain a skeleton telescope network operational based on the telescopes in Haleakalā, Siding Springs, and Wise Observatory. The ongoing, albeit limited, coverage by the LCOGT network enabled the continuation of time-sensitive observations.

3. APRIL THROUGH SEPTEMBER 2020: RESUMING OPERATIONS

After a reorientation period, safety protocols got established and depending on their local situation and governmental mandates, observatories started to open again. McDonald Observatory gave the go-ahead to reopen April 7$^{\text{th}}$, followed by Teide Observatory on April 13$^{\text{th}}$ 2020. SAAO Sutherland was able to open on May 4$^{\text{th}}$, and CTIO in Chile was last to allow operations on September 21$^{\text{st}}$ 2020.

As with the shutdown procedure, we prepared instructions for the on-site teams to restore the services they shut down before, and we could then remotely start operations of the telescopes and instruments. As expected after a complete shutdown, restarting the telescopes was not without issues. E.g., not all cryostat-based instruments were able to cool down and required vacuum pumping by site personnel before we could resume operations. For the NRES spectrograph units, where the cryostat is embedded into a thermal and pressure-regulated enclosure, access to the vacuum port of the cryostat by site personnel was not possible at that time (more about that in Section 6) When the NRES unit in Chile was unable to cool, we had to give up operating that instrument with unknown prospects for recovery. Thanks to redundancy in our network, the loss of one out of the four NRES units was acceptable.

In a steady-state operation, when issues occur, an expert at LCOGT would contact observatory support staff directly with a help request, and it would not be unusual to have several parallel ongoing conversations between multiple LCOGT and local observatory staff in a self-organized manner. During the restart of our facilities that relied entirely on the local observatory staff, and given the multitude of help requests to them, we temporarily changed our communication model to have one LCOGT staff member act as a single point of contact to the remote site to keep the conversations comprehensible and to convey clear priorities.

Back at the LCOGT headquarter in Santa Barbara, during the first few months of the Pandemic shutdown, access to the offices and labs was extremely limited - only one person was allowed access to the building on a given day to check on the safety of the building and to do most essential jobs, such as shipping and receiving. While scientists, software developers, and administrators could largely continue their work routine from home (there is another story to be told about IT support during the pandemic), work on engineering projects that required access to real hardware and lab space had stalled. The engineering group used this forced timeout to catch up with documentation of procedures, system schematics, design enhancements, project planning, and advancing our inventory management system.

The initial COVID-19 shutdown resulted in a relatively short hiatus for some telescope operations, but after a few weeks, most sites were back open and operational. Travel to our sites for maintenance and new installations would remain out of the picture though for an unknown period of time. In the following, we will present some examples of how we adapted to the new boundary conditions and were still able to deploy a new instrument (MuSCAT3), deployed two new telescopes at Teide Observatory, and kept the telescope network mostly operational.

4. FALL OF 2020: MUSCAT3

In Fall 2019, the Astrobiology Center of Japan, Tokyo (ABC) and LCOGT reached an agreement to build (ABC) and operate (LCOGT) the third incarnation of ABC's multi-channel optical imaging camera MuSCAT[3,4] (PI: Norio Narita) for the 2-meter telescope at Haleakalā. MuSCAT3[5] uses dichroic beamsplitters to allow simultaneous imaging in four photometric bands (SDSS g' r' i' z'). The initial installation and commissioning of the instrument at the telescope were planned for July 2020. In-person scouting of the telescopes and site by the ABC team and collaborative visits to our headquarters to clarify the integration of MuSCAT3 into LCOGT's software infrastructure were already completed before the Pandemic.

As Japan was less severely impacted by COVID-19, the construction of the MuSCAT3 instrument at ABC in Japan was only slightly delayed by 2-3 months due to restricted access to lab space and minor delays with suppliers. The software development had already reached a prototype stage by January 2020, and the further development at LCOGT proceeded with only minor delays. The software-controllable parts of MuSCAT3 are limited to the four Princeton Instruments cameras (Pixis and Sophia series) and an off-the-shelf linear stage (Thorlabs) to move photonic diffusers into the beam.

To validate the software function we set up a server at ABC similar to an instrument control computer at an LCOGT site to which we then connected the cameras and motion controllers before they were integrated into the instrument. This test setup allowed our software engineers – still working from home – to fully test MuSCAT3-specific software with hardware in the loop in Tokyo. This setup was devised already before the Pandemic to limit the travel needs between ABC and LCOGT, but proved extremely valuable as the world shut down.

The instrument was approaching completion in the summer of 2020, and so was the issue of how to deploy the instrument to Haleakalā during the Pandemic. It became evident that a classical instrument installation campaign with a crew traveling to the site was not viable - both for our safety concerns and due to travel restrictions: The overall COVID-19 situation in Japan was not as dire, but travelers would have to plan for a 2-week quarantine when entering Hawaii and then again for two weeks upon returning to Japan. No one was willing to commit to spending a total of 4 weeks in quarantine. In California, we were still mostly limited to working from home. Remember, vaccines were not yet publicly available.

Rather than delaying the MuSCAT3 installation indefinitely until traveling restrictions would ease, we developed an alternative installation strategy: The instrument would ship to the site and then be installed solely by the residing site manager with some additional local support to ensure safety and sanity checks. Expertise by the instrument team at ABC and the commissioning team at LCOGT headquarters would be brought in via teleconferencing (Zoom). We approached local personnel at Maui who are familiar with the LCOGT environment and with whom prior relationship indicated that protocols to prevent the spread of COVID-19 would be followed. The site manager with one or two helpers was working in the open, well-ventilated enclosure environment. As the MuSCAT3 instrument itself is fairly simple in design, it was more important to have local expertise of the site and telescope than on the instrument itself.

The MuSCAT3 team at ABC carefully prepared a very detailed step by step assembly and alignment instructions that were reviewed by the Haleakalā and Santa Barbara teams before the installation via online teleconferencing sessions. During the installation phase itself, we kept Zoom sessions open all day, with personnel from LCOGT headquarters and from ABC advising and supporting with real-time data analysis (e.g., while aligning the four channel cameras to the optical axis) on each step of the installation. With Hawaii located between California and Japan, there was reasonably good overlap in time zones.

Naturally, we encountered a few issues during the installation (e.g.: The handling cart would mechanically interfere with the telescope and had to be modified; the interface bolt pattern was off and new holes had to be drilled), and were able to resolve them by stopping all work, assembling ABC's and LCOGT's teams on Zoom within a few hours, and talked through the issues and devised a plan how to drill a new pattern into the MuSCAT3 interface plate without harm to the optics. Screen sharing and whiteboarding functions of Zoom profoundly supported those brainstorming exercises.

With a minimum telescope downtime of the order of a week, we were able to integrate Muscat3 into the LCOGT software environment and proceed to first light with MuSCAT3. The telescope was returned to regular science operations with the Floyds Spectrograph within a week, while the scientific commissioning of MuSCAT3 continued for another four weeks, until its release for public shared risk science use.

The planning and design phase for the MuSCAT3 instrument was already completed in January 2020, and only the installation and commissioning phases were truly affected by COVID-19, for which we had to develop an alternative plan. Some of the lessons from this new form of deploying an instrument at site will hold their value beyond the Pandemic:

- Only a minimal local crew was truly required to install the new instrument. Albeit often perceived as a reward or entitlement to partake in the on-site installation campaign, not everyone who participated in the building of the instrument had to be physically present.

- The installation of the instrument without traveling was certainly less straining on the remote participants who would do their work from the comfort of their homes. In contrast, the local installation team was doing difficult, laborious work in a high-altitude environment. While for most participants this felt like an easy remote installation, for the team on site it was a very local event!
- It was important for the remote participants to properly coordinate with the on-site crew: Appreciate the need for breaks, understand that tasks take longer than initially thought or perceived from afar, and that priorities and next steps are to be clearly communicated. To that end we conducted daily all stakeholders meeting to coordinate everyone's activities and, most importantly, expectations.
- MuSCAT3 is a fairly simple instrument that was an ideal candidate for remote participation during installation. Prior software integration tests had retired significant risk for the first light. Not all types of instruments would be viable for this installation model.
- As the entire installation was planned and centered around teleconferencing-based participation, a larger group of experts was accessible during the installation than during a classical in-person installation campaign. First light, done via remote control and shared via Zoom, allowed all stakeholders to participate and experience the rewarding moment of a first image. While no one traveled to the site, this overall first light experience was more inclusive and enabled non-local people to participate.
- LCOGT is a special case as our facilities were from the start designed for robotic operations. E.g., we do not truly have a control room on our sites. Even if located at the site, one would work through the same browser-based interfaces on a laptop. Our entire operational model was predestined for this installation type.

At the time of this writing, funding has been secured from the Heising-Simons Foundation to build a southern MuSCAT instrument for the LCOGT 2-meter telescope in Siding Springs. We plan to model the installation after the MuSCAT3 experience, where we will only send a minimum contingent of personnel to the site (probably the site manager from Haleakalā for the integration experience, and one team member from the MuSCAT team for the instrument alignment). As soon as the instrument is bolted to the telescopes, and the telescope is balanced, other than for hardware interventions, there is little to do on the site itself since all data acquisition is based on web interfaces or robotic actions.

5. SUMMER 2021: TWO NEW 1-METER TELESCOPES AT TEIDE OBSERVATORY

The project to fabricate and install two new telescopes at Teide observatory was already in the pipeline in 2019. The two dome enclosures already installed at the site in Fall 2019, providing all the required facility infrastructure for the new telescopes and their instruments. The installation of the telescopes was originally planned for 2020, but the initial work from home mandate and subsequent slow return to work severely delayed the completion of the telescopes. Once the assembly areas were accessible again with proper precautions mid-2020, the LCOGT team finished the assembly and testing of two 1-meter telescopes. With indications that the summer of 2021 would be a good installation window, we shipped the telescopes to site. Global port shutdowns due to COVID-19 delayed cargo logistics adding uncertainty to trip planning.

During the low infection rate window in the summer 2021, and immediately after the immunizations of the installation team were completed, the crew traveled to Teide Observatory. COVID-19 restrictions required to complete timely paperwork including Spanish consulate, essential worker verification, endorsed by both LCOGT and Instituto de Astrofísica de Canarias, COVID-19 testing, ultimately complicating travel, but it was achievable.

Because the pandemic taught all LCOGT engineering and science support personnel to handle site operations remotely by now, the on-site installation team was well-supported by the global LCOGT staff during data-analysis heavy tasks such as the collimation of the mirrors and the commissioning of the telescope and instruments.

Upon a three-week installation trip, one of the telescopes was installed and commissioned and became available for science operations as the crew was on their return flight. The second telescope followed a week later. At previous new telescope installations, there were several more weeks of commissioning time required to bring a new installation to regular science operations. COVID-19 forced us to further adapt remote work – well aligned with the LCOGT operational model – and lead to better supported and hence more efficient site campaigns.

6. 2021: VACUUM MAINTENANCE OF THE NRES SPECTROGRAPH

Preventative maintenance during regular site trip has ceased since the onset of the Pandemic. We always enlisted the help of local observatory support to, e.g., exchange consumables as dry air gas bottles, cleaning of an encoder strip on a telescope axis, or replacing air filters in electronic chassis. Some more invasive activities such as deep dedusting of electronic boards remain deferred. A typical activity during a scheduled maintenance trip would be the vacuum maintenance of the 1-meter telescope CCD cameras that are used in the Sinistro imaging cameras and the NRES spectrograph. Of the order of every 18 month on a site trip we vacuum-pumped the cryostats and recharged or replaced components of the Cryotiger cooling system.

The maintenance of the imaging cameras at our 1-meter telescopes was well supportable by the observatory's crews, as all systems (vacuum port, Cryotiger compressor) are easily accessible and there were already well-established procedures, e.g. for vacuum pumping a cryostat. At most sites, even before the Pandemic, we had asked local staff to initiate vacuum pumping or the Cryotiger recharge procedure. Cryomaintenance is essential when trying to keep cameras operational. For this we were entirely reliant on local staff, who kindly stepped in while we could not reach the sites.

The camera in the precision radial-velocity NRES spectrographs are located inside a thermally insulated pressure vessel (Fig. 2), and is therefore inaccessible for routine cryomaintenance procedures, without opening the thermal enclosure and pressure vessel and exposing the spectrograph's optical bench. Recognizing the impact on operations of this design, in Fall 2019, we installed an upgrade kit for the NRES unit at McDonald Observatory; the vacuum pump port now extends through the pressure enclosure wall and is accessible for easy vacuum pumping of the camera. COVID-19 prevented the deployment of this upgrade to the other sites in Chile, South Africa, and Israel, and these remaining three NRES units still opening the pressure vessel in order pump the camera. This procedure typically involves four individuals working in a confined space including an LCOGT NRES expert.

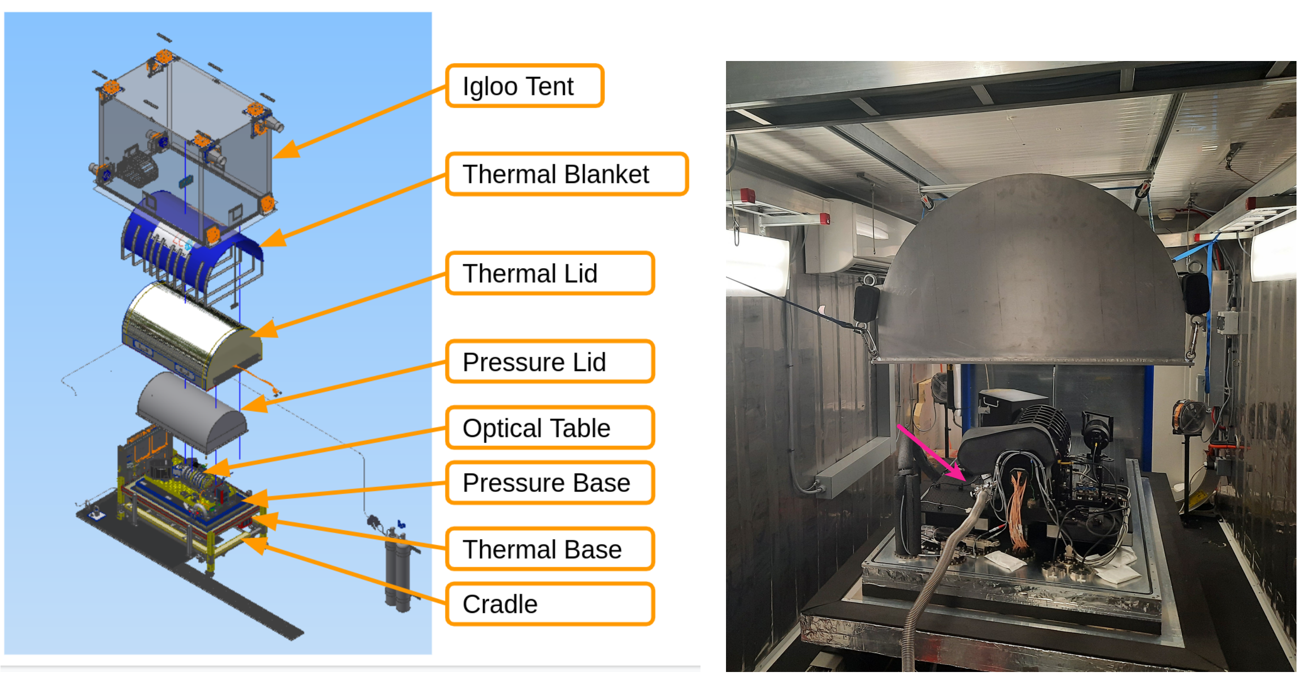

Figure 2. Left: Exploded view of the NRES optical bench that is pressure and temperature stabilized. Thermal stabilization is provided through multiple layers: an isolated shipping container with an A/C reduces ambient-temperature swings to within 10 deg K; inside the container is a tent with temperature-regulated air intake fans so the temperature is stable to within 0.5 deg K; finally, a thermally insulated and heater-controlled vessel stabilizes the spectrograph bench temperature in the milli-Kelvin range. The optical bench is enclosed by a pressure vessel that is filled with dry air and regulated to slightly above ambient pressure. Right: The NRES spectrograph bench was opened by Wise observatory staff with the camera being pumped via the stainless steel bellows annotated by a pink arrow.

Due to natural diffusion through O-rings, the vacuum in the NRES science cameras started to degrade by the end of 2020. For a while, we decided to operate the cameras at SAAO and Wise Observatory at an elevated CCD temperature of -80 deg C instead of the default -90 deg C, leading to higher dark current and hence less sensitivity. A year into the Pandemic, without scheduled maintenance, these two spectrographs were running on borrowed time - and the unit at CTIO was already taken out of commission. In late May 2021, the cooling system at Wise Observatory was finally failing and we had to cease operations there. In the Northern Hemisphere, the NRES unit at McDonald Observatory was still operational, but it was evident that the NRES in South Africa would stop operating soon as well.

The prospect of operating only one out of four NRES spectrograph units lead us to reassess the risk/benefit calculation of engaging in a cryomaintenance campaign for NRES. As NRES was the only LCOGT instrument at the Wise Observatory, that telescope was incapacitated, adding some urgency to bring NRES back to an operational state there. The documentation work early in the Pandemic also included detailing the procedure to open the NRES pressure vessel and access the camera for pumping, a two-day operation plus pumping time on the cryostat. We evaluated several scenarios of how a minimum crew could be sent to the Wise Observatory, but influenced by the success of a remote MuSCAT3 installation we converged on the idea of asking local site staff to execute the procedure with remote supervision and consultation by an LCOGT NRES expert. The calculus is simple; the procedure may not succeed, but in that case, we are still left with in the same situation of an instrument out of commission. *The key was to have sufficient confidence in our documentation, communication, and most importantly in the technical skills and judgment of the local staff so the instrument would not be harmed.*

In early June, we agreed with Wise Observatory's management and site staff to do such a remotely supervised procedure, and by June 23 2021, the pumping procedure – opening the pressure vessel, pumping, and closing up the pressure vessel – was completed. We subsequently had to resolve several other cooling system issues, all related to deferred maintenance. We had to ask site staff to follow additional procedures to recharge the Cryotiger cooling system and exchange the Cryotiger compressor itself. We returned NRES at Wise observatory back to science operations in August 2021.

At the same time as the NRES unit at Wise Observatory became operational again, the cooling system at the SAAO NRES ceased operations. We stopped operations there and secured the instrument. Now we had a situation where both of the Southern hemisphere NRES units were inoperable. Given the overall COVID-19 and staffing situations at sites, we approached the CTIO management to establish if a resurrection of NRES, similar to what we did at Wise Observatory, was feasible. Getting the green light, we were able to work with the site staff in the established manner: share the procedure, talk through it in a video conference, and then execute the procedure with live remote consultation and daily reviews of the state of the work. Thanks to the effort of the site team, we could return the NRES unit at CTIO back to service in mid-September 2021. With three out of four NRES units operational, the pressure to revive the remaining defunct unit at SAAO was reduced. As of this writing, due to a defective imager at Sutherland, we are revisiting the urgency to revive NRES at SAAO.

We summarize a few key takeaway points from the NRES maintenance campaigns:

- With proper documentation, preparation, and most importantly, well-qualified local staff at the observatory, even very complex maintenance tasks can be executed without the domain expert on site.
- We identified stages in the procedure at which the spectrograph could be left in a safe state if the procedure had to be paused or aborted. This allowed flexibility in scheduling the work as site-support staff could be called away for higher priority tasks.
- At CTIO we approached the observatory director first, to establish if an extended support campaign would even be feasible - with respect to safety, liability, and resource level. Only after receiving high-level clearance to further explore this option, did we contact the technical site staff. We choose this approach to not put undue pressure on observatory staff who we know will always try to help us in any way possible.
- Similar to the experience with the MuSCAT3 installation, it is important to recognize that the on-site staff are doing the actual work in a different environment than your home-office provides.

Our usual interval for cryo-maintenance is 18 months. By asking site support staff to execute a more complex procedure to pump the cryostats in the NRES spectrographs we were able to reset the clock on this deferred maintenance item and keep the NRES system in service. However, by the end of 2022 we will again face the question of how to handle regular site maintenance in a still COVID-19-affected world.

7. DELAYED PROJECTS

While we were able to complete several projects that were in the development queue before the start of the Pandemic, some new or not as advanced developments were progressing slower than anticipated.

In preparation for an additional new site deployment of two 1-meter telescopes at the Ali Observatory (Tibet, China), LCOGT has outfitted the first of two new Planewave CDK1000 telescopes. This included designing a new instrument package, assembling of the hardware, integrating new control software for robotic operation, and system testing. Given the ongoing COVID-19 situation in China during the first half of 2022, and the added difficulty of accessing Tibet, installation of the dome and telescope had to be delayed until 2023.

8. SUMMARY

Due to the robotic nature of our telescope network operational model – no telescope operators or observers are required on-site to take observations – we could remain largely operational throughout the pandemic. A minimum level of site support was required for viable operations, e.g. there must be site support to intervene in the case of a catastrophic failure. The established practice of remote, robotic operations was a key strength of LCOGT early in the Pandemic, but the distributed nature of our network also turned out to be a weakness in our operational model: The still limited practicability of traveling to our sites led to an accumulation of deferred maintenance, and we had to adjust our operations by calling for help from local observatory staff more frequently and for more complex issues. While the observatory staff at all sites kindly work with us to keep up with even complex reactive maintenance tasks, we are still engaging mostly in spot treatment until full maintenance trips can resume at all sites.

To get help from local observatory staff who may not be as intimately familiar with our telescopes and instrumentation as LCOGT staff, we have created very detailed step-by-step procedures for those tasks we ask site staff to do for us. Once a procedure was written and reviewed at LCOGT headquarter, we sent those out to site staff with a request for comment. For the most complex procedures we scheduled Zoom meetings to talk through the procedure, and let the personnel at the site judge if they thought that procedure was within their expertise level. During the execution of some tasks, we maintained a real-time online presence or organized daily status meetings. This process not only helped us to keep the telescopes operational but also had the side benefit of improving our overall system documentation and preserving critical knowledge within the organization.

The concept of supporting an on-site engineering team with remote expertise via internet presence was already ingrained into the LCOGT operational model. The normalization of telepresence in the everyday life during the Pandemic accelerated the adaption of remote consultation for our site trips and helped to bring the new two telescopes at Teide to science operations in a very short time.

While our engineering teams resumed visiting the sites to where we can fairly easily travel (Haleakalā, McDonald Observatory) or LCOGT staff is present (SSO), we still have not been able to visit our installations at some sites (CTIO, SAAO) for general preventative maintenance and upgrade campaigns. We continue to operate while incurring a significant debt of deferred maintenance in our telescope network.

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