2018 CFHT Annual Report

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Front and back covers: A spectacular image of NGC 253 captured by CFHT's MegaCam is shown. Also known as the Sculptor Galaxy, this starburst galaxy was discovered by Caroline Herschel in the 1800's and is easily visible in binoculars. The photo on the back by Jean-Charles Cuillandre shows the spectacular sunset colors at CFHT with tourists gathered at the base of the observatory.

Director's Message

Over the past few years the Maunakea Observatories have established robust communications and government relations programs intended to engage numerous audiences in Hawaiʻi and beyond. We made these investments in response to various challenges, recognizing the importance of speaking with a unified voice and representing our interests in a coherent manner to stakeholders, elected officials, and various community sectors. We developed an impressive array of presentation materials, brochures, fact-sheets, etc. to brief everyone from local civic clubs to elected officials. Among all the charts we have in our quiver, the chart below seems to resonate almost universally when shared with audiences in Hawaiʻi. Each year Dennis Crabtree from Herzberg Astronomy and Astrophysics sends to observatory directors worldwide his annual analyses of astronomy publications and I (along with my counterparts I'm sure) eagerly sift through his charts to see how observatories are performing using various metrics. This is a valuable service that has been in circulation for many years and in a sense Dennis' analyses serve as a "standard" that allows year-by-year tracking of numerous metrics. Obviously I've graphically embellished the chart below to emphasize Maunakea Observatories but the numbers remain the same. I do that for good reason. By the metric of science impact, which gauges numbers of papers and their citation rates (quantity x quality), the Maunakea Observatories lead co-located ground based astronomy research facilities around the world. This chart conveys that simple and important fact for elected officials, educators, community leaders, journalists, the general public, etc. It gives pride to Hawaiʻi residents who naturally seek a mark of importance as a tiny archipelago thousands of miles removed from continents bustling with resources that in many ways are beyond the reach of Hawaii. It emphasizes that despite our geographical separation the natural resources unique to Hawaiʻi, including

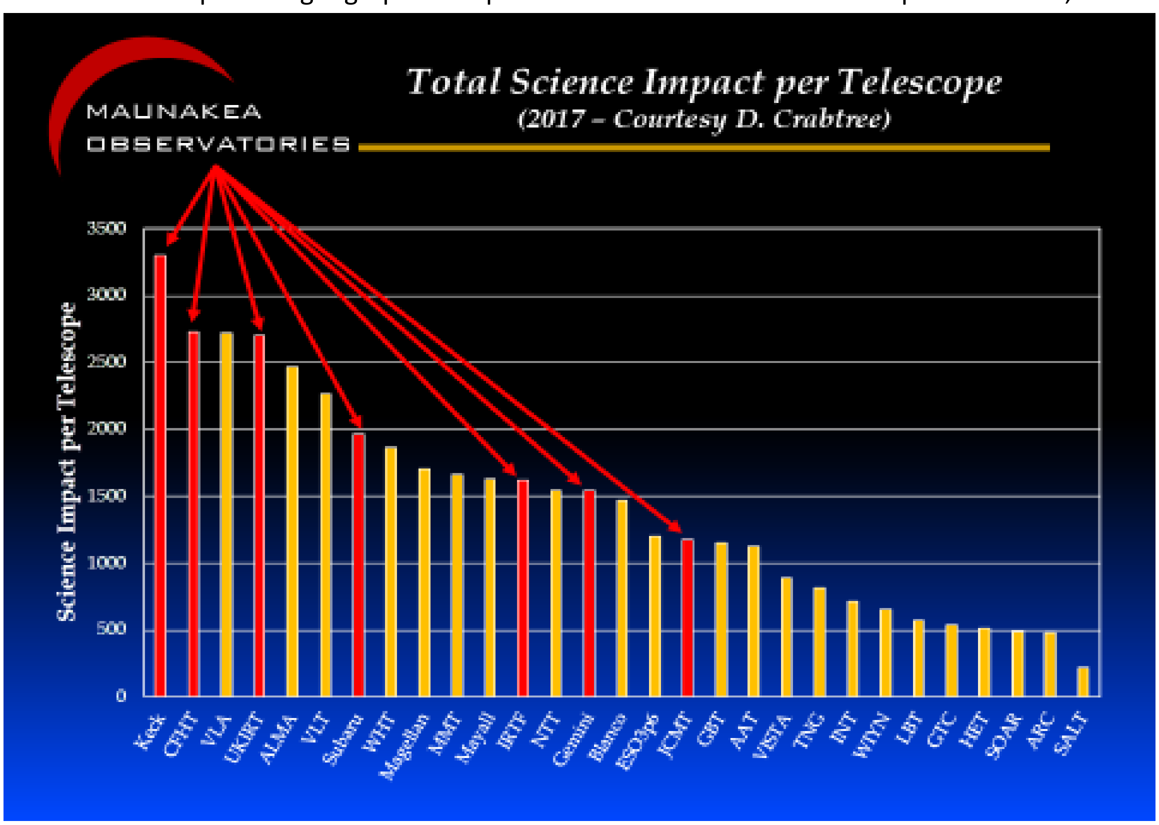


Figure 1 – The Maunakea Observatories, and CFHT in particular, are well represented in this chart which stems from an analysis Dennis Crabtree performs annually on research publications derived from observations made on observatories worldwide.

our spectacular skies above the world's tallest and most isolated shield volcano, makes Hawai'i and its residents special and important.

When I show this chart to our Waimea community, noting that Keck and CFHT are ranked #1 and #2 by this metric, you can imagine the reaction. Waimea has a population of ~10,000 – larger than the entire population of Moloka'i but smaller than many cities across Hawai'i. Waimea is a rural community known for cattle, sheep, paniolos (Hawaiian cowboys), friendly residents, and feral chickens running around town. It is not known by our community as the home to a veritable global powerhouse in modern astronomy. Shaping perceptions and giving new meaning to our community in a global arena is something that Hawai'i astronomy uniquely offers. Raising local awareness of the special nature of Hawaii astronomy and how Maunakea enables that special nature links back to centuries of adoration for Maunakea in the local community. Contemporary astronomy validates that Maunakea is the portal on the Universe engrained in Hawaiian culture.

A natural question is how can CFHT, a nearly 40 year old 3.6 m telescope, compete with a pair of 10 m telescopes on Maunakea? The answer is that both observatories have, in their own ways, optimized their scientific products around their strengths. Both communities have cleverly used their research tools to conduct observations that are attuned to their strengths and research strategies. Keck has the advantage of aperture, meaning sensitivity and resolution that pushes observational frontiers. CFHT has the advantage of field of view and Large Programs that yield enormous well-calibrated datasets that spawn papers for years, sometimes in areas that aren't envisioned when the observations are initially planned. Revolutionary research on Kuiper Belt Objects (OSSOS), Andromeda (PAndAS) and beyond is possible at CFHT. Strategically aligning community interests through Large Programs was a painful process at first, since it involved fewer PI programs and organizing research goals/teams in new ways. Today Large Programs are well established at CFHT and combined with a robust suite of PI programs that probe everything from upper atmospheric wind profiles on Venus to the fundamental lower limit of stellar mass, CFHT research remains potent even in an age of 8-10 m telescopes. Combined with the exquisite properties of Maunakea a 40 year old 3.6 m telescope like CFHT is demonstrably competitive with all other O/IR telescopes in the world.

Figure 2 – A "super moon" over Maunakea. Photo taken by Don Mitchell, a longtime resident of Hilo and member of the EnVision Maunakea team. CFHT is the white dot on the right.

Thanks to the willingness of CFHT's community to take risks and reinvent the tools they need to enable their research ambitions, CFHT remains on the left side of Figure 1 year after year. Most telescopes in the world aren't even on that chart, yet alone the far left side. As I look out my office window in the predawn hours, ready to launch another day at the helm of CFHT, I am humbled by what we have all achieved over the remarkable history of CFHT. "On paper" we shouldn't be in a leadership role in today's astronomy. Nonetheless, as I drink my first cup of coffee in the morning and listen to the chickens calling on our front lawn, I know better.

Science Report

A PRISTINE Star

An international team of researchers using MegaCam at the Canada-France-Hawaii Telescope discovered a star that is among the least polluted by heavy elements. Such stars are extremely rare survivors of the early ages of the Universe, when the gas forming stars hadn't been contaminated by the remnants of successive generations of dead stars. This new discovery opens a window onto star formation at the beginning of our Universe.

For the study of the early Universe, astronomers have different methods at their disposal. One is to look far into the Universe and back in time, to see the first stars and galaxies growing. Another option is to examine the oldest surviving stars of our home galaxy, the Milky Way, for information from the early Universe. The "PRISTINE" survey, led by Nicolas Martin (CNRS/INSU, University of Strasbourg), and Else Starkenburg (Leibniz Institute for Astrophysics, Potsdam) is looking for exactly these pristine stars.

The early Universe contained almost exclusively hydrogen and helium. Throughout the life of any star, the thermonuclear reactions taking place in their core creates elements heavier than helium (carbon, oxygen, calcium, etc.) from the hydrogen and helium making up the vast majority of their gas. When these stars explode at the end of their lifetime, they enrich the surrounding gas of with these “heavy” elements. This newly enriched gas serves as the birthplace for the next generation of stars. Each subsequent generation becomes more and more enriched with heavy elements created by their ancestors. About 2% of the mass of our Sun comes from these heavy elements. In contrast, very old stars contain very small quantities of heavy elements. They are however extremely rare and extremely difficult to find in our cosmic neighborhood.

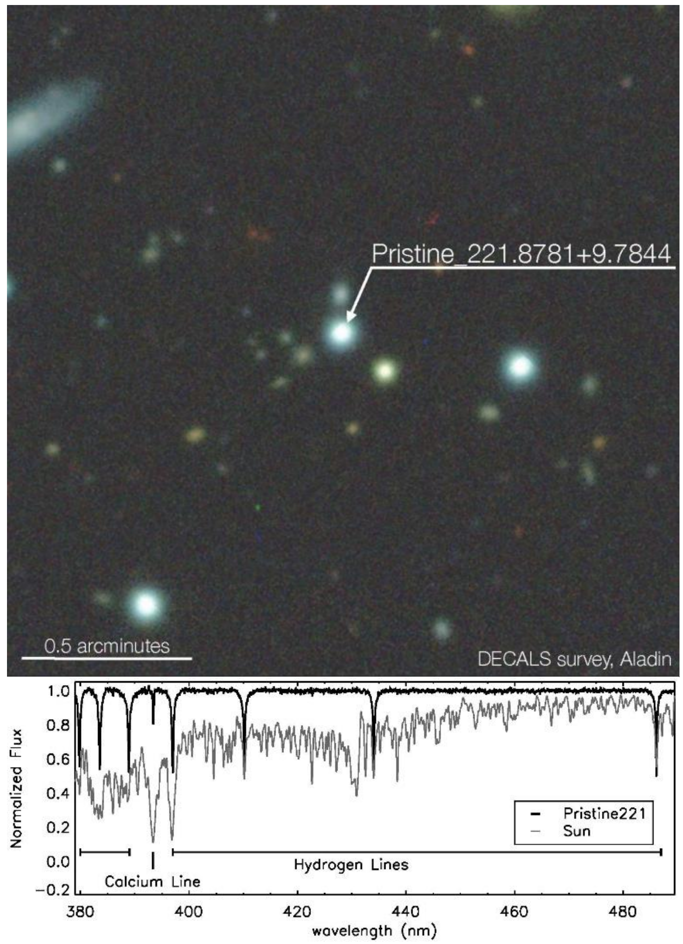


Figure 3 – Top: Pristine_221.8781+9.7844 and its surroundings. Credits: N. Martin and the Pristine collaboration, DECam Legacy Survey, Aladin Sky Atlas. Bottom: The spectrum observed with the William Herschel Telescope on La Palma for Pristine_221.8781+9.7844, compared to the spectrum of the Sun. As can be seen, the spectrum of Pristine_221.8781+9.7844 contains far fewer features. Only hydrogen (the large dips) and a small amount of calcium (the small dip) can be seen in the spectrum of Pristine_221.8781+9.7844. This tells us that the star is ultra metal-poor, it has an unusual lack of heavy elements in its atmosphere, which means that it belongs to an early generation of stars formed in the Galaxy. Credits: E. Starkenburg and the Pristine collaboration.

The discovery of the star unveiled by the "PRISTINE" team was made possible thanks to a new mapping of the night sky conducted at CFHT. The PRISTINE team used MegaCam to observe a small part of the ultra-violet light that is very sensitive to the abundance in heavy elements and enables a discrimination of the rare, pristine stars from the much more common stars polluted with heavy elements. The team estimates that less than one star in a million is as pristine as the newly discovered star. Follow up observations with spectrographs of the Isaac Newton Group, located in Spain, and the European Southern Observatory, located in Chile, confirmed that star Pristine_221.8781+9.7844 is almost devoid of heavy elements, with the concentration of heavy elements being 10,000 to 100,000 times lower than that found in the atmosphere of our Sun.

This star, whose discovery is presented in a publication of the Monthly Notices of the Royal Astronomical Society, brings strongly needed constraints on star formation models of the very first stars and opens a window onto an epoch that is still poorly understood. The discovery of Pristine_221.8781+9.7844 at the start of the "PRISTINE" project bodes well for the discovery of many such stars in the years to come.

Link to paper.

Is ‘Oumuamua Really a Comet?

The interstellar object ‘Oumuamua was discovered back on October 19, 2017, but the puzzle of its true nature has taken months to unravel, and may never be fully solved.

Meaning ‘scout from the distant past’ in Hawaiian, ‘Oumuamua was found by astronomers working with the University of Hawai‘i‘s Pan-STARRS1 survey as it came close to Earth’s orbit. But what is it? An asteroid, a comet or a rock that just happens to be passing by? As soon as it was spotted, astronomers from around the world were on the case.

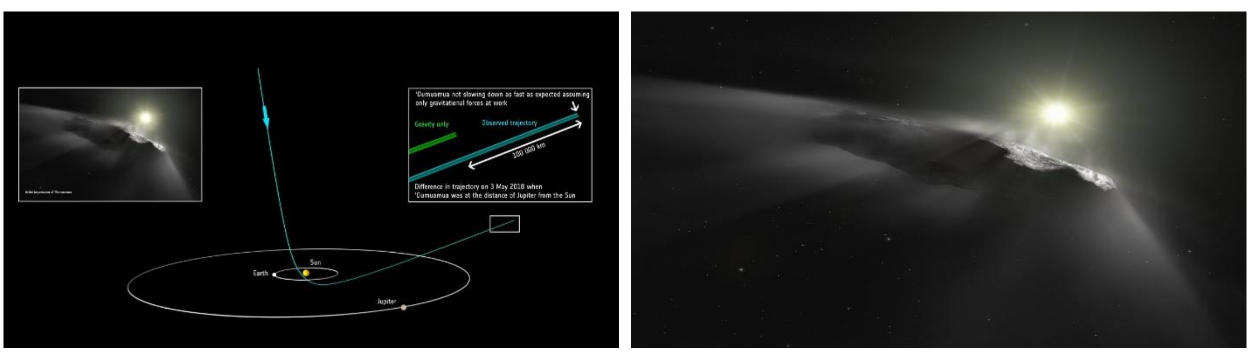


Figure 4 – Left: This diagram shows the orbit of the interstellar object ‘Oumuamua as it passes through the Solar System. It shows the predicted path of ‘Oumuamua and the new course, taking the new measured velocity of the object into account. ‘Oumuamua passed the distance of Jupiter’s orbit in early May 2018 and will pass Saturn’s orbit January 2019. It will reach a distance corresponding to Uranus’ orbit in August 2020 and of Neptune in late June 2024. In late 2025 ‘Oumuamua will reach the outer edge of the Kuiper Belt, and then the heliopause — the edge of the Solar System — in November 2038. Credit: ESA. Right: This artist’s impression shows the first interstellar object discovered in the Solar System, ‘Oumuamua. Observations made with the NASA/ESA Hubble Space Telescope and others show that the object is moving faster than predicted while leaving the Solar System. Researchers assume that venting material from its surface due to solar heating is responsible for this behaviour. This outgassing can be seen in this artist’s impression as a subtle cloud being ejected from the side of the object facing the Sun. As outgassing is a behaviour typical for comets, the team thinks that ‘Oumuamua’s previous classification as an interstellar asteroid has to be corrected. Credit: ESA/Hubble, NASA, ESO, M. Kornmesser.

The first clue: its trajectory. Extensive follow-up observations at CFHT, the European Space Agency's (ESA) Optical Ground Station telescope in Tenerife, Canary Islands, and other telescopes around the world have helped pin it down.

'Oumuamua was first spotted about a month after its closest approach to the Sun, which took it within the orbit of Mercury. Unlike any asteroid or comet observed before, this new object sped past the Sun, approaching from 'above' the plane of the planets on a highly inclined orbit, moving fast enough (70,800 miles per hour as of July 1, 2018) to escape the Sun's gravitational pull and eventually depart our Solar System.

Initially, astronomers assumed 'Oumuamua was a comet. Current understanding of planet formation predicts more interstellar comets than interstellar asteroids. However, astronomers did not see evidence of gas emission or a dusty environment in the observations. Without these hallmarks of cometary activity, it was classified as the first interstellar asteroid.

But the story has another surprising twist.

Following the initial discovery observations with Pan-STARRS, a team of astronomers led by Marco Micheli of ESA's SSA-NEO Coordination Centre, and Karen Meech of the University of Hawai'i Institute for Astronomy, continued to make high precision measurements of the object and its position using many ground-based facilities like CFHT, as well as the Hubble Space Telescope. The final images were taken with Hubble in January, before the object became too faint to observe as it sped away on its outbound orbit.

Contrary to their expectations, the team found that the object was not following the anticipated trajectory if only the gravity of the Sun and the planets were determining its path. "Unexpectedly, we found that 'Oumuamua was not slowing down as much as it should have due to just gravitational forces", says Marco, lead author of the paper reporting the team's findings. What could be causing this curious behavior?

Rigorous analysis ruled out a range of possible influences, such as radiation pressure or thermal effects from the Sun, or interaction with the Sun's solar wind. Other, less likely scenarios, such as a collision with another body, or 'Oumuamua being two separate, loosely held-together objects, were also discarded.

Comets contain ices that sublimate, or turn directly from a solid to a gas when warmed by the Sun. This process drags out dust from the comet's surface to create a fuzzy 'atmosphere' and sometimes a tail. The release of gas pressure at different locations and times can have the effect of pushing the comet slightly off-course compared with the expected path if only gravitational forces were at play.

"Thanks to the high quality of the observations we were able to characterize the direction and magnitude of the non-gravitational perturbation, which behaves the same way as comet outgassing" says Davide Farnocchia of NASA's Jet Propulsion Laboratory.

The team has not detected any dusty material or chemical signatures that would typically characterize a comet, even in the deepest images from ESO's Very Large Telescope, Hubble and the Gemini South telescope." 'Oumuamua is small-- no more than a half a mile long-- and it could have been releasing a small amount of relatively large dust for it to have escaped detection," said Meech. "To really understand ‘Oumuamua we would need to send a space probe to it. This is actually possible - but it would be very expensive and take a long time to get there, so it isn’t practical this time. We just have to be ready for the next one.”

“It was extremely surprising that ‘Oumuamua first appeared as an asteroid, given that we expect interstellar comets should be far more abundant, so we have at least solved that particular puzzle,” says Olivier Hainaut of the European Southern Observatory. “It is still a tiny and weird object that is not behaving like a typical comet, but our results certainly lean towards it being a comet and not an asteroid after all.”

Because of its small size and faintness, current observations of ‘Oumuamua do not provide all the information astronomers need to determine important aspects of the comet’s surface. “When ‘Oumuamua was discovered, the astronomy community gathered as much data as possible, but ultimately, the object was just not visible long enough to answer all our questions, “ says Ken Chambers from PanSTARRS. “With PanSTARRS monitoring the skies, we hope to discover more ‘Oumuamua-like objects in the future and begin to answer the really interesting questions about this class of objects.”

Link to paper.

Revealing the Complexity of the Nebula in NGC 1275 with SITELLE

Located 250 million light-years from Earth, NGC 1275 is a galaxy like no other. It sits in the middle of the Perseus galaxy cluster, a gigantic cluster harboring thousands of galaxies in the constellation of the same name. NGC 1275 is immersed in a hot, diffuse intracluster gas with an average temperature of tens of millions of degrees- a gas that forms most of the luminous mass of galaxy clusters. This environment is very complex: on one hand, the hot gas tends to cool and fall toward the galaxy but on the other hand, the central supermassive black hole releases powerful jets of very energetic particles visible by radio telescopes and blowing gigantic bubbles into the hot gas, preventing it from cooling completely.

Figure 5 - Hα filamentary structure around NGC 1275. Credits: SDSS/CFHT, Marie-Lou Gendron-Marsolais, Julie Hlavacek-Larrondo, Laurent Drissen and Maxime Pivin-Lapointe

However, a spectacular network of thin intricate filaments surrounding the galaxy NGC 1275 is visible at specific optical wavelengths. "These types of filaments are often visible around galaxies that lie in similar environments but their origin is a real mystery", declares Marie-Lou Gendron-Marsolais, lead author on the paper.

Extending over 250,000 light-years, two and a half times the size of our own galaxy, the link connecting this large nebula to its environment is still very poorly understood. Two hypotheses clash: it could be filaments condensing from the hot intracluster gas and sinking toward the center of the galaxy or rather gas lifted by the bubbles created by the central supermassive black hole jets and driven out of the galaxy.

To unravel the mystery of these filaments, the international team of researchers came up with the idea to use SITELLE, an instrument at the Canada-France-Hawaii Telescope able to map the galaxy at several different wavelengths simultaneously. "You get a spectrum for each pixel in the image" said professor Julie Hlavacek-Larrondo. "But what is unique about SITELLE is its vast field of view, covering NGC 1275 in its entirety for the first time since the discovery of the nebula, 60 years ago", she adds. SITELLE, funded by the Canadian Foundation for Innovation, is the result of a collaboration between ABB's high-performance technology company, CFHT, Université de Montréal and Université Laval, under the scientific supervision of Professor Laurent Drissen.

Thanks to this instrument, the team of researchers could measure the radial velocity, namely the speed along the line of sight, of each of the filaments, thus revealing their dynamics with an unequaled level of detail. "It seems that the movement of this network of filaments is very complex, there does not seem to be any uniform movement, it is extremely chaotic," said Marie-Lou Gendron-Marsolais. The researchers are convinced that such observations can help unravel the mystery of these structures. Overall, the understanding of the dynamics of these filaments is directly related to the processes of heating and cooling of the gas that feeds the central black hole. It therefore constitutes a key element in the study of galaxy evolution and, on a larger scale, environments such as clusters of galaxies.

The results of the research conducted by Marie-Lou Gendron-Marsolais, Julie Hlavacek-Larrondo, Laurent Drissen, Thomas Martin, as well as international collaborators, appear in Monthly Notices of the Royal Astronomical Society.

Link to paper.

Widespread Galactic Cannibalism in Stephan's Quintet Revealed by CFHT

The wide field image captured with the 340 megapixel camera called MegaCam is focused on the nearby galaxy NGC 7331. The image exhibits several galactic and extragalactic features, some very extended and dim, including filaments of interstellar dust in the foreground (galactic cirrus). The scientists' attention was however captured by the condensation of galaxies in the field, much further beyond NGC 7331: the famous Stephan's Quintet named after the French astronomer Édouard Stephan who was the first to observe it in 1878.

Figure 6 - Stephan's Quintet in true colors as featured in the CFHT/Coelum 2018 calendar. NGC 7317 is the lower right member of the group. Image: CFHT/Coelum, Jean-Charles Cuillandre (CFHT/CEA Saclay/Obs. de Paris) & Giovanni Anselmi (Coelum).

Stephan's Quintet is a compact group of 5 spiral and elliptical galaxies (excluding a spiral in appearance related to the system but actually present in the foreground, at the same distance as NGC 7331). The Hubble Space Telescope immortalized this region after observations of the group became one of the telescope's iconic images. Stephan's Quintet is the poster child for studies on the collective evolution of galaxies subjected to a range of effects such as interactions and slow collisions creating gravitational stellar streams, high speed galactic collision, gas ramming, starbursts and creation of intergalactic stellar systems.

Due to its unique features, Stephan's Quintet has been widely observed across the entire electromagnetic spectrum, and has been the subject of many complex numerical simulations. The team detected a red halo composed of old stars centered on a galaxy, NGC 7317. NGC 7317 was thought to be in a stable state or recently arrived near the group. The detection of red stars implies the contrary, that this galaxy has been interacting for a very long time with the other members of the group. Interactions such as the one seen in these observations are called galactic cannibalism. This occurs when the gravitational forces from a larger galaxy or group of galaxies slowly tear apart a smaller galaxy. Characteristic features of galactic cannibalism are streams or halos of stars orbiting the larger galaxy, like the halo of red stars seen around NGC 7317. A first implication is that Stephan's Quintet is far older than currently thought. The models of formation and evolution of this emblematic system will have to be revised. This global case of galactic cannibalism should eventually lead to the formation of a giant elliptical galaxy.

This new result illustrates the current renewed interest in the scientific field for deep imaging on nearby galaxies. Many observing programs, including several developed at CFHT which is particularly well suited for such studies, aim at decoding the past history of galaxies through the detection in their direct environment of faint extended features, a technique known as galactic archeology.

Link to paper.

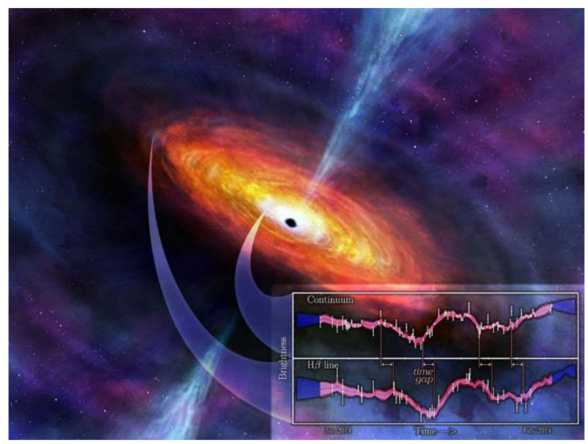


Figure 7 – An artist's rendering of the inner regions of an active galaxy/quasar, with a supermassive black hole at the center surrounded by a disk of hot material falling in. The inset at the bottom right shows how the brightness of light coming from the two different regions changes with time. The top inset panel of the plot shows the "continuum" region, which originates close in to the black hole. The bottom inset panel shows the H-beta emission line region, which comes from fast-moving hydrogen gas farther away from the black hole (the general vicinity is indicated by the other "swoosh"). The time span covered by these two light curves is about six months. The bottom plot "echoes" the top, with a slight time delay of about 10 days indicated by the vertical line. This means that the distance between these two regions is about 10 light-days (about 150 billion miles, or 240 million kilometers). Image Credit: Nahks Tr'Ehnl (www.nahks.com) and Catherine Grier (The Pennsylvania State University) and the SDSS collaboration.

Finding Extragalactic Supermassive Black Holes

Supermassive Black Holes (SMBHs) are found in the centers of nearly every large galaxy, including those in the farthest reaches of the Universe. The gravitational attraction of these supermassive black holes is so great that nearby dust and gas in the host galaxy is inexorably drawn in. The infalling material heats up to such high temperatures that it glows brightly enough to be seen all the way across the Universe. These bright disks of hot gas are known as "quasars", and they are clear indicators of the presence of supermassive black holes. By studying these quasars, we learn not only about Super Massive Black Holes (SMBHs), but also about the distant galaxies that they live in. But to do all of this requires measurements of the properties of the SMBHs, most importantly their masses.

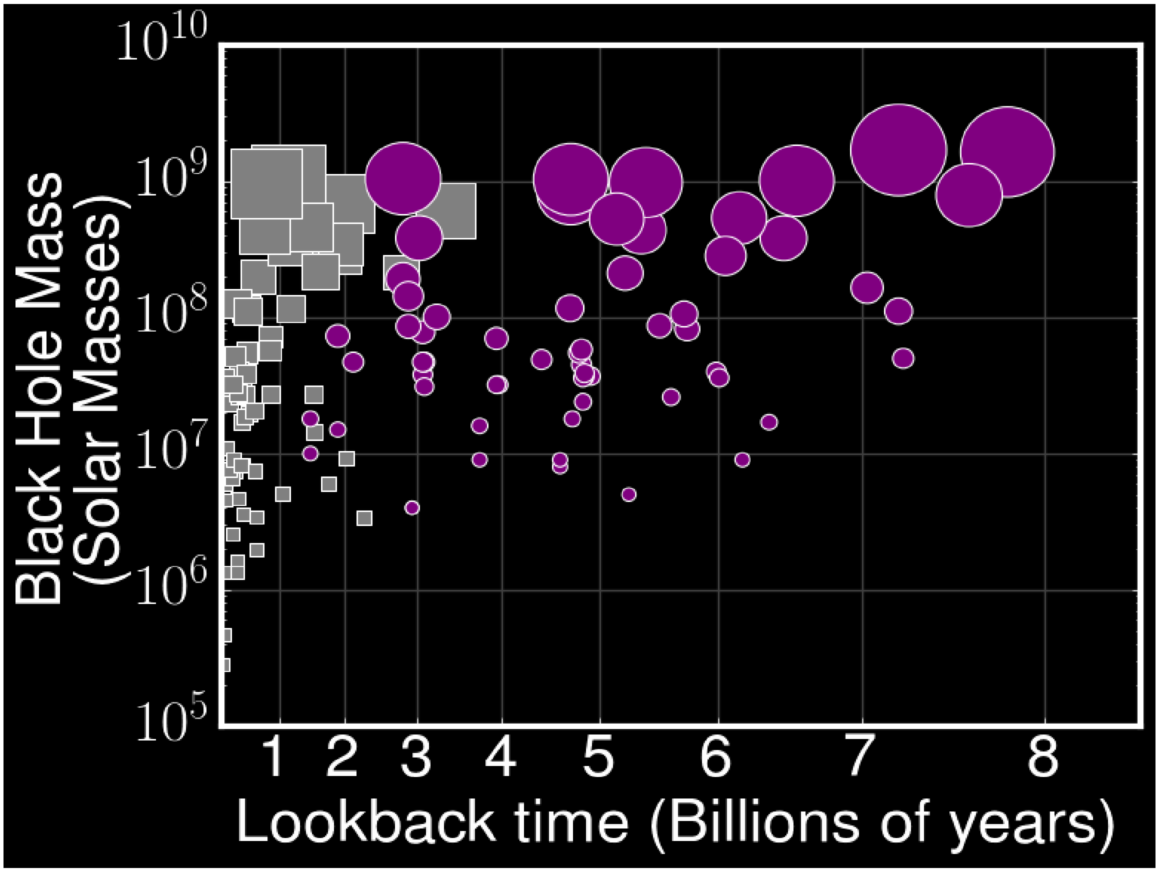


Figure 8 – A graph of known supermassive black hole masses at various "lookback times," which measures the time into the past we see when we look at each quasar. More distant quasars have longer lookback times (since their light takes longer to travel to Earth), so we see them as they appeared in the more distant past. The Universe is about 13.8 billion years old, so the graph goes back to when the Universe was about half of its current age. The black hole masses measured in this work are shown as purple circles, while gray squares show black hole masses measured by prior reverberation mapping projects. The sizes of the squares and circles are related to the masses of the black holes they represent. The graph shows black holes from 5 million to 1.7 billion times the mass of the Sun. Image Credit: Catherine Grier (The Pennsylvania State University) and the SDSS collaboration.

Measuring the masses of extragalactic SMBHs is a daunting task. Astronomers measure SMBH masses in nearby galaxies by observing groups of stars and gas near the galaxy center -- however, these techniques do not work for more distant galaxies, because they are so far away that telescopes cannot resolve their centers. Direct SMBH mass measurements in galaxies farther away are made using a technique called "reverberation mapping". "This is the first time that we have directly measured masses for so many supermassive black holes so far away", says Catherine Grier, a postdoctoral fellow at the Pennsylvania State University and the lead author of this work. "These new measurements, and future measurements like them, will provide vital information for people studying how galaxies grow and evolve throughout cosmic time."

Reverberation mapping works by comparing the brightness of light coming from gas very close in to the black hole (referred to as "continuum" light) to the brightness of light coming from fast-moving gas farther out. Changes occurring in the continuum region impact the outer region, but light takes time to travel outwards, or "reverberate." This reverberation means that there is a time delay between the variations seen in the two regions. By measuring this time delay, astronomers can determine how far out the gas is from the black hole. Knowing that distance allows them to measure the mass of the supermassive black hole - even though they can't see the details of the black hole itself.

Over the past 20 years, astronomers have used the reverberation mapping technique to laboriously measure the masses of around 60 SMBHs in nearby active galaxies. Reverberation mapping requires getting observations of these active galaxies, over and over again for several months -- and so for the most part, measurements are usually made for only a handful of active galaxies at a time. Using the reverberation mapping technique on quasars, which are farther away, is even more difficult, requiring years of repeated observations. Because of these observational difficulties, astronomers had only successfully used reverberation mapping to measure SMBH masses for a handful of more distant quasars -- until now.

In this new work, Grier's team has used an industrial-scale application of the reverberation mapping technique with the goal of measuring black hole masses in tens to hundreds of quasars. The key to the success of the SDSS Reverberation Mapping project lies in the SDSS's ability to study many quasars at once -- the program is currently observing 850 quasars simultaneously. But even with the SDSS's powerful telescope, this is a challenging task because these distant quasars are incredibly faint. "You have to calibrate these measurements very carefully to make sure you really understand what the quasar system is doing", says Jon Trump, an assistant professor at the University of Connecticut and a member of the research team.

Improvements in the calibrations were obtained by also observing the quasars with CFHT and the University of Arizona Steward Observatory Bok telescope over the same observing season. After all of the observations were compiled and the calibration process was completed, the team found reverberation time delays for 44 quasars. They used these time delay measurements to calculate black hole masses that range from about 5 million to 1.7 billion times the mass of our Sun. "This is a big step forward for quasar science", says Aaron Barth, a professor of astronomy at the University of California, Irvine who was not involved in the team's research. "They have shown for the first time that these difficult measurements can be done in mass-production mode".

These new SDSS measurements increase the total number of active galaxies with SMBH mass measurements by about two-thirds, and push the measurements farther back in time to when the Universe was only half of its current age. But the team isn't stopping there -- they continue to observe these 850 quasars with SDSS, and the additional years of data will allow them to measure black hole masses in even more distant quasars, which have longer time delays that can't be measured with a single year of data. "Getting observations of quasars over multiple years is crucial to obtain good measurements", says Yue Shen, an assistant professor at the University of Illinois and the Principal Investigator of the SDSS Reverberation Mapping project. "As we continue our project to monitor more and more quasars for years to come, we will be able to better understand how supermassive black holes grow and evolve".

The future of the SDSS holds many more exciting possibilities for using reverberation mapping to measure masses of supermassive black holes across the Universe. After the current fourth phase of the SDSS ends in 2020, the fifth phase of the program, SDSS-V, begins. SDSS-V features a new program called the Black Hole Mapper, which plans to measure SMBH masses in more than 1000 more quasars, pushing farther out into the Universe than any reverberation mapping project ever before. "The Black Hole Mapper will let us move into the age of supermassive black hole reverberation mapping on a true industrial scale", says Niel Brandt, a professor of Astronomy and Astrophysics at the Pennsylvania State

University and a long-time member of the SDSS. "We will learn more about these mysterious objects than ever before".

Link to paper.

Astronomers Find a Famous Exoplanet's Doppelgänger

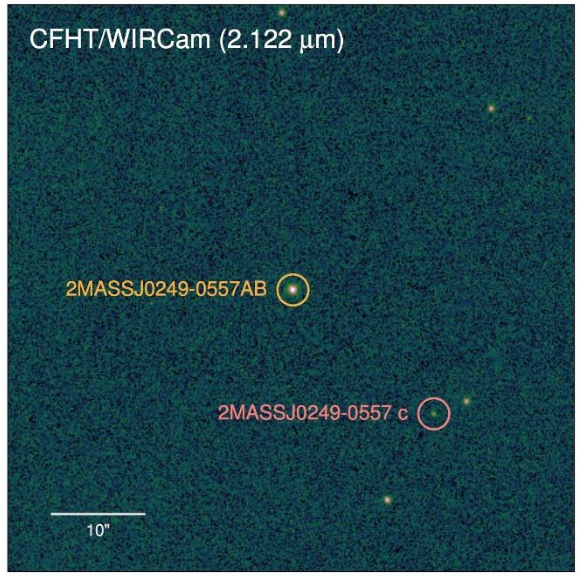


Figure 9 – Direct image of 2MASS 0249 system taken with CFHT's infrared camera WIRCam. 2MASS 0249c is located 2000 astronomical units from the host brown dwarfs that are unresolved in this image. Credits: T. Dupuy, M. Liu.

“We have found a gas-giant planet that is a virtual twin of a previously known planet, but it looks like the two objects formed in different ways,” said Trent Dupuy, astronomer at the Gemini Observatory and leader of the study.

Emerging from stellar nurseries of gas and dust, stars are born like kittens in a litter, in bunches and inevitably wandering away from their birthplace. These litters comprise stars that vary greatly, ranging from tiny runts incapable of generating their own energy (called brown dwarfs) to massive stars that end their lives with supernova explosions. In the midst of this turmoil, planets form around these new stars. And once the stellar nursery exhausts its gas, the stars (with their planets) leave their birthplace and freely wander the Galaxy. Because of this exodus, astronomers believe there should be planets born at the same time from the same stellar nursery - stars that have moved far away from each other over the eons, like long-lost siblings.

“To date, exoplanets found by direct imaging have basically been individuals, each distinct from the other in their appearance and age. Finding two exoplanets with almost identical appearances and yet having formed so differently opens a new window for understanding these objects,” said Michael Liu, astronomer at the University of Hawai`i Institute for Astronomy, and a collaborator on this work.

Dupuy, Liu, and their collaborators have identified the first case of such a planetary doppelgänger. One object has long been known: the 13-Jupiter-mass planet beta Pictoris b, one of the first planets discovered by direct imaging, back in 2009. The new object, dubbed 2MASS 0249 c, has the same mass, brightness, and spectrum as beta Pictoris b. After discovering this object with the Canada-France-Hawaii Telescope (CFHT), Dupuy and collaborators then determined that 2MASS 0249 c and beta Pictoris b were born in the same stellar nursery. On the surface, this makes the two objects not just look-alikes but genuine siblings.

However, the planets have vastly different living situations, namely the types of stars they orbit. The host for beta Pictoris b is a star 10 times brighter than the Sun, while 2MASS 0249 c orbits a pair of brown dwarfs that are 2000 times fainter than the Sun. Furthermore, beta Pictoris b is relatively close to its host, about 9 astronomical units (AU, the distance from the Earth to the Sun), while 2MASS 0249 c is 2000 AU from its binary host.

These drastically different arrangements suggest that the planets’ upbringings were not at all alike. The traditional picture of gas-giant formation, where planets start as small rocky cores around their host star

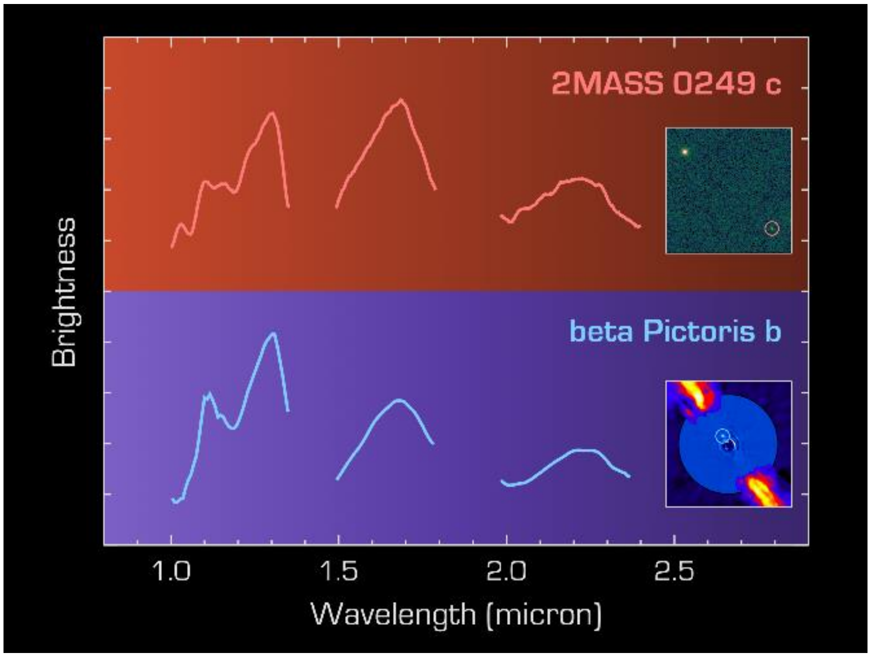


Figure 10 – The infrared spectra of 2MASS 0249c and beta Pictoris b are similar, as expected for two objects of comparable mass that formed in the same stellar nursery. Unlike 2MASS 0249c, beta Pictoris b orbits much closer to its massive host star and is imbedded in a bright circumstellar disk. Credits: T. Dupuy, ESO/A.-M. Lagrange et al.

and grow by accumulating gas from the star's disk, likely created beta Pictoris b. In contrast, the host of 2MASS 0249 c did not have enough of a disk to make a gas giant, so the planet likely formed by directly accumulating gas from the original stellar nursery.

"2MASS 0249 c and beta Pictoris b show us that nature has more than one way to make very similar looking exoplanets," says Kaitlin Kratter, astronomer at the University of Arizona and a collaborator on this work. "beta Pictoris b probably formed like we think most gas giants do, starting from tiny dust grains. In contrast, 2MASS 0249 c looks like an underweight brown dwarf that formed from the collapse of a gas cloud. They're both considered exoplanets, but 2MASS 0249 c illustrates that such a simple classification can obscure a complicated reality."

The team first identified 2MASS 0249 c using images from CFHT, and their repeated observations revealed this object is orbiting at a large distance from its host. The system belongs to the beta Pictoris moving group, a widely dispersed set of stars named for its famous planet-hosting star. The team's observations with the W. M. Keck Telescope determined that the host is actually a closely separated pair of brown dwarfs. So altogether, the 2MASS 0249 system comprises two brown dwarfs and one gas-giant planet. Follow-up spectroscopy of 2MASS 0249 c with the NASA Infrared Telescope Facility and the Astrophysical Research Consortium 3.5-meter Telescope at Apache Point Telescope demonstrated that it shares a remarkable resemblance to beta Pictoris b.

The 2MASS 0249 system is an appealing target for future studies. Most directly imaged planets are very close to their host stars, inhibiting detailed studies of the planets due to the bright light from the stars. In contrast, the very wide separation of 2MASS 0249 c from its host binary will make measurements of properties like its surface weather and composition much easier, leading to a better understanding of the characteristics and origins of gas-giant planets.

Link to paper.

Engineering Report

SITELLE Debugging and Performance

SITELLE cameras were removed and sent for test to Université Laval. Unfortunately, they were unable to measure the individual lens surfaces either by profilometry or interferometry due to test equipment incompatibilities.

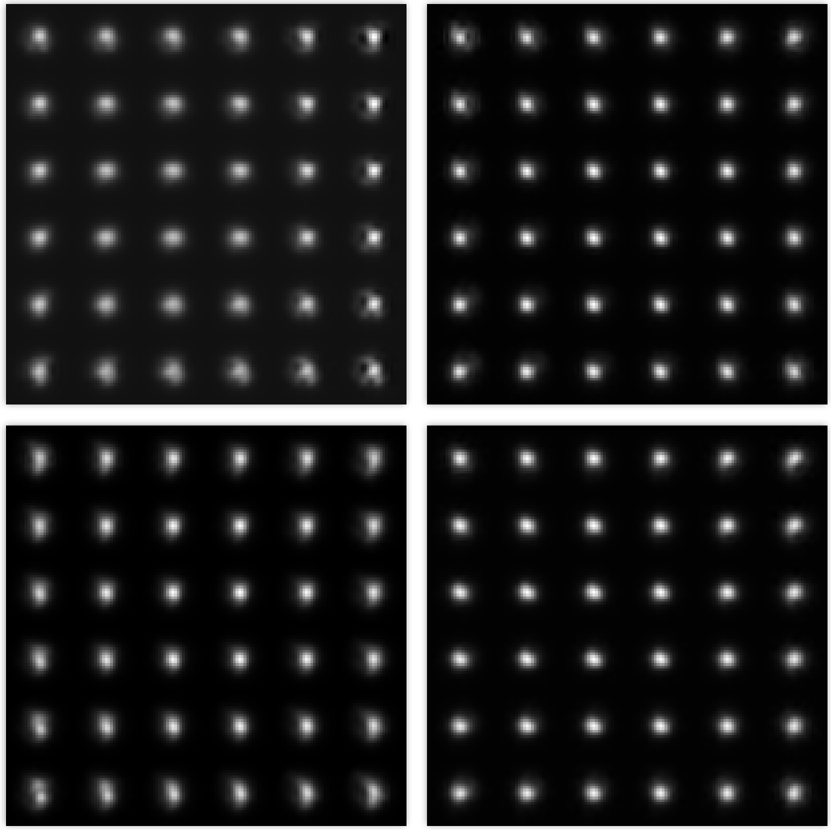


Figure 11 – Top: Camera #1 best focus on sky before (L) and after (R) realignment. Each star image is taken in filter SN3 at the same focus. Stars are scaled to the same peak intensity and displayed with a linear scaling. Positions on the display represent the approximate location on the SITELLE field. Bottom: Camera #2, best focus on sky before (L) and after (R) realignment

U. Laval was however able to perform interferometric and point source testing on the cameras. The interferometric tests in particular were not consistent with the previous CFHT results as they showed wavefront errors at less than half of that measured by CFHT. The root cause of the inconsistencies between the U. Laval tests and the CFHT tests is unknown. Nonetheless, the U. Laval testing did identify asymmetries in the image quality of one of the cameras. U. Laval attempted to repair this issue by realignment of the first two lenses in the camera but were unsuccessful.

After testing at U. Laval, the cameras were shipped back to CFHT and reassembled into the system. Zemax modeling by CFHT staff indicated that a non-axisymmetric PSF similar to what was being seen on sky could be obtained by tilting the entire instrument with respect to the telescope by 0.5°. As a result, CFHT staff proceeded to reassess the global alignment of the instrument. After extensive testing that included the development of new testing hardware, it was found that the SITELLE mounting flange had a tilt of 0.26 ± 0.02° along the north north-easterly direction, with the telescope at zenith. Although Zemax modeling by CFHT staff suggested that a tilt of this magnitude could not explain the entire image quality issue, the direction of the tilt was in the direction of the IQ variations in the images, and in a direction consistent with the shape of the PSF variations seen with larger tilts in Zemax. This coupled with the fact that CFHT staff believed the Zemax model they were working with did not accurately contain all of the manufacturing errors, suggested that it might be beneficial to correct for this tilt and

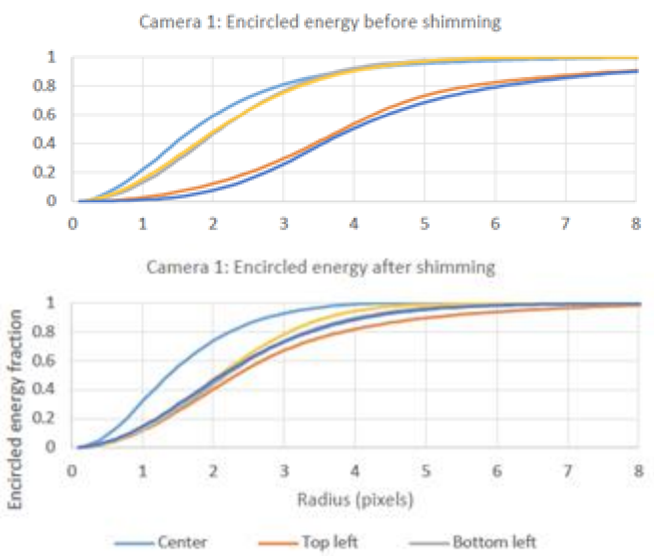


Figure 12 – Encircled energy near best focus in Camera 1 for stars in the corner of the field (same stars shown in Figure 11) and the center before the instrument was shimmed (top), and after shimming and correction of CCD tilt (below). Encircled energy was computed from the centroid of the PSF in every case.

optimize the CCD tilts on-sky prior to any further work with the instrument. Additional camera testing indicated a camera tilt on the order of 0.16° could be present, therefore an alignment adjustment was made to minimize this tilt.

SITELLE went on sky for two nights at the end of September 2018, primarily to allow for adjustment of the CCD tilts following the correction of the global instrument tilt and to obtain better through focus measurements to characterize the field-curvature seen in earlier testing (March 2016).

After realignment, significant improvement in image quality due to the realignment can be seen in both cameras. Encircled energy plots taken at the approximate best focus for stars in the corners of the field and center, before and after the instrument alignment are shown in Figure 11 for Camera 1. These were computed from the same images shown in Figure 12. As can be seen, the encircled energy plots for the PSFs in the top corners of the image after global tilt correction are more consistent. The shallower encircled energy curve for the PSF for the center star in the "before" case compared to "after" may be due to focus not being reached in the focus sequence and probably does not indicate an IQ improvement in the center of the field following shimming. Also, in order to remove any uncertainty due to a tilt of the CCD focal plane in the "before" images, the encircled energy plots shown are taken close to the best focus for the stars at the edge of the field in both the before and after cases.

SPIRou Technical Commissioning (TC)

Alternating with laboratory tests, we had 5 commissioning periods, summarized below. In addition to testing the instrument itself, the new queue-operation tools have been tested during these nights, since the previous tools were never adapted to SPIRou.

The technical down time due to instrument failures has been very limited and was used to our benefit to learn something about the instrument: a half night without the ISU (loose connection) made it possible to assess and quantify the ISU performance and explore in what limits we could observe without it; a night with a failure on the acquisition system led us to change the program and do more complete tests with the acquisition and guiding camera, all proving very useful. These times are still counted as "downtime" above because the instrument was not available at its fullest.

Some optical parts or software pieces were different from one TC run to the next, making the mid-term RV stability somewhat challenging to demonstrate. In the short term, however, several time series of several hours were obtained on quiet and bright M stars (e.g., 632 spectra on Barnard's star and 466 on Gl15A), to explore the RV error budget in the hour time scale. On longer time scales, the stability relies on the repeatability of wavelength calibrations, which measure an RV zero point each day – as for all PRV instruments.

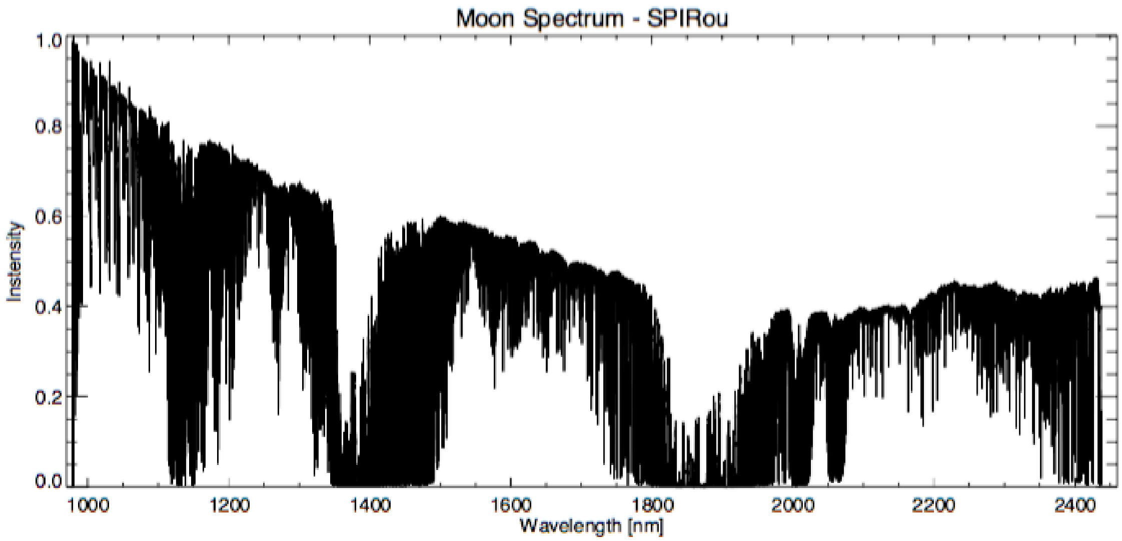


Figure 13 – Intensity spectrum of the Moon taken on 22 September 2018, as extracted by the online pipeline. It shows the nominal spectral range and resolution of SPIRou.

During TC, all spectra were processed and extracted online with the data flow organizer developed at CFHT and called "DRS trigger". This proved extremely useful in assessing the data quality with no delay. It is noticeable that, in addition to the spectrum quality (S/N per order), the CFHT operation software collects all available parameters that can relate to the RV precision and copy their value in the headers, for instance:

- Guiding precision (star to hole offset on both axes)
- Seeing and magnitude estimated from guiding images
- External parameters (extinction, DIMM seeing, air mass, etc.)
- Exposure meter calculation (from the real time ramp building)

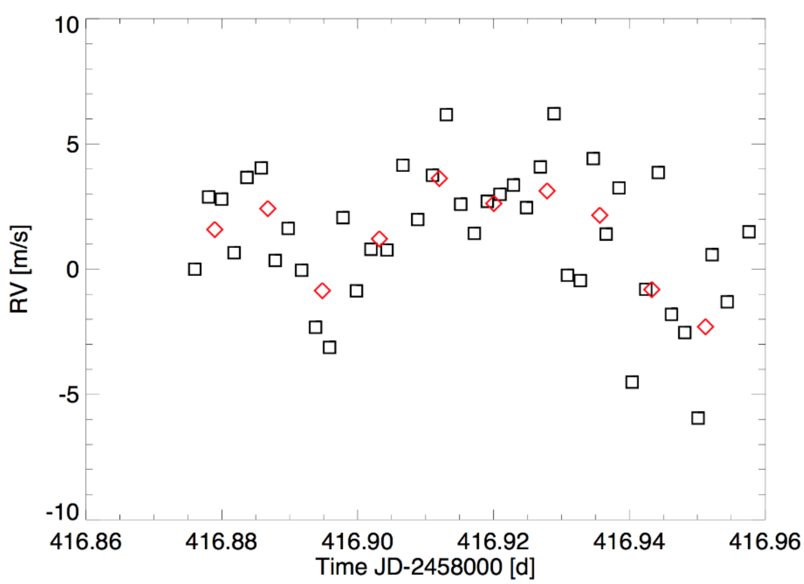


Figure 14 – The RV time series obtained on 24 Oct 2018 on the quiet planet-host star Gl15A during 2 hours. The rms on the polarization sequences (red diamonds) is 1.9 m/s. Conditions changed at the end of the sequence. Scatter origin at this level is still under investigation.

MegaCam Performance Improvements

SLINK

Last year, a small fraction of the science, flat, and bias images were lost due to corrupted data originating from the dethost computer. The data appear to be shifted left by 1 bit or twice the nominal value. The problem was very intermittent and manifested in several forms. The corrupted data was evident as rows of bright stripes, swaths across the CCD or as alternating bright pixels (see the images below.) The cause was traced to the PCI-bus fiber communication boards, SLINK (CERN standard fiber communication protocol). Two SLINK boards are used in MegaCam, one in the dethost computer and the other in the detector controller. The SLINK technology has been obsolete for over a decade; the next generation board is also obsolete and the current version is incompatible. An extensive search for replacements by CFHT staff proved unsuccessful.

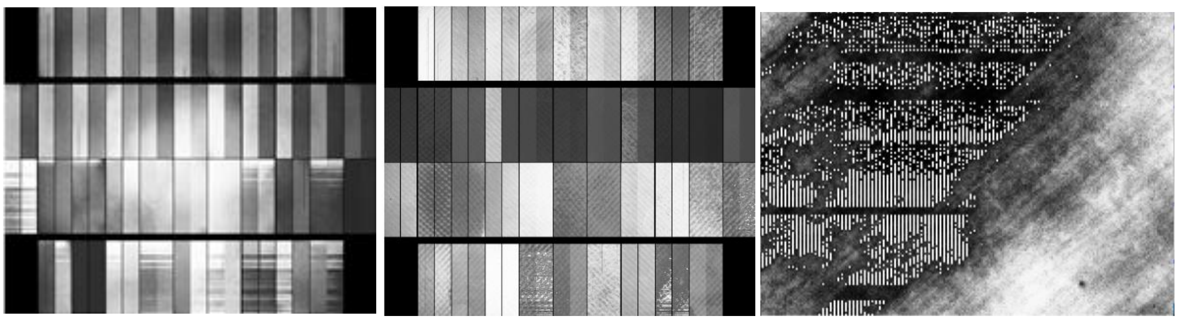


Figure 15 - Rows of corrupted pixel values (left) and swaths of corrupted pixel values (center). Alternating corrupted pixel-to-pixel values (right).

With no available replacements, the engineering group evaluated options to repair the existing boards. While all the major ICs are obsolete, a supply on the secondary market in China was located. Using the secondary market components, the two boards in MegaCam have been repaired along with three spare board-pairs. MegaCam has been working with these two repaired boards without issues during the past two runs.

In order to support MegaCam for the next 10-15 years, a decision was made to migrate from the SLINK boards, which are proprietary and obsolete technology. The plan is to replace the SLINK with a GigE interface. It is an industry standard with many commercial cameras using a GigE interface. Current scientific detector controllers such as Markury's MACIE controller proposed for SPIRou and for the NIRPS instrument use a GigE interface.

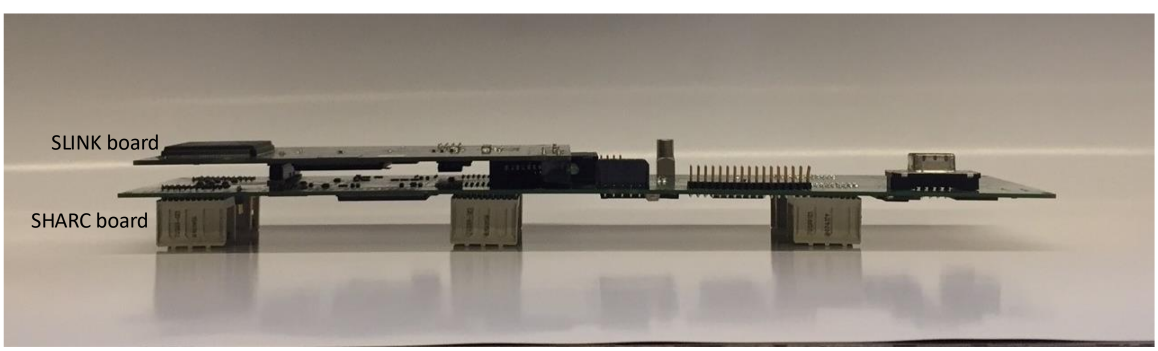


Figure 16 - Current SHARC uP board with SLINK daughterboard.

MegaCam Filter Exchange System Failure

MegaCam suffered a failure of the filter exchange system in July 2018, which curtailed observing and forced the removal of the instrument from the telescope. ESPaDOnS was installed in its place the following day. The cause of the failure was determined to be a loose screw holding the detent on the back of the frame, which had lodged into the side of the slide rail. See Figures below. The filter was removed and fortunately there was no damage to slide rail or to any other parts of the system. To prevent this incident from occurring in the future, a threadlocker, Locktite, was applied to detent screws on all the filters and a step was added in the monthly preventive maintenance procedure to check all screws.

Figure 17 - (Left) The detent is used to lock the filter in its jukebox slot. Two counter-sunk, stainless steel screws hold the detent in-place. (Right) The slide rail is mounted on the superior plate and can only be accessed by first removing the MegaCam cover, camera and supporting structure.

During the reassembly and testing of MegaCam, the +24 VDC line on the filter sensing PCB shorted to ground and the resultant heat charred the PCB. The board was replaced and a small fuse was added in-line to limit the current and to protect the PCB and its circuitry.

ESPaDOnS/GRACES

ESPaDOnS and GRACES have had a number of issues in 2018. First, in mid-June there was a failure of the camera focus stage. The stage was promptly removed and serviced, solving the problem. Later, on 18 August 2018, in the middle of an ESPaDOnS run during daytime observations of Venus, lightning struck Gemini with the result that all stages in the ESPaDOnS enclosure, including those on the GRACES bench, stopped working.

It is not clear as to the path of entry for the lightning as very few other systems at CFHT were affected by this lightning strike. ESPaDOnS/GRACES are on the building UPS power as is SPIRou, which has its electronics in the same room and was unaffected. One hypothesis is that the lightning entered the ESPaDOnS enclosure through the steel strain relief cable inside the GRACES fiber jacket. A preliminary analysis is underway to understand options and better ground the jacket/strain relief.

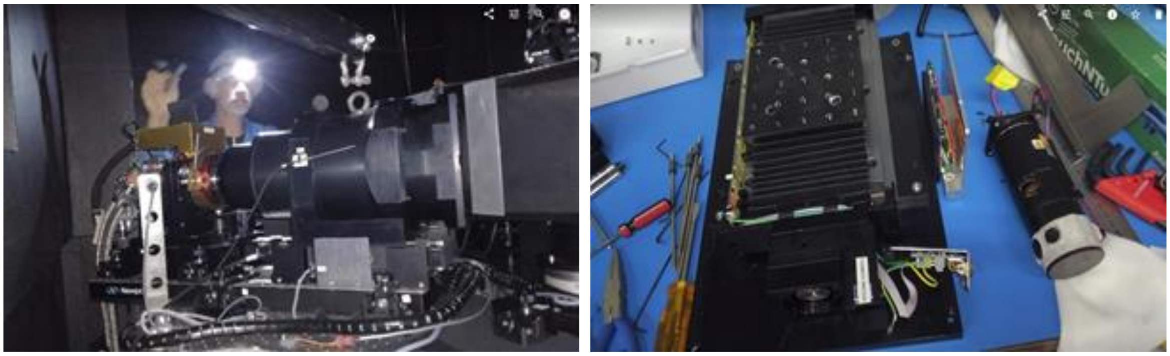


Figure 18 - (Left) Focus stage with camera optics on top within the ESPaDOnS enclosure. (Right) ESPaDOnS focus stage removed and disassembled for repair.

Investigation of ESPaDOnS showed that the motors were functional, but the encoders were not. Because of the time sensitivity of the Venus observations, which was to be simultaneous with satellite observations, a plan was developed to setup ESPaDOnS in a single mode manually. This setup, along with software changes to allow the normal observing software to run properly, allowed the Venus observations to be done and for observations in one ESPaDOnS mode to continue for the rest of the run. The Venus observations were successful while the rest of the run was mainly lost due to bad weather. The success of the Venus observation is a testament to the dedication of the entire CFHT team.

All failed motors and encoders have been replaced and ESPaDOnS is currently fully functional. Due to the extraordinary efforts of the engineering staff these repairs and realignment were completed by 20 September 2018, less than a month after total system failure. ESPaDOnS went on for a successful run on 28 September.

GRACES is currently under repair by the CFHT team. All failed motors and encoders have been replaced and the system is currently being integrated and tested. We are optimistic that GRACES will be functional by the GRACES run in January 2019.

Other Technical Activities

Cooling System Performance

A new fluid cooler system has been designed and built by the operations staff. This cooler replaces the original “Icewagon” Instrument chiller and provides cryogenic cooling for the MegaCam, WIRCam, and SPIRou instruments more efficiently and at higher capacity, both saving operations cost and allowing for instrument expansion.

The MegaPrime and WIRCam instruments utilize helium compressors (5kW each) to provide close-cycle cooling to their respective cold-heads. The heat removed by the helium compressors is then transferred to the GCI refrigerant chillers that in turn release the heat through our building exhaust system, away from the Observatory. The addition of the SPIRou spectropolarimeter similarly utilizes 2 helium compressors (5kW each) for cryovessel cooling which forced CFHT to increase their closed-cycle cooling requirements, leading to the introduction of the fluid cooler. The new Colmac Coil fluid cooler provides cooling water at 21 C to 4 helium compressors. Rated to remove 30 kW of heat, it is now operating at approximately 65% capacity, removing 20kW total. This represents 10 kW (MegaCam and WIRCam) of

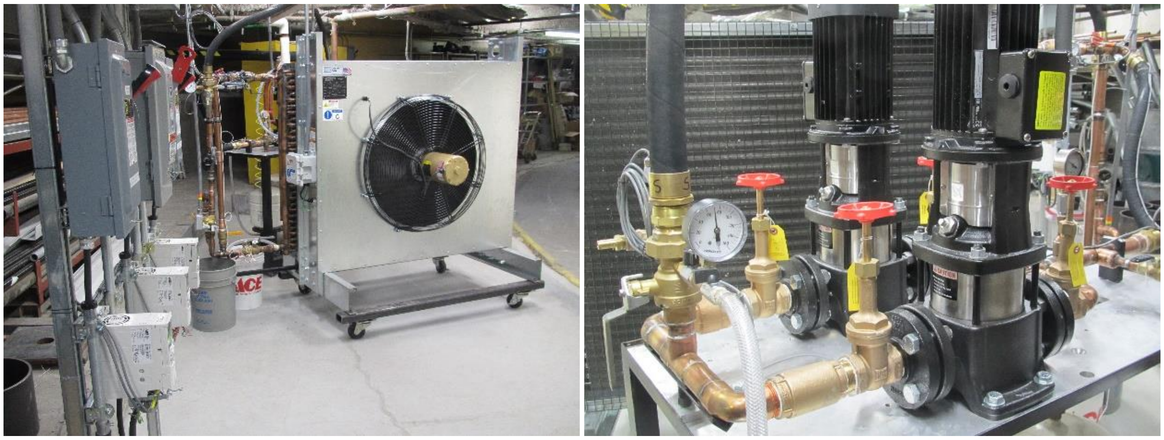


Figure 19 - (Left) Fluid cooler and VFD’s shown in contained area. (Right) Cooling water pump cart upstream of the cooler.

heat load transferred from the original Icewagon Instrument chiller, plus the addition of 10kW of heat load introduced by the newly integrated SPIRou spectropolarimeter. The fluid cooler has been operating since 16 February 2018.

The fluid cooler removes all the heat from the “water-cooled” compressors at a substantially lower purchase price ~$7000 (30 kW) vs ~$22,000 (12 kW) for the existing (MegaPrime and WIRCam) chiller, plus saving $48,000, which was the quoted market price to obtain a secondary chiller for the 2 SPIRou compressors. Operating costs have similarly been reduced from ~$7,000 per year to ~$3.000 with the introduction of variable-frequency drive pumps and fans, and maintenance costs are down to ~$500 per year due to the elimination of refrigeration components and corresponding service contracts. All fluid cooler maintenance is conducted in-house.

Handling Ring Repair

On 28 August 2018 during an instrument exchange, the handling ring used to exchange the telescope upper ends failed. The problem was isolated to a failed gate segment motor/brake/gearbox assembly.

Figure 20 - (Left) Handling ring gate segment shown. (Right) Gate segment motor/brake/gearbox repaired.

The problem escalated when 2 spare motor/brake assemblies that were swapped with the damaged unit were shown to be not fully functional.

After investigation, it was determined that a short in the original motor caused the brake assembly to fail. While removing the gearbox assembly the reducer was also found to be damaged. Electro Motors Inc. in Hilo inspected the (3) motors/brake/gearbox assemblies and was able to salvage (2) complete working units with the assistance of CFHT. One assembly was re-installed on the handling ring and tested for proper function. The other assembly was returned to spare as a viable/tested unit. The handling ring has been operating flawlessly since.

Hydraulic Hose Failure

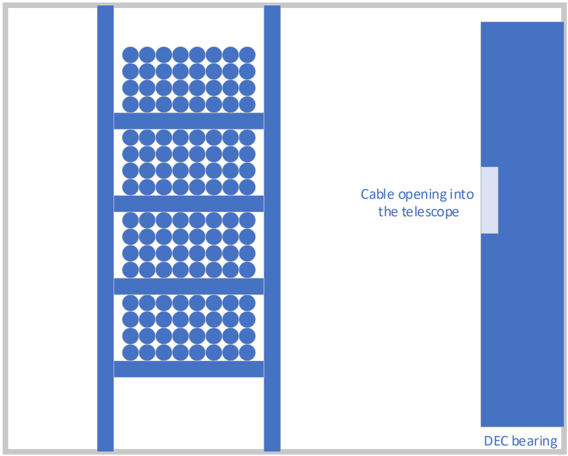
The redundant telescope hydraulic pump station has a transfer hose on both circuits that are routinely replaced due to excessive wear. During a recent troubleshooting effort to fix a faulty low-pressure transducer on circuit #2, the transfer hose ruptured, resulting in a hydraulic oil spill in the observatory basement. The spill was approximately 50 gallons (190 liters) and fully contained by the recently completed fluid containment system, which can hold up to 145 gallons (550 liters). A Dorlen leak sensor was activated during the failure which automatically closed the main supply valve and turned off the hydraulic pumps. As demonstrated by this incident, having leak sensing features in place reduces the contamination risk by reducing total amount of oil that can be released during a system failure. To further decrease the risk, CFHT is currently evaluating 2 additional upgrade features, adding additional sensors and shortening the reaction time between when the sensor is activated and when the valves/pumps are commanded “Closed/Off”.

TCS

High Current and Dec Wrap

The source of high DEC axis slew currents was caused by the DEC cable wrap. The cables are tied together into one giant bundle. At low ambient temperatures, especially during the winter months, the cables in the DEC cable wrap become very stiff and taut and require substantially more torque to move. To lessen the effect of the stiffness and to relieve some of the tension, the plan is to separate the cables into several smaller compartments and pull some of the cables back to provide slack. Figure 22 shows a conceptual drawing of the cableway which will be used to separate the cables. The cableway will be constructed in a way to allow the cables to be slipped into the compartments in situ, without having to

Figure 21 - Telescope hydraulic pump station showing the location of the transfer hose.



DEC bearing cavity - side view (N.T.S.)

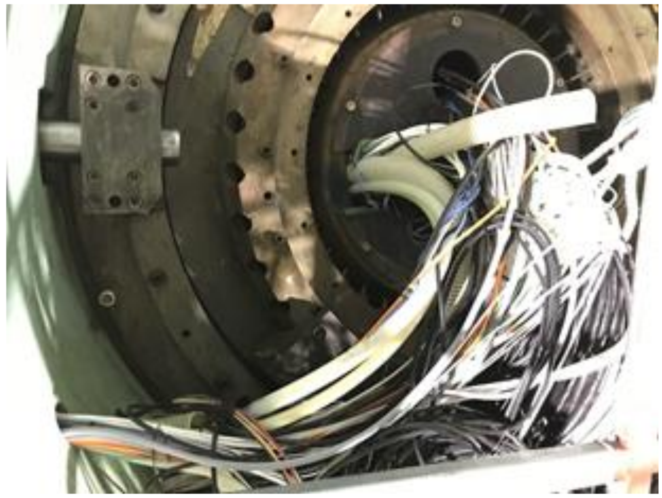


Figure 22 - View of the structure to compartmentalize the cables into smaller bundles. The cables run parallel to DEC bearing and then curve at a right angle through the opening, which is visible on the right. The DEC cable wrap includes a rope holding the bundle of cables near the center of rotation.

disconnect and rerun the cables. The cables run parallel to DEC bearing and then curve at a right angle through the opening, which is visible in Figure 22.

An assessment of the DEC cable wrap situation and a preliminary concept has been developed. The plan is to have the cableway in place before the end of 2018.

TCS RBUS

Much progress was made toward the completion of the RBUS upgrade project in the last year. All three device controllers have been checked for proper function on the lab bench and are ready to integrate and test within the telescope control stations. In collaboration with the software group, the existing TCS simulator-balance-weight-control software was modified to command the new RBUS device controllers. In efforts to prevent damage to the one-of-a-kind balance weight hardware on the telescope, extensive testing on the lab bench involved the development of a custom client, in Python, to ensure that each device controller functions as intended.

Several preliminary tests were conducted in the past week using control station 5 to demonstrate that a device controller can act as a full substitute for the CS5 system crate. To be a step up from the lab bench tests, the TCS simulator GUI was used to control the device controller while controlling the actual balance weight motors and reading their encoders. Movement of all motors for this station and reading of their encoders were successful. Moment calculations were also verified to be consistent with the existing RBUS system. Through testing on this station, procedures were created to make implementing the device controller on control stations 4 and 6. Since different encoder resolutions and word formats are used for the vertical and horizontal weights, the device controller code is configurable to account for this. Also, the motor rotation directions and encoder directions are configurable. As a result, a simple step by step checklist-like procedure was created to ensure that a safe and guess-free roll-out will occur for the remaining control stations.

After passing the integration and test phase, the code modifications will be rolled out into the operational TCS by simply replacing the balance weight code with simulator code. Integration and test of all three device controllers is scheduled to be completed before the conclusion of the 2018 calendar year. The first operational test will occur at the first exchange that occurs in 2019. Should any problems occur with the RBUS upgrade during this exchange, provisions have been made to revert back to the existing balance weight control system in a short amount of time.

Figure 23 - Three RBUS device controllers have been fabricated and are ready to deploy.

Large Coating Chamber Refurbishment

In 2017A the then Director of Engineering, Derrick Salmon, was asked to evaluate the scientific impact of increased re-coating cadence from once every 3 years to once every 2 years. The results of that analysis are published in the SAC report "Operation Status and Upgrades December 2016 – April 2017". When looking at predicted telescope usage once SPIRou comes online that report concluded that the benefits of coating every 2 years vs every 3 years was 4.25 nights per year in equivalent saved time. The question is whether the 4.25 nights per year would outweigh the added risk to the telescope and coating chamber due to the increased recoating cadence.

The large coating chamber is 39 years old and has not had a major refurbishment in its lifetime. Many of the filament mounting posts in the chamber are cracked, and the cracks have been widening over time (see Figure 24). At this time, it has become clear that the chamber should be only used to coat mirrors a very few more times before refurbishment. The engineering team has evaluated options for upgrading the coating system and a plan is in place to do so before the next shutdown, currently scheduled for summer 2020.

Figure 24 - Original electrode design. A crack is visible at the cusp.

The electrodes in the large coating chamber are in need of replacement. There are 224 electrodes. The original system holds the filaments in place by

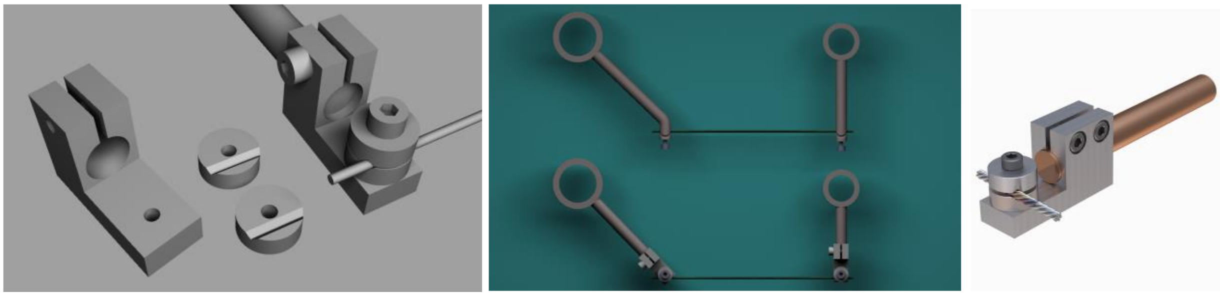


Figure 25 - Preliminary design for a new electrode tip. (Center) - Original electrode design and preliminary electrode design. (Right) - Rendering of the new bracket design, extended to allow additional contact with the existing electrodes and better clamping force.

positioning them in a slot cut into the electrode and clamping them with a single screw. Since all of the cracks we see in the electrodes originate at the bottom end of the slots, the plan is to move away from this design altogether.

The electrodes cannot be removed from the chamber to be modified, so all modifications must be made in-situ. The proposal is to use a clamp consisting of two washers with v-grooves cut in them, as shown in Figure 25, to hold each end of the filament. The washers are then bolted into a new electrode tip that can be clamped over the end of the cut electrode. Figure 25 center shows a comparison between an original electrode and a modified electrode.

Software Activities

The software group has been making an effort to expand their ability to collect metrics on the performance of computers, software systems and networks in order to anticipate problems and generate alerts. Secondarily, to assist us in troubleshooting problems after they happen.

During the OAP project as we transitioned to remote observing we built a substantial infrastructure for remote sensing, monitoring and alerting. In the past few years it became clear that we were still not monitoring carefully enough the computers and networks we depend on, or the software they support. In response we have been deploying systems for collecting metrics and querying them in a way that is scalable. Currently we collect thousands of metrics per second and we intend to continue expanding. Most of these data are not immediately useful but collecting it will help identify trends and baseline values which in turn will help design alerting rules that are accurate.

Several new technologies make this type of metric collection possible but in parallel we're trying to develop ways to query across multiple systems, including those we have been using for a long time, to support the possibility of identifying trends more broadly.

MSE Report

Summary and Overview

As the Conceptual Design Phase drew to a close after the System Design Review in January 2018, the Project Office (PO) transitioned from leading the engineering design to coordinating the outreach and promotion activities to raise the profile of MSE in the international astronomical community. This led to the remarkable growth of the science team, from 102 to 336, and the US National Optical Astronomy Observatory and Texas A&M University joined the Management Group as observers to explore possibilities of becoming participants.

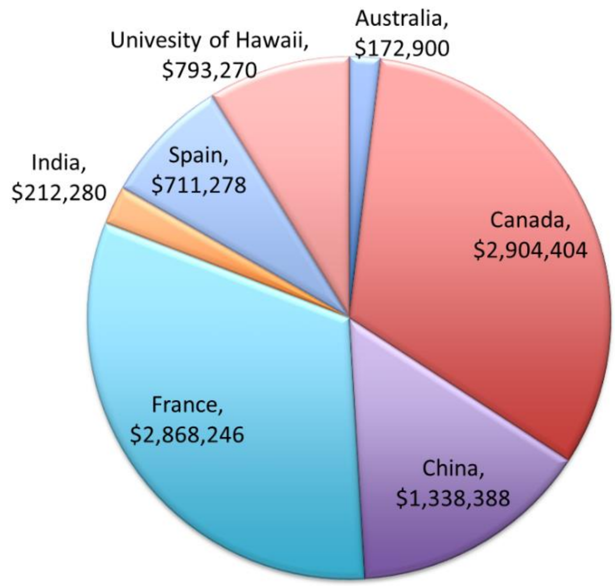


Figure 26 - The distribution of in-kind contributions among the MSE participants including the CFHT's MSE PO operating budget. Here, contributions from CFHT are distributed among Canada, France and Hawaii (0.425 : 0.425 : 0.15), and contributed effort is valued at $110/hr.

The PO effort in 2018 affirmed MSE's science relevance in an era of large scale photometric and astrometric surveys, resulting in MSE being recognized internationally as a mainstream project. For 2019, our objective is to convert MSE's "science capital" into tangible high-ranking return in the upcoming national strategic planning processes in 2020, including the Australian mid-term review, Canadian Long Range Plan, French Prospective and the US Decadal Plan. Attaining national priority will ensure each participant's ability to support the Preliminary Design Phase and help lead to funding for final design and construction. China and India also represent tremendous potential for collaborations and funding sources albeit without any organized national planning and ranking processes.

2018 also saw extensive deliberation on the Statement of Understanding (SOU) by the Management Group. The SOU states the participants' anticipated non-binding contributions to complete the Preliminary Design Phase and declares their commitments on supporting the final design and construction phase. Once signed by the participants' national authorities, the SOU establishes a Collaborative Board to direct the project with a formal partnership agreement that outlines partners' rights and responsibilities.

Partnership and Governance

Under the leadership of Patrick Hall, Management Group (MG) Chair, 2018 saw the finalization of the SOU. It was distributed to the participants for legal review and sanction for signatures. The current MSE participants' national authorities are:

- Australian Astronomical Optics (AAO), Macquarie University;
- Association of Canadian Universities for Research in Astronomy (ACURA);

- Centre National de la Recherche Scientifique (CNRS);
- Indian Institute of Astrophysics (IIA);
- National Astronomical Observatories of China (NAOC), Chinese Academy of Sciences;
- University of Hawaiʻi (UH).

The majority of participants have indicated they will be able to sign the SOU by early next year. Due to the length of their approval process, IIA has agreed to become an affiliate to MSE until they receive approval from their governing agencies to participate in the SOU and then be reinstated as a participant afterward. However, the SOU will become effective once the remaining participants have signed.

The SOU is an agreement between CFHT and the MSE participants (including those representing Canada, France and Hawaiʻi) to state their anticipated (but not binding) contributions to complete the pre-construction phase, a.k.a. Preliminary Design Phase (PDP), and commitments to plan and support the final design and construction phase. The agreement establishes a Collaborative Board that will define the formal partnership, its membership rights and responsibilities according to the values of their contributions, and control the direction of the project. The agreement also recognizes CFHT as the project's executive agency, along with the associated obligations and limitations.

2018 also saw the US National Optical Astronomy Observatory (NOAO) and Texas A&M University (TAMU) join the MSE MG as observers to explore the possibility of becoming participants. Throughout the year, the MG and PO actively promoted MSE to prospective participants to solicit interest in joining the project.

The SOU contains the concept and provisions for granting Beneficial Interest (BI) to participants based on their relative contributions to the project. Although specific details of the BI and how it is determined are not fully developed, the current MG members accept this principle and are willing to sign the SOU based on their current involvement. However, prospective participants have requested clarification on the BI in order to assess their interest. Using similar collaborative survey projects partnership agreements as references, the MG has started the BI discussion and formed a Tiger Team to propose options to recognize and reward extraordinary contributions from science team members who may or may not be associated with an MSE participant. The goal of these activities is to facilitate and encourage MSE participation while maintaining a fair and equitable recognition system.

Science

The MSE science team experienced tremendous growth in 2018, tripling in size to a total of 336 members from 31 countries. The growth is attributed to the extensive outreach and promotion activities after the membership call and a testament of the MSE's science relevance and synergetic links with the large scale photometric and astrometric surveys planned for the next decade.

Science Team Membership

The breakdown of science team membership by countries is as follows: (* denotes current MSE participants) –

- Australia* – 30
- Belgium – 5
- Canada* – 35
- Chile – 7

- China* – 32
- France* – 37
- Germany – 10
- India* – 11
- Italy – 11
- Spain – 12
- United Kingdom – 26
- USA – 86 (Hawaii* – 9)
- Other – 34

As stated, the priority of the science team is to update the contents of the Detailed Science Case (DSC) document. A new version of the DSC will be released in early 2019. To facilitate this endeavor, nine science working groups have been formed according to MSE's science areas under the leadership of Alan McConnachie. Each group's membership was filled by science team members according to their interest with two group leads appointed in each group.

Science Working Groups

The science topics of the nine working groups are as follows:

- Exoplanets and Stellar Astrophysics
- Chemical Nucleosynthesis
- The Milky Way and Resolved Stellar Populations
- Galaxy Formation and Evolution
- Active Galactic Nuclei and Supermassive Black Holes
- Astrophysical Tests of Dark Matter
- Cosmology
- Time Domain Astronomy and the Transient Universe
- Integral Field Unit Development Team

Science Development

All of the SWGs are currently crafting an updated version of the DSC. This document is on track for completion in time for the January 2019 AAS meeting. The updated DSC will be the accompanying public document with the MSE 2018 book for outreach and promotion, and a key reference on MSE's science capabilities in support of the participants' national strategic planning processes.

In January, Alan McConnachie will transition from Project Scientist to Spokesperson. We expect the new Project Scientist will lead the science team in developing the Design Reference Survey, with Alan's diminishing support in the background to facilitate a smooth changeover. In parallel, Nicolas Flagey will coordinate the development of the survey scheduler simulation tool. The survey scheduler is one of the trio of tools along with the exposure time calculator and fiber allocator required for the DRS study.

Working with the PO and science team, the Project Scientist will lead the process of reconciling the system non-conformances (against the MSE science requirements) identified in the System Design Review. The expected resolution will be a combination of science requirements revision and design baseline modifications in order to bring the MSE system into full compliance. This will be an iterative process as the DRS development may uncover additional design and operation requirements needed at the system level.

Project Office Activity

After the System Design Review, the PO underwent a planning process to organize engineering work with the following objectives:

- Supporting the outreach and promotion activities as our priority
- Supporting the science team activities
- Incorporating the review panel's recommendations to improve the three Level 1 foundational documents: Observatory Architecture Document (OAD), Operations Concept Document (OCD), and Observatory Requirements Document (ORD)
- Preparing for an anticipated Preliminary Design Phase start in 2019

However, it was understood that the engineering tasks would be postponed in order to support the partnership development work such that the PO team could work at a sustainable pace through 2018.

Highlights of the PO development activities for 2018 while supporting the outreach and promotion activities are as follows:

- Established a science calibration advisory panel consisting of experts with real-world experience in fibre-fed multi-object spectrographs to provide feedback and oversight on all aspects of science calibration, hardware and methodology. The panel members are Sam Barden, David Schlegel and Rob Sharp. (This effort was led by Alan McConnachie.)
- Consolidation of the system budgets (throughput, injection efficiency, noise and image quality) into a single document. This ensured the budget items are cohesive and consistent since the original set of system budgets were developed over a period of two years by different team members. The consolidated system budgets and the associated parameters are incorporated into the exposure time calculator which is one of the simulation tools required by the science team. (Led by Nicolas Flagey)
- Released the fiber allocator simulator tool for the science team. (Led by Nicolas Flagey)
- Incorporation of functional analysis and product breakdown structure in the OAD to rationalize the system architecture selected for the conceptual design baseline (Led by Kei Szeto and Calum Hervieu)
- Incorporation of use case analysis to rationalize the operations concept presented in the OCD as the current MSE baseline, (Led by Calum Hervieu and Nicolas Flagey)
- Completion of the 160-page MSE 2018 book describing the detailed technical development of the MSE Observatory, subsystem-by-subsystem. (Led by Alexis Hill)
- Closeout of the delta-CoDR of the Fibre Transmission System (Led by Kei Szeto)
- Completion of lite preliminary level optical design of the high resolution spectrograph (Led by Kai Zhang)
- Organized the M1 system readiness review to evaluate and compare the TMT and ESO ELT segmented primary mirror system technologies. The review will recommend to the PO the

optimal M1 system to adopt for MSE based upon technical and programmatic considerations (Led by Alexis Hill and Eric Williams)

Development of Outstanding Subsystem Conceptual Designs

We were unable to complete all of the conceptual designs identified in last year's report given PO resource constraints and the much-reduced support from the international design team. The work accomplished in 2018 includes:

- Observatory Building and Facilities conceptual design review - Due to the departure of Steve Bauman from CFHT, the review did not occur. However, the structural integrity of the outer building and telescope pier, including their foundations, has been confirmed in the M3 Engineering & Technology Corp's design study.
- Acquisition and Guide Camera System - Initial analysis completed to determine the field of view required based on availability of guide stars, guiding accuracy and mount control bandwidth in order to support high-level design requirements development. (Analysis performed by Derrick Salmon)
- Science Calibration System - Initial analysis to determine the feasibility of using telescope-mounted light sources and enclosure screen to support the daytime and nighttime calibration for flats and arcs has started. (Analysis supported by Derrick Salmon).

Strategy Going Forward

With the above Maunakea activity now underway, we expect confidence on astronomical investment for Maunakea will be restored. 2019 is a momentous year for the future of MSE as many participants' national strategic planning processes for the next decade will be underway:

- Australia (mid-term review)
- Canada (Long Range Plan)
- France (Prospective)
- US (Decadal Survey)

In order for MSE to be funded for construction, it must attain high rankings in these national strategic plans. To this end, the PO will participate in outreach and promotion activities at the participants' national levels in 2019. The PO will rely on national MG, Science Advisory Group (SAG) and science team members to advance MSE's ranking while providing the necessary support. We anticipate the PO support will range from informational only to physical presence at strategic events. Working with the outreach manager, the PO will support the overall outreach and promotion activities to ensure consistency since the specific needs may be different among the participants at their national level.

Administration Report

Overview

The Finance & Administration Department supports the mission of CFHT by providing and overseeing all shared service functions of the Observatory: Finance, Human Resources, Safety, Office Services, and Fleet and Building Maintenance. The goal of the Administrative group is to be helpful to the organization and provide outstanding service to our internal customers.

Summary of 2018 Finances

CFHT continues to operate in a challenging economic environment of limited member agency contributions compounded with inflationary cost pressures. For 2018, member agency contributions increased 1% from the prior year. During the last 4 years, agency contributions have grown an average of 1% per year. Personnel costs represent the largest portion of CFHT's budget, with average annual inflation pressure on salaries and benefits of between 2.5% to 3% per year. To date, CFHT has been able to successfully balance these cost pressures and maintain a balanced budget due to a strategic focus on efficiency improvements in both personnel and operating costs and a disciplined eye on expenditures.

Agency Contributions (US$)		
	2018	2017
NRC	3,300,000	3,261,145
CNRS	3,300,000	3,261,145
UH	765,214	756,204
Total	7,365,214	7,278,494

Table 1 - Contributions from CFHT partners increased 1% from 2017 to 2018.

Table 2 shows our 2018 Operating Fund expenditures on a comparative basis with 2017. In spite of the budget constraints, we have been able to maintain a balanced budget in both years with nominal amounts unspent and transferred to reserves. These results are due to conscientious and targeted cost containment in several categories. As we look towards the future, CFHT will continue to work closely with its member agencies to maintain stable and efficient operations while continuing to deliver world class service.

Operating Fund Expenditures (US$)		
	2018	2017
Maunakea Facility and Operations	487,909	497,209
Base Facility and Operations	137,917	160,509
Services	377,579	258,568
Maunakea Support Services	135,198	132,001
Management & General	435,313	404,116
Staffing	5,551,289	5,576,064
Outreach	74,567	73,991
Instrumentation	57,858	91,470
Science	64,101	52,988
Transfer to Reserve	43,483	31,578
Total	7,365,214	7,278,494

Table 2 – Operating expenditures broken down by cost categories.

In addition to member agency contributions, CFHT receives payments under collaborative agreements with other agencies as reimbursement for costs associated with their use of CFHT facilities. In 2018, CFHT received $254,000 and $414,750 from the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) and the National Astronomical Observatory of China (NAOC), respectively. Money received under the collaborative agreements are used to fund instrument and project development costs, with the current focus on MSE. Efforts are ongoing to seek additional collaborative agreements and partner with agencies throughout the world.

Accounting Group Developments

In the spirit of continuous improvement, the following are some of the significant changes and accomplishments within the Administration Group during the 2018:

- Awarded recognition as one of Hawai'i's Best Places to Work – based on independent surveys conducted of at least 75% of our employees, CFHT received recognition as one of Hawai'i's best places to work among small employers across the state.
- Redesign and rollout of new compensation structure. CFHT's previous compensation structure dated back to the origination of the observatory and was based on a preset step function that did not allow for flexibility or adaptability to changing circumstances. The observatory developed a new structure that allows the Executive greater flexibility in immediately addressing compensation discrepancies and recognize individual employee performance. Feedback on the new structure has been generally positive from the staff.
- Enhancements to the Retirement Plan – We successfully negotiated significant fee reductions in the observatory retiree plan as well as improved the fiduciary oversight with the addition of an independent investment advisor to oversee the plan's investment offerings. The fee reductions directly benefit all plan participants and will have the effect of increasing investment returns.

Staff Safety

Due to a vacancy in our safety specialist position created in late 2017 by the departure of Jake Braden, CFHT assessed options on how to most effectively and efficiently oversee its safety program. After considering several options, we decided that the best model would be to use the services of an outsourced safety specialist. In early 2018 we engaged Tim Matthews, with Risk Solution Partners, to serve as our safety coordinator. Tim brings an extensive depth of safety experience along with training credentials that allow him to provide the bulk of our safety training.

CFHT has a designated Safety Committee with members representing all departments across the observatory to address safety concerns or issues. The Committee meets at least monthly. Additionally, health, safety and environmental surveys are conducted at company facilities as well as ongoing reviews of programs and processes.

During 2018, we experienced one OSHA recordable injury. An employee suffered a repetitive motion injury; however, there was no lost time. The employee was limited to light duty work for three days before resuming normal duties. This accident, along with any near miss or non-recordable incidents, are addressed promptly to identify opportunities for improvement in our operating processes or training.

	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009
Injuries	1	0	0	2	2	0	0	1	0	0
Lost work days	0	0	0	0	10.5	0	0	1	0	0

Table 3 – A decade of top-level statistics pertaining to safety are listed above.

Arrivals and Departures

During 2018 we bid farewell to three of our staff ‘ohana who have chosen to move on to their next adventures in life. In their places, we have welcomed one new member and promoted one of our long-standing staff members. Two of our permanent positions were vacant as of year-end and are actively being recruited. We wish to pay tribute and extend our best wishes to those who have moved on and provide a warm welcome to our new staff members.

Farewell

Steve Bauman

Steve was our Operations Manager from November 2008 to August 2018. He and his wife, with their two young daughters, felt that now was the right time to return to the mainland to be closer to family. During his time here, Steve oversaw many operational improvement projects to increase efficiency and reduce costs. Most notable of those would be installation of the dome vents which was delivered on time and on budget with no observing downtime. We are excited to report that we promoted an employee from within the organization, Ivan Look, to assume the Operations Manager role vacated by Steve.

Jennifer Kibler

Jennifer joined us in late 2016 as an Administrative Support Specialist, responsible for accounts payable, travel and all front office duties. Though Jennifer was with us for less than two years, she was instrumental in helping streamline many of our administrative support procedures. Jennifer and her husband returned to the mainland to pursue opportunities in a family owned business.

Mercedes Stevens

After nearly 40 years with CFHT as the Executive Assistant to the Director, Mercedes began a well-deserved retirement in December 2018. As one of the last remaining employees who was here at the time the observatory began operations, she was the go to resource for any and all historic information in the company. We will miss her deep institutional knowledge. However, being the organized individual she is, Mercedes has left an easy to follow road map to keep the current Executive on course. We wish Mercedes all the best as she begins her next adventures in retirement.

Welcome

Patti Freeman

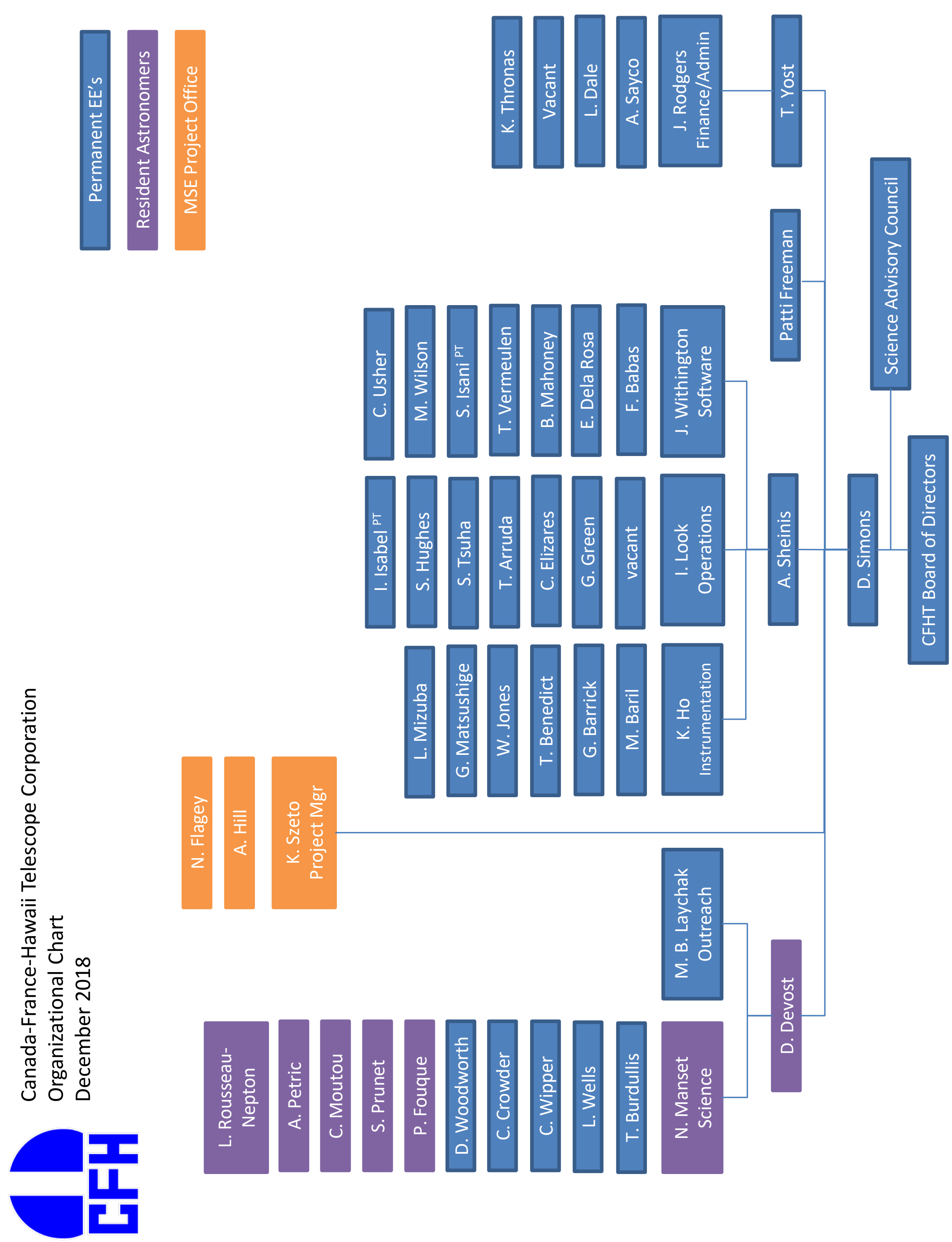
Patti joined the observatory last November as the new Executive Assistant, replacing Mercedes. Patti has an extensive background in administrative support functions with over 12 years of direct executive and board level support experience. Prior to joining us, she served as the Executive Assistant to the Chancellor of Hawaiʻi Community College. Patti joined just in the nick of time to coordinate our annual Board Meeting and passed that trial by fire with flying colors.

Promotion

Ivan Look

Ivan has been with the company since January 2001 as our Mechanical Engineer in the Operations Group. Upon Steve Bauman's departure, Ivan filled the Operations Manager role on an interim basis during recruitment for the replacement. Ivan was the strongest candidate for the position and we are pleased to report he assumed the Manager role on a permanent basis in November. With his extensive background of our operations, infrastructure and relationships, Ivan has quickly and effectively stepped into his new role.

Organization Chart



Staff List at the End of 2018

Name	Position	Name	Position
Arruda, Tyson	Mechanical Technician	**Mahoney, Billy**	Database Specialist
Babas, Ferdinand	System Administrator	**Manset, Nadine**	QSO Manager/Resident Astronomer
Baril, Marc	Instrument Engineer	**Matsushige, Grant**	Sr. Instrument Specialist
Barrick, Gregory	Optical Engineer	**Mizuba, Les**	Instrument Specialist
Benedict, Tom	Instrument Specialist	**Moutou, Claire**	Resident Astronomer
Burdullis, Todd	QSO Operations Specialist	**Petric, Andreea**	Resident Astronomer
Crowder, Callie	Remote Observer	**Prunet, Simon**	Resident Astronomer
Dale, Laurie	Administrative Specialist	**Rodgers, Jane**	Finance Manager
Dela Rosa, Eric	System Administrator	**Rousseau-Nepton, Laurie**	Resident Astronomer
Devost, Daniel	Director of Science Operations	**Sayco, Arturo**	Accountant
Elizares, Casey	Summit Operations Manager	**Sheinis, Andy**	Director of Engineering
Flagey, Nicolas	MSE Systems Scientist	**Szeto, Kei**	MSE Project Engineer
Fouque, Pascal	Resident Astronomer	**Simons, Doug**	Executive Director
Freeman, Patti	Assistant to the Exec Director	**Thronas, Kahea**	Vehicle/Facility Maint. Specialist
Green, Greg	Mech Designer/Instr. Maker	**Tsuha, Seizan**	Mechanical Technician
Hill, Alexis	MSE Project Engineer	**Usher, Christopher**	Software Programmer
Ho, Kevin	Instrument Manager	**Vermeulen, Tom**	System Programmer
Hughes, Steve	Electrician	**Wells, Lisa**	Remote Observer
Isabel, Ilima	Custodian	**Wilson, Matt**	Computer Software Eng.
Isani, Sidik	Software Engineer	**Wipper, Cameron**	Remote Observer
Jones, Windell	Instrument Engineer	**Withington, Kanoa**	Software Manager
Laychak, Mary Beth	Outreach Program Manager	**Woodworth, David**	Remote Observer
Look, Ivan	Operations Mgr/Mech. Eng	**Yost, Tracy**	Director of Finance and Admin.

Outreach Report

Outreach in Canada

CFHT continued writing a column in the bi-monthly Royal Canadian Astronomical Society's journal, entitled "CFHT Chronicles." The CFHT Chronicles debuted in the June 2015 edition. The column focuses on all aspects of CFHT instrumentation, staff and science. Our strategy with the column is to make the work of CFHT relatable to the predominately amateur astronomy community readership and cultivate a sense of connection with CFHT. We have received nice feedback from RASC members who enjoy reading the column. In 2019, the columns will highlight scientific contributions from CFHT's 40-year history combined with current work.

CFHT participated in various celebrations of the RASC's 150th Birthday Celebration. We submitted a video filmed by Canadian staff members, which appeared as part of their birthday event in early 2018. We also reached out to the Canadian Mint and received one of the official RASC coins to incorporate into our social media campaign supporting the RASC.

CFHT continued to partner with Discover the Universe on our 4th annual teacher's workshop at the June CASCA meeting. The workshop was free of cost to participants and focused on hands-on activities they can use in their classrooms. We hosted two workshops in Victoria, one for elementary and one for secondary teachers, including authentic First Nations content. Staff attending the CASCA meeting also visited a few local schools while in Victoria.

Canadian Resident Astronomer Laurie Rousseau-Nepton filmed an episode of the "Sans Reserve" show for APTN (Aboriginal Peoples Television Network) focusing on her First Nations background and science. That interview lead to a Radio-Canada interview on a similar topic in May, inclusion in the Montreal Science Center's Women in Science Day and an invited speaker position in the Women in Physics conference in July.

In 2019, we plan a similar outreach strategy, combining CASCA and the User's Meeting for opportunities for outreach in Eastern Canada. We are aiming to set up talks in Montreal, visits to First Nations' Reservations and other potential collaborations. We will continue to work with Discover the Universe on Teacher Workshops and continue to work with the Friends of the DAO to support initiatives in Victoria.

Outreach in France

In summer 2017, CFHT worked with Helene Courtois and Brent Tully on a documentary called "Cosmic Flows". The film follows their work on the Laniakea supercluster. They filmed at the summit and CFHT's Waimea Headquarters. The film crew plans to air the film in France on primetime TV and possibly in the US, hopefully in winter 2018/2019.

We hosted another French film crew this year. They interviewed staff, particularly Nicolas Flagley from the MSE project office. The date of that production's release is still tbd.

In 2019, we plan to highlight CFHT's 40th Anniversary in France with sessions at SF2A and the debut of both of the film productions above.

Outreach in Hawai‘i

CFHT participated in the usual assortment of community events, school visits, portable planetarium shows and summit tours. At each community event, our booth featured hands on activities designed to explain who we are and what we do. Our displays were visited by ~7000 people over the course of the year, similar numbers to last year.

As part of CFHT's effort to reach local school students, we have several projects in the works with Big Island and Hawai‘i schools. We have partnered with Honoka'a Intermediate and High School. Currently, Mary Beth Laychak serves on the School and Community Council for two local schools and offers support to the new STEM building built at Waimea Middle School. She also served on the North Hawaii School Advisory Council for facility upgrades statewide. These connections give CFHT a prominent role in the local educational community.

Matt Wilson teaches a weekly afterschool programming class at Waimea Elementary School each spring. The lessons developed by Matt and his collaborators teach the students to program in Python using MineCraft. Matt works with the IT lead for WES to run the program. In 2019, we are looking to develop a teacher training workshop and curriculum based around the program so teachers across the Big Island and hopefully the state have access to Matt's lessons.

2018 continued the expansion of the North Hawaii Journey Through the Universe. We partnered with Honoka‘a Elementary, Intermediate and High School, Waimea Elementary School and Paauilo to visit with over 1800 students during Journey week. Staff from the Keck Observatory and UH's Institute for Astronomy joined our efforts. Between Journey Through the Universe and other classroom visits, CFHT staff directly interacted with over 3500 students, K-12. Our primary focus remains on North Hawai‘i schools, but we are working with teachers across the island.

For the 2018-2019 school year, Maunakea Scholars dramatically expanded. We now work with twelve schools, reaching schools on every major Hawaiian Island, the first fully statewide astronomy outreach program. We have twelve mentors, primarily graduate students from the University of Hawai‘i's Institute for Astronomy. Imiloa garnered funding to provide cultural and Polynesian wayfinding presentations to the students and communities in all of our participating schools. All of the Maunakea Observatories contributed time to the MKS program.

MKS received two grants this year - a $50,000 grant from the Hawaii Community Foundation and a two-year, $50,000 grant from First Hawaiian Bank. The HCF grant establishes an online astronomy class in partnership with UH Manoa for students at our participating Big Island MKS schools. The course will be held in Spring 2019 and Summer 2019. The First Hawaiian Bank funding will cover the travel expenses of bringing students from across the state to tour Maunakea.

CFHT sponsored three major community events this year: Manufacturing Day on October 5th, the Waimea Solar System Walk held on October 27th and the Winter Star Party on December 1st. Manufacturing Day blossomed from last year's inaugural event to include over 320 participants from schools across Hawai‘i Island. We received a $1500 sponsorship from SolidWorks to cover busing for students in Kona and Hilo. The event was held in conjunction with National Manufacturing Day. We invited local school students and the general public to tour our facility. Greg Green set up machining, spectroscopy, weather sensing, 3D printing and design demonstrations. The event received coverage on state wide news broadcasts.

The Solar System Walk was organized in conjunction with Keck Observatory and IfA Hilo and focused on the contributions the Maunakea Observatories have made towards our understanding of the solar system. Roughly 500 people participated in the walk, which received coverage on the state television news broadcasts and in Big Island newspapers.

Eight of the Maunakea Observatories, ʻImiloa and University of Hawaiʻi continued the Kamaʻaina Observatory Experience summit tours. In August, the tours were expanded to reach 48 people per month with tours of two observatories a month complete with lunch at HP, environmental and cultural briefings. A Visitor Information Station and ʻImiloa staff member with observatory personnel at the summit guides each tour. CFHT plays an active role in the organization and coordination of the tours. The program is very successful. The reservations fill quickly each month and the post visit reviews are stellar.

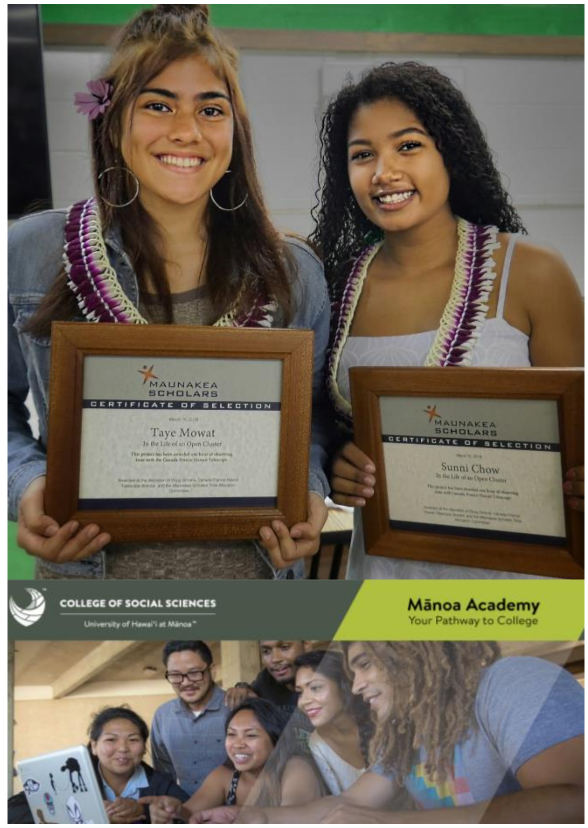


Figure 27 – Top - The Maunakea Scholars program came to Molokaʻi High School for the first time. Bottom – The program launched a new partnership with UH creating a dual credit on-line astronomy classroom program for students on Hawaiʻi Island at MK Scholar host schools.

AstroDay Hilo is a Big Island event occurring every May for the past 16 years. This year the Maunakea Observatories expanded the event to West Hawaii for the first time on October 6th. We estimate 2000 people attended. Astro Day West received statewide coverage on television and Big Island newspapers.

We offer a variety of unpaid internships and volunteer opportunities to local high school students. The students are all interested in astronomy or engineering and find mentor support from the CFHT staff.

Social Media

The CFHT FaceBook page grew from ~2100 followers last year to 2,777 as of this report. Posts are made daily Monday-Friday and focus on good news coming out of CFHT with emphasis on the staff, science, instrumentation and outreach. The CFHT cloud cams and webcams prove popular and are often reposted or used by media to show snow in Hawaiʻi. The lava cam installed to view the 2018 eruption was quite popular.

CFHT continues to maintain a Twitter presence. The content is more astronomy focused since many of our PIs are on Twitter, but we are often reTweeted by the Hawaiʻi State Department of Education. Our followers have increased from 610 in 2017 to 988 followers today. We are likely going to add an Instagram account in 2019.

Media Presence

'Oumuamua continued to generate considerable attention in 2018. The team led by Karen Meech at UH had a second Nature paper on the object in June. CFHT was mentioned in the corresponding news articles.

Astronomy received a public boost with the publication of a featured article in "Hana Hou" magazine, the inflight magazine of Hawaiian Airlines. The article was a behind the scenes look at the technical side of astronomy focusing on engineers and the daycrews of CFHT, Keck and Subaru. The article remained on Hawaiian planes for two months.

CFHT contributes a monthly column for the North Hawaii News called "Across the Universe". The North Hawaii News was integrated into the West Hawaii Today, which has a readership of 18,000 people. The column primarily focuses on news and discoveries from CFHT, but occasionally other astronomy stories are covered. For example, we worked with the Office of Maunakea Management and Maunakea Support Services to write a column on snow safety on the summit.

SPIRou's arrival in January was featured on the statewide local news stations with a more in depth look at the instrument appearing in the Hawaii Tribune Herald and a video segment on Big Island Video News. Laurie Rousseau-Nepton appeared alongside Jessica Dempsey from the East Asian Observatory discussing women in science on the Hawaii News Now morning show in celebration of International Women's Day. They, along with several other staff from across the observatories, were featured in a story in the Hawaii Tribune Herald for the same event.

CFHT and MSE are featured on the SolidWorks website, cover of SolidWorks 2019 and are the subject of a ~6 minute long video by the company. Greg Green attended the SolidWorks 2019 launch and was interviewed extensively for all of the SolidWorks materials. The video should be finalized by the time of the board meeting.

Figure 28 – A feature story about the Maunakea Observatories in Hawaiian Airlines Hana Hou magazine was among the big achievements of 2018's outreach efforts. This high-impact full-length article was unprecedented in one of the most sought after publications in Hawai'i.

2018 Publications Including CFHT Data

This year 88 facility papers were published along with 69 archival papers and 63 papers based on CFHT cataloged data. In total for the year that amounts to 219 unique papers published. This tops the 217 papers published in 2017 and represents another record "harvest" of science publications. Year after year, thanks to our research community, funding agencies, and instrument developers working in concert with CFHT's staff, CFHT has some of the highest science impact in astronomy.

Facility papers (88)

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Alencar, S. H. P.; Bouvier, J.; Donati, J. -F., et al. 2018, Inner disk structure of the classical T Tauri star LkCa 15, A&A, 620, A195.

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van der Burg, Remco F. J.; McGee, Sean; Aussel, Hervé, et al. 2018, The stellar mass function of galaxies in Planck-selected clusters at $0.5 < z < 0.7$: new constraints on the timescale and location of satellite quenching, A&A, 618, A140.

Schreiber, C.; Glazebrook, K.; Nanayakkara, T., et al. 2018, Near infrared spectroscopy and star-formation histories of $3 \leq z \leq 4$ quiescent galaxies, A&A, 618, A85.

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