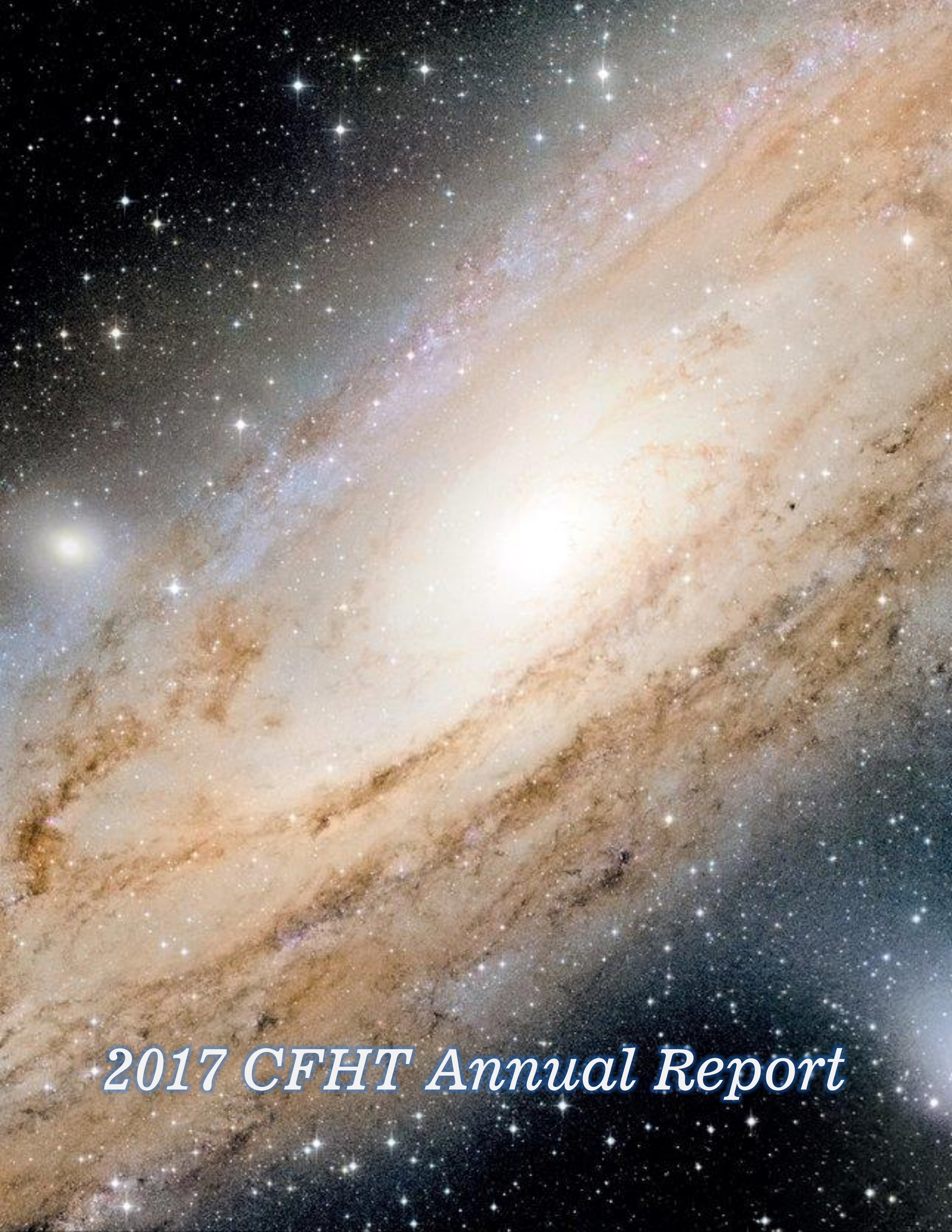

2017 CFHT Annual Report

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Front and back covers: The iconic Andromeda galaxy (M31) as imaged by CFHT's MegaCam is shown. The subject of vast amounts of research as the nearest galaxy that is similar to our own Milky Way, M31's enormous size across the sky is beautifully captured by MegaCam's field of view. On the back is a CAD rendering of the planned upgrade to CFHT – the Maunakea Spectroscopic Explorer. This incredible machine will enable unprecedented spectroscopic surveys of millions of galaxies or, in the case of M31, vast numbers of its stars.

Director's Message


Figure 1 – A very proud team poses for a group shot after a spectacularly successful summer engineering shutdown at CFHT in which the primary was recoated, ready to reflect ancient photons as we seek answers to ancient questions. The torch was passed from Derrick Salmon to Andy Sheinis in 2017, both pictured front/center of the team they lead.

Once a month we hold a "talk story" session in our Waimea office and on the summit at CFHT's facilities. I term these events "unscripted reality". No agenda is needed as staff members bring topics to discuss that are of broad interest or concern. It's a great way to level the playing field, from a communications standpoint. Topics range from safety program concerns to the use of CFHT vehicles to Hawaii astro-politics. Often a bottle of wine circulates with the discussion topics around the room. The beauty of these conversations isn't so much the content, as the fact that they happen at all. They help us feel like we're part of something bigger than ourselves – part of an 'ohana. By letting the conversation create its own path, we share an unconscious faith in our collective destination. Despite our differences of opinion, we are propelled in a common direction by our spirit and pride to be in the company of each other, driving one of the most powerful telescopes in history in whatever direction discovery takes us.

At the end of these sessions, we peel away from the conference table, often still hotly debating the topics raised, inspired to move on by the smell of food and beer in the staff lounge as we celebrate pau hana (end of work). More often than not I report to the staff during these talk story sessions about what I've been up to since the last talk story session – recounting community engagement, Maunakea Observatory issues, local politics, TMT news, etc. By the time I complete my "report" to the staff, a recurring thought is how it would be utterly impossible for me to pursue so much community engagement and outreach if I didn't have a staff that, to be blunt, knows what they're doing and don't need me for day-to-day decision making. These days about half of my time is spent involved in some form of community engagement, be it outreach, education, discussions with legislators and the County Mayor, business leaders, civic clubs, UH leadership, students in our Maunakea Scholars program, etc. The amount of time I invest in building these relationships is a bit unusual for an observatory director, but given the Maunakea conflict and uncertainties about the future of Hawaii astronomy, I have no doubt that it is time well spent. With a degree from UH, a wife of Chinese ancestry born and raised in Honolulu, 3 "hapa" kids educated in Hilo schools, driving a beat out truck with scars from countless hunts on Maunakea, and having lived 30+ years in Hawaii, I am probably the closest thing to a "local" that has ever piloted observatories on Maunakea. For all of these reasons and more, my sense is I landed at the right observatory at the right time. I remain upbeat about the future of Hawaii astronomy, fully cognizant of the challenges ahead. I am upbeat because I can connect what I know is occurring on Maunakea's summit with my community, who cherish Maunakea in its entirety. Deepening that connection for everyone, with a particular emphasis on the younger generation that will take my place someday, is the key to the future of Hawaii astronomy.

As time marches on I find myself pausing occasionally to capture events, sights, and sentiments that I know I'll value for the rest of my days. Among them is the time I spent with CFHT's Director of Engineering – Derrick Salmon. He retired in 2017 and the sight of long time staff member Moani Akana, with all of her incredible struggles, dancing hula at Derrick's farewell party at our Waimea office, is one that will stick with me for a very long time. Derrick's tenure with CFHT spans all the way back to telescope commissioning and when you think about all the contributions he made to CFHT over the past ~40 years, he may be the most important single person in CFHT's history. In the back of this Annual Report you'll find the titles to over 200 papers published in 2017 based upon CFHT data – a record single year "harvest" of discoveries. Not bad for a 40 year old 3.6 m telescope. Mahalo nui Derrick – you should be beaming with pride for all you achieved at CFHT.

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'Blown away by their creativity'

Maunakea Scholars program puts massive telescopes in the hands of high school students

By TOM CALLIS
Hawaii Tribune-Herald

Titan, the largest moon that orbits Saturn, was long shrouded in mystery after being discovered in the 17th century.

Following the recent Cassini spacecraft mission, it's now known the moon, which is larger than Mercury, hides lakes and seas made of liquid hydrocarbons under its thick atmosphere, and that its surface temperature is a frigid minus 292 degrees Fahrenheit. On this world, it rains methane, though oceans of liquid water and ammonia are likely present below the surface.

That could make it a challenging place for life to develop, at least as we know it.

On a September evening atop Maunakea, three Honokaa High School students — Anika Wiley, Marie-Claire Ely and Kaitlin Villafuerte — sought to find out by using the NASA Infrared Telescope Facility.

"We had a couple moons in mind and we narrowed it down to Titan mainly because of the atmosphere," said Marie-Claire, 15, a senior. "We're looking for something that can show us evidence there has been life."

Each are active in the school's astronomy club and jumped at the opportunity to use one of the mountain's telescopes through the Maunakea Scholars program.

These students are doing more than shadowing astronomers. They are doing the research and coming up with the ideas themselves, sometimes at PhD levels, said Mary Beth Laychack, outreach manager for the Canada-France-Hawaii Telescope and the students' mentor.

"We're continually blown away by their creativity," she said, noting that some research ideas have to be turned down because they would take years to conduct.

About 315 students, most of whom received school credit, have

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HOLLYN JOHNSON/Tribune-Herald

Honokaa High School students, from left, Kaitlin Villafuerte, Anika Wiley and Marie-Claire Ely observe Titan with the NASA Infrared Telescope Facility.

Figure 2 – Honoka'a High School Maunakea Scholars huddle in front of a computer terminal at the NASA Infrared Telescope Facility on Maunakea. They are looking for biomarkers in Titan's atmosphere, the largest satellite in our solar system. Photo from Hawaii Tribune Herald's "Stars Over Maunakea"

Speaking of beaming with pride – our community's keiki (kids) reached new heights in 2017. CFHT's signature education program, Maunakea Scholars, left students across the State beaming with the pride of knowing their research ideas are worthy of the most powerful telescopes in the world to explore. With ~1/4 of the public high schools in Hawaii currently hosting the Maunakea Scholars program on 4 islands, and further expansion anticipated, 2017 was an incredible year for this program. The Maunakea Scholars are an experiment in 21st century STEM education – a new dimension of the spirit of risk taking and innovation that has driven CFHT's legacy. Behold in the photo above the future of Hawaii astronomy – a generation that grew up on the flanks of Maunakea, and now takes their first bold steps to explore the universe from its summit. The future of Hawaii astronomy is in good hands, as each generation inspires the other in profound ways. Part of the answer to the conflict over Maunakea was always in plain sight. That answer just needed to be given a chance, a voice. Now it has one.

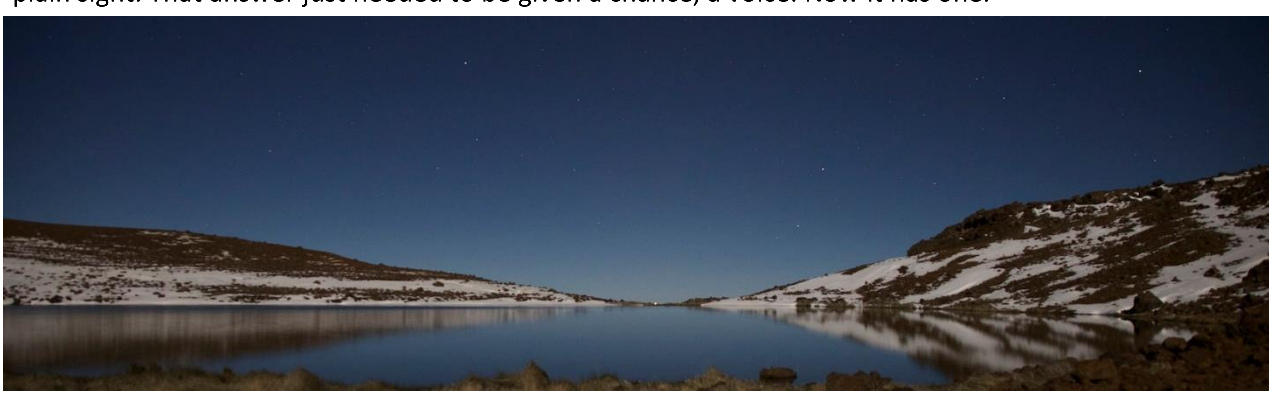


Figure 3 – A nighttime photo of lake Waiau, surrounded by snow, on Maunakea – the highest altitude lake in all of Polynesia, lake Waiau is among the most sacred places in Hawaii. Even after hundreds of trips to the summit, I still find Maunakea's beauty to be stunning and among my cherished memories of a life dedicated to Hawaii astronomy (photo courtesy Billy Mahoney).

Science Report

Hawaii Observatories Track an Interstellar Visitor

A team lead by Karen Meech from the University of Hawaii used CFHT, UKIRT and the W.M. Keck Observatory along with Gemini South and ESO's Very Large Telescope in Chile to observe a unique object discovered by Pan-STARRS1 on Haleakala. The discovery and subsequent detailed observations were published in the journal Nature.

On October 19, 2017, Pan-STARRS1 discovered an unusual object moving fast toward the west. Pan-STARRS1 is a 1.8 meter telescope located on the summit of Haleakala on the island of Maui. With one instrument, the world's largest digital camera with 1.4 Gigapixels, PanSTARRS1 has mapped the majority of the sky at several wavelengths. The telescope is also part of an early warning system designed to detect Near Earth Objects (NEOs) and measure their orbits, sizes, and threat levels to Earth. NEOs discovered by Pan-STARRS1 are often followed up at CFHT to establish more accurate orbits. These observations occurred on October 22nd and allowed the first accurate determination of the eccentricity (e) of its orbit. Rapid follow up observations were essential because the object had already passed its closest point to the sun and was rapidly moving back into interstellar space, getting dimmer each night. Orbital eccentricity measurements determine if an object is gravitationally bound to the sun (objects with e>1 are unbound). Based upon CFHT data the team calculated a value of e=1.188 (highly eccentric) which confirmed the unusual nature of this object. This measurement established that the object is the first asteroid detected that originates from outside the Solar System. It was soon observed by several other observatories, refining the eccentricity measurement and leading to a value of e=1.1956. The team also used CFHT and other observatories to measure the light curve of the object and determined it was dimensionally very oblong, with an aspect ratio of 10:1 and a mean radius of ~100 meters, the size of a football field. It spins very fast with a rotation period of 7.34 hours. Spectroscopy revealed the rocky object has characteristics similar to Kuiper Belt objects, organic-rich comets and Trojan asteroids.

After consultation with ʻImiloa Astronomy Center for guidance on a Hawaiian name, the team officially named the object ʻOumuamua which means scout or messenger sent from the distant past to reach out to us ('ou means "reach out for", and mua with the second mua placing emphasis, means "first, in advance of"). The object's official name is 1I/2017 U1 (ʻOumuamua). Originally denoted A/2017 U1 (with the A for asteroid), the body is the first to be designated by an "I" (for interstellar).

The discovery of ʻOumuamua demonstrates that relics of the formation of other stellar systems can be detected in our Solar System. This may someday enable direct measurement of elemental abundances in other stellar systems and test theories of planet formation that are broadly applicable across our Galaxy.

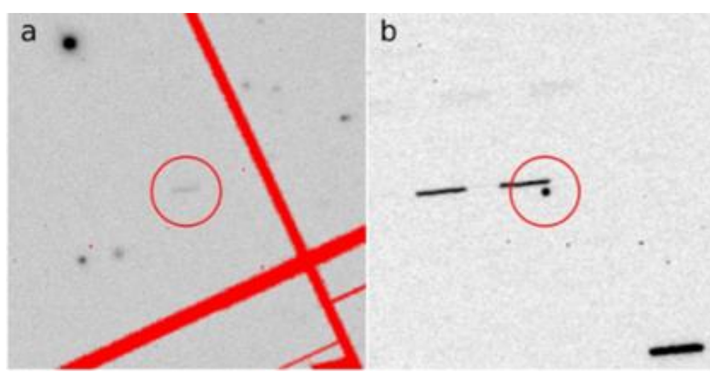


Figure 4 – Left: Pan-STARRS1 discovery image of 'Oumuamua. The red stripes are masked bad pixels. The new discovery is the black line inside the red circle. Right: CFHT recovery image of 'Oumuamua. On this image, the dot is the asteroid and the lines are stars. Non-sidereal tracking was used for this image in order to determine if there was any trace of a cometary tail. Image taken from Meech's Nature paper.

WIRCam and Herschel Observations of Interstellar Dust

A team of astronomers from Canada, the United States, Germany and Chile using WIRCam at CFHT and the Herschel space telescope found that dust models may need some rework. They studied three isolated dust cores in molecular clouds and found that the properties of the cores could not completely account for their observations using state of the art dust modeling. Their paper was accepted for publication in the Astrophysical Journal.

Dust is found everywhere in the universe and has to be accounted for when studying stars and galaxies. For example, dust will alter the light of a star and make it look red or obscure a region of space and make it look starless. However, it is not a trivial matter to account for dust properties. It will absorb light chromatically meaning that the amount of light absorbed varies with color. Also dust emits light and can shine in the infrared or all the way down to submillimeter wavelengths. The amount of emission or absorption of light by dust depends on the grains' physical properties like size, composition, density and geometry. To top it off, dust properties are also influenced by their surroundings. For example, a nearby hot star will raise the temperature of the dust and will also affect its geometry. In short, dust is messy and difficult to model.

However, dust models are needed in the vast majority of astrophysical studies since dust affects almost every astronomical measurement. In a study aimed at assessing the reliability of such models, the team took WIRCam images of dust cores in isolated molecular clouds and determined how much dust in these clouds was blocking light from background stars. They then compared these results with the far-infrared emission seen in the Herschel data by that same dust to see if the emission was consistent with that expected from dust models used in the literature. Though they found consistency between dust models and the observed absorption/emission, they surprisingly could not find a single model that was consistent for all three clouds.

Refining dust models is an important task in astrophysics and the results of this study provide important clues to help improve existing models. In time, this will help astronomers better compensate for the effects of dust in the observations of stars and galaxies across the cosmos.

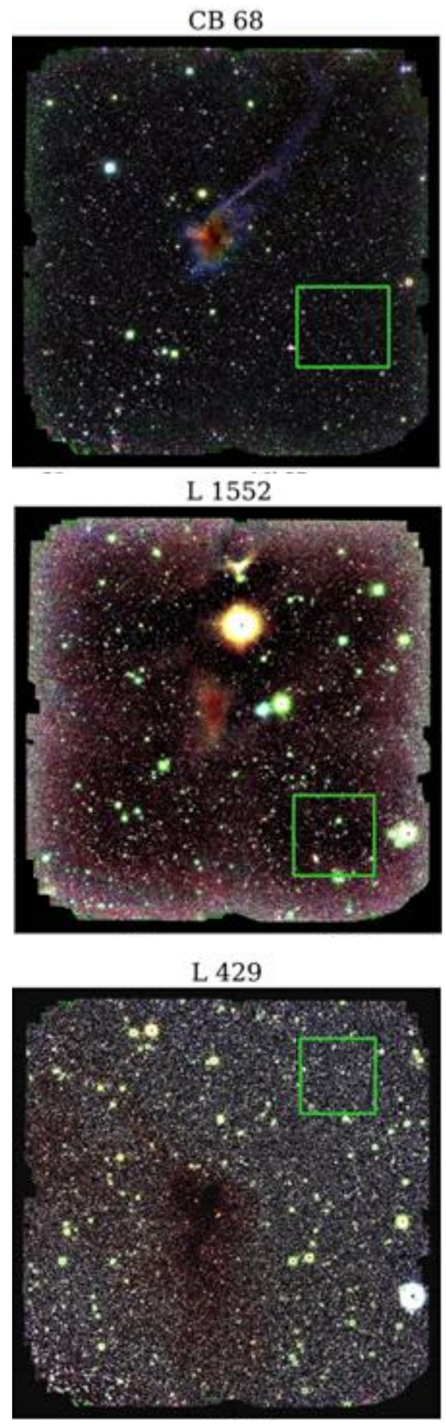


Figure 5 - JHK WIRCam false-color images of the cores of dusty regions. Areas with minimal extinction that were used to calibrate the intrinsic color scatter in the background stars are outlined in green. Image from the paper.

The Little Star That Survived a Supernova

An international team of astronomers led by Stephane Vennes at the Astronomical Institute in the Czech Republic has identified a white dwarf moving faster than the escape velocity of the Milky Way. This high velocity star is thought to be "shrapnel" thrown millions of years ago from the site of an ancient, peculiar Type Ia supernova explosion. The team used telescopes located in Arizona, the Canary Islands and Maunakea – the latter involving GRACES, the high resolution Gemini/CFHT spectrograph. Their research was published in the journal Science.

Progenitors of Type Ia supernovae have always remained elusive but understanding them is essential to obtaining a complete model of these standard candles. A class of Type Ia SN called SN Iax, whose prototype is SN 2002cx, provides hope for such identification. These explosions are subluminous and are expected to leave remnants that could be used to identify the progenitors of Type Ia SN.

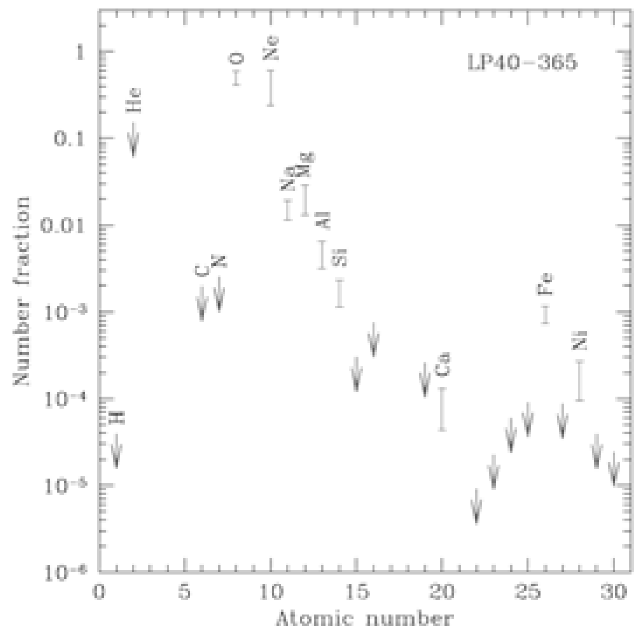


Figure 6 - Elemental abundance of LP 40-365. The atmosphere is dominated by oxygen and neon followed by sodium and magnesium. Iron dominates over nickel and other elements in the iron group by at least a factor 10. Figure from paper.

The team studied the white dwarf star LP40-365 for two-years. The new star was first identified with the Mayall four-meter telescope at Kitt Peak National Observatory in Arizona. A final, crowning data set was obtained with the help of team member Viktor Khalack at the Université de Moncton using GRACES. Analysis of the data showed that the star is compact, has an effective temperature of ~10,000 K and has an atmosphere with an exotic chemical composition. Hydrogen and helium are heavily depleted and oxygen and neon are the most abundant elements. Analysis of the GRACES spectra also revealed an interesting trajectory. The star never encountered the Galactic Center and is on a path out of the Milky Way at a velocity exceeding 540 km/s, characteristic of hypervelocity stars ejected from the Galactic Center

The unique object LP40-365 is the first observational evidence for surviving bound remnants of failed supernovae and therefore is a valuable object to improve our understanding of these cosmological standard candles. Many more of these objects are lurking in the Milky Way and awaiting discovery. The recent ESA/Gaia mission may help us discover many more of these objects and help us understand how a little white dwarf star can survive supernova explosions.

Rocky Planet Engulfment Explains Stellar Odd Couple

A team of astronomers led by Carlos Saffe (Instituto de Ciencias Astronómicas, de la Tierra y el Espacio, Argentina) used GRACES to discover remarkable differences in the abundance of heavier elements, and the lithium content, in a binary star pair. The research team speculates that this difference is caused by the engulfment of rocky planets early in the system's evolution which enriched one of the stars. The work also hints at a formation scenario resulting in gas giant planets forming far from their host stars.

Detecting chemical signatures of planet formation around stars is a difficult challenge for current generation telescopes. Studies estimating the deficiency in refractory elements in solar twins proposed that the missing refractories are probably locked up in terrestrial planets. These methods had some success but studying wide binary systems with similar components that are believed to have formed coevally from a common molecular cloud are ideal laboratories for a direct measurement of planetary chemical enrichment. Their research was published in Astronomy and Astrophysics.

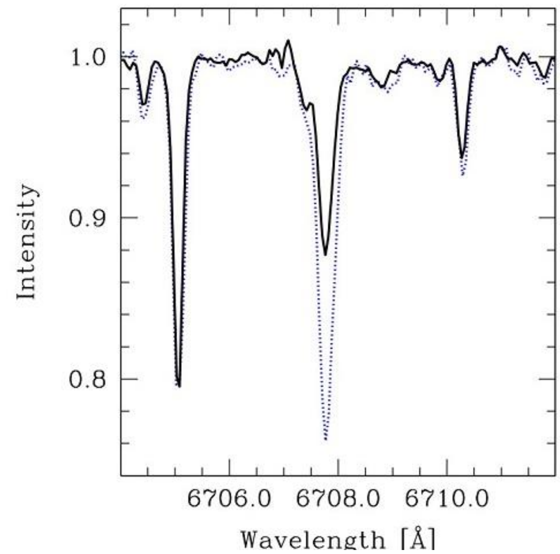


Figure 7 - Stellar spectra near the Li line. Star A (blue dotted) shows a Li abundance higher by about 0.3 dex than star B (black). Figure from paper.

The team observed the peculiar binary system HAT-P-4, which includes a confirmed exoplanet orbiting one of the stars in the pair. They used GRACES and OPERA to measure abundances to a high degree of precision on the two stars. Their analysis revealed that the bulk stellar parameters of each star are remarkably close but that they have markedly different metallicities and lithium abundances.

Stellar parameters derived for each star.

(Star – reference)	T_{eff} [K]	log g [dex]	[Fe/H] [dex]	v_{turb} [km s^{-1}]
(A–Sun)	6036 ± 46	4.33 ± 0.13	0.277 ± 0.007	1.29 ± 0.07
(B–Sun)	6037 ± 37	4.38 ± 0.14	0.175 ± 0.006	1.21 ± 0.07
(B–A)	6035 ± 36	4.39 ± 0.10	-0.105 ± 0.006	1.22 ± 0.06

Table 1 - Stellar parameters derived for each star. While the effective temperature, surface gravity and turbulence of both stars are fairly similar and within each other's error bars, a metallicity difference of 0.1 dex is measured between them that is well outside the error bars. Table from paper.

Since both stars are thought to have formed with the same chemical composition, the difference in metallicity points toward a history of rocky planets being engulfed by the high metallicity star. However, the lithium abundance tells another story. The same star that displays a higher lithium abundance, HAT-P-4-A, also hosts a gas giant planet orbiting at only 0.04 AU from the star. This is another unexpected feature in this type of binary system. The authors use the data collected with GRACES to exclude other possible explanations, such as a peculiar composition of the stars or different rotational velocities. They concluded that HAT-P-4-A formed the known gas giant planet while rocky (refractory) material accreted closer to the star, possibly due to migration of the gas giant. They estimate that at least 10 Earth masses are locked up in refractory material to be consistent with the observations.

Capturing What Lies in the Space Between Galaxies

The mysterious web of material that connects and spans galaxies across the universe came into better focus through research in part conducted at CFHT. A group of researchers at the University of Waterloo generated a remarkable “image” of dark matter spanning galaxies though weak lensing measurements in the same line-of-sight. While dark matter comprises about ¼ of the matter/energy budget in the universe, its fundamental form remains a mystery and the subject of intense research in both astronomy and high-energy physics. While attempts to create dark matter at facilities like LHC are underway, research at CFHT helps to characterize this substance which could be anything from WIMPS to black holes generated soon after the Big Bang. Research conducted by the Waterloo team further confirms that the anatomy of dark matter on cosmic scales is in the form of an enormous 3D web, the intersections of which correspond to galaxy clusters. University of Waterloo professor Mike Hudson notes that "This image moved us beyond predictions to something we can see and measure".

The weak lensing technique used by Hudson's team has been perfected in recent years and benefits from the exquisite image quality at CFHT, perched atop what is arguably the best astronomy site in the world. Lensing is manifest in a variety of observations in modern astronomy and can be used to map intergalactic dark matter or detect planets within our Galaxy. To support this discovery the Waterloo team used images of more than 23,000 background galaxies across a distance of 4.5 billion light-years to map intervening dark matter. They showed that the filamentary structure of dark matter is prevalent on scales of ~40 million light-years – a sort of cosmic "yard stick" for intergalactic structures.

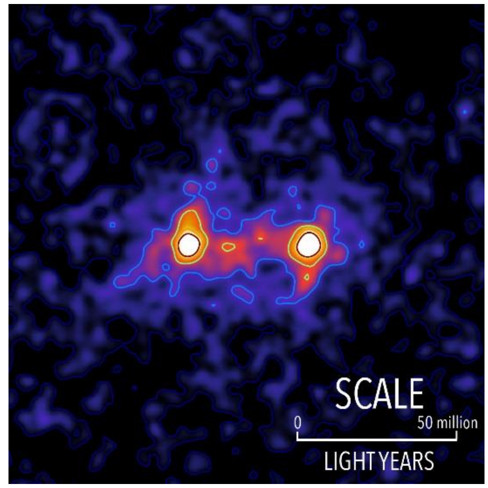


Figure 8 – In this false color image, dark matter appears to be forming a bridge between neighboring galaxies (white areas). Credit: S. Epps & M. Hudson / University of Waterloo.

Astronomers Define the Great Divide Between Stars and Brown Dwarfs

"Not everything that could be a star 'makes it,' and figuring out why this process sometimes fails is just as important as understanding when it succeeds." – says Trent Dupuy of the University of Texas at Austin who, together with the University of Hawaii's Mike Liu published pivotal measurements of brown dwarfs that empirically defined minimum mass requirements for stars better than perhaps any research to date. Stars form from giant molecular clouds with the singular characteristic of having sufficient mass to create core conditions that trigger fusion of hydrogen. At some point, objects with ever lower masses that coalesce in stellar nurseries do not have core pressure and temperature conditions needed to fuse hydrogen and are, in effect, failed stars or brown dwarfs. The make-or-break mass point that distinguishes stars from brown dwarfs has long been theorized to be ~0.08 solar masses, from fairly straightforward physics. Confirming theory with observation has taken decades though, because identifying the precise mass transition requires identifying a range of low mass binary systems that can be well enough characterized to pin down the precise minimum mass needed for core fusion to make a star. That in turn means making orbital measurements of many binary systems, applying Kepler's laws to make mass measurements, and astrometric measurements to determine the center of mass of each system. All of these measurements critically calibrate models of mass, age, and luminosity of low mass (sub)stellar objects, meaning those same models can be used with greater confidence to distinguish between low mass stars and brown dwarfs across the Galaxy.

The Dupuy/Liu team, through a decade of painstaking observations of 31 nearby low mass binary systems using principally Keck (to measure orbits) and CFHT (to measure centers of mass with respect to background stars), concluded that the transition between star and brown dwarf occurs at 70 Jupiter

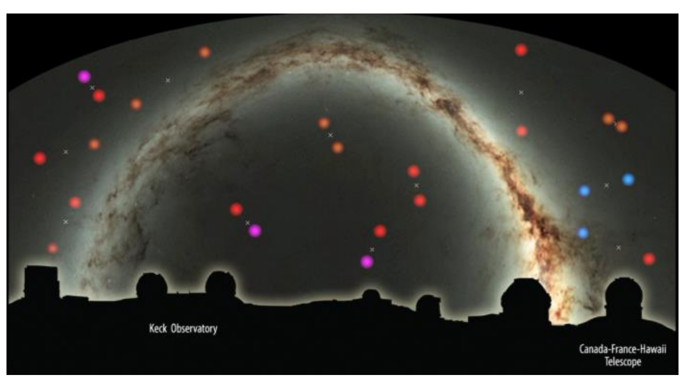


Figure 9 – Positions in the sky of the various binary systems used in this study, superposed on an image of the northern sky by PanSTARRS, are shown. A video showing the revolutions of these objects is also available.

masses, or slightly lower than theory predicted. This is a fundamental property of objects which have collapsed out of molecular clouds – if the mass of an object is below 70 times that of Jupiter, it cannot be a star. As simple as this conclusion may sound, it has been the better part of a century in the making. Because mass and temperature are fundamentally linked, they also concluded that any object cooler than 1600 K is a brown dwarf (or planet). Again, this simple property, now grounded in extensive measurements from Maunakea, can be used to discriminate between stars and brown dwarfs anywhere in the Galaxy. Liu rightfully points out that "These measurements will be fundamental to understanding both brown dwarfs and stars for a very long time."

Blue Binaries Tell an Ancient Story


Figure 10 – Through queued simultaneous observations at CFHT and Gemini-N, accurate colors of Kuiper Belt binaries were made. These measurements revealed an odd subpopulation of "blue binaries" that shed light on the dynamical conditions of our solar system billions of years ago. Photo courtesy Gemini/AURA, by Joy Pollard.

For the past several years one of the most successful Large Programs at CFHT has been OSSOS or the Outer Solar Systems Origins Survey. Through nearly 600 hours of MegaCam observing time, OSSOS provided comprehensive observations of the Kuiper Belt since the discovery of this dynamically important part of our solar system several decades ago by observations at the University of Hawaii 2.2 m telescope. OSSOS found nearly 1000 Trans Neptunian Objects (TNOs) lurking near or beyond Neptune's orbit – a huge trove of objects from which the dynamics, composition, and history of the outer solar system can be studied. Some important properties of the Kuiper belt were revealed including a dynamically "hot" part with highly inclined and eccentric orbits, out of the ecliptic, and a dynamically "cooler" part which typically consists of redder colored objects.

An adjunct of the OSSOS survey was the Col-OSSOS survey (Colors of Ossos), which exploited the ability of queued observations at CFHT and Gemini to make simultaneous observations of many of the binaries in dynamically cold regions of the Kuiper Belt. These objects rotate fast enough that it would be impossible to accurately measure their colors with a single telescope, but with two telescopes observing the same TNOs at the same time, accurate measurements of their intrinsic colors were recorded. Interestingly, five of the dynamically cold binaries were found to have blue colors, unlike their counterparts in this component of the Kuiper Belt. These objects were also found to be widely separated in rather tenuous orbits, making them hard to explain. "Facilitating the simultaneous observations with the Col-OSSOS team and Gemini Observatory was challenging, but paved the way for a greater understanding of the origins of these blue binaries. In tandem, the two facilities observed all the colors of the outer solar system for the Col-OSSOS team" said Todd Burdullis, queued service observing operations specialist at CFHT who was in charge of the CFHT observations and a coauthor of the study. In their Nature paper, the team (led by Wes Fraser of Queen's University in Belfast) explained various possible mechanisms for this anomaly in the outer solar system and concluded the best interpretation is that these binaries were gently pushed into the outer solar system billions of years ago through slow migration. That in turn means the outer planets, which define the Kuiper Belt through their domination of the gravitational potential of the outer regions of the outer solar system, had to migrate slowly as well.

Engineering Report

Primary Mirror Recoating Shutdown August 2017

The primary mirror was successfully removed and recoated in August 2017 and then reintegrated with the primary mirror cell and then telescope. The mirror support system (hoses, clamps, fittings, and support pads) was checked and pressure tested. No issues were found and the primary mirror 24 support puck diaphragms did not require replacement. Both PM vacuum and pressure cosine regulators were disassembled, cleaned, and rebuilt. In parallel, a list of suggested process improvements and upgrades were made. The process and results of the shutdown were fully documented.

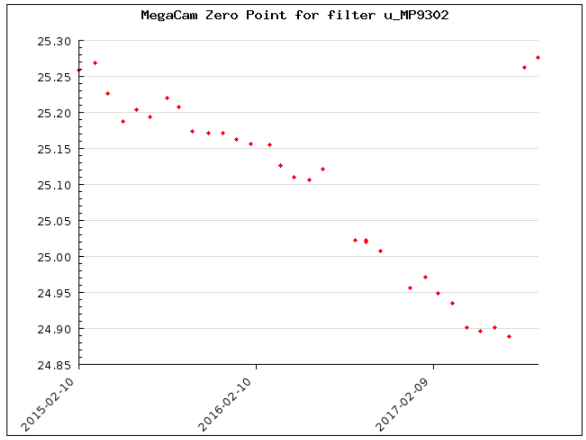


Figure 11 – Top: MegaCam zero point measurements over time, clearly demonstrating the return to full optical throughput for the telescope after recoating. Bottom: A happy staff after a successful engineering shutdown.

This recoating shutdown was the shortest shutdown in CFHT history to date at 6 days which beat the previous 2014 shutdown by one day, and past shutdowns (10-11 day average) substantially. At 6 days we have probably reached the minimum duration engineering shutdown for recoating the primary mirror. The procedures executed were at a high level of detail while many past issues were addressed and no longer hinder the process. Moreover, the crew is the real hero of the shutdown process and their dedication, ability to overcome any obstacle thrown at them, and work ethic during the event was exceptional.

SPIRou Development and Performance

A flurry of activity in Toulouse culminated in successful pre-ship acceptance tests conducted in late 2017 and shipment of the instrument to Hawaii soon thereafter, marking an enormous milestone for this exciting instrument. SPIRou stands to revolutionize exoplanet research by probing at near-infrared wavelengths for the existence of terrestrial class planets around nearby low mass stars – by far the most abundant stars in the universe. SPIRou will be the first instrument to use a 1-2.5 µm science grade H4RG in astronomy. The focal plane assembly which houses SPIRou's H4RG was completed by the SPIRou team at the University of Montreal, as well as tests need to make the selection of the H4RG detector for SPIRou among those provided by

Teledyne. The overall noise performance and cosmetics of the SPIRou H4RG detector are outstanding, and should lead to clean spectral extraction from the echellogram projected onto this detector. The use of a cryogenic ASIC array controller and sophisticated temperature control of the detector assembly together help ensure optimal overall instrument performance.

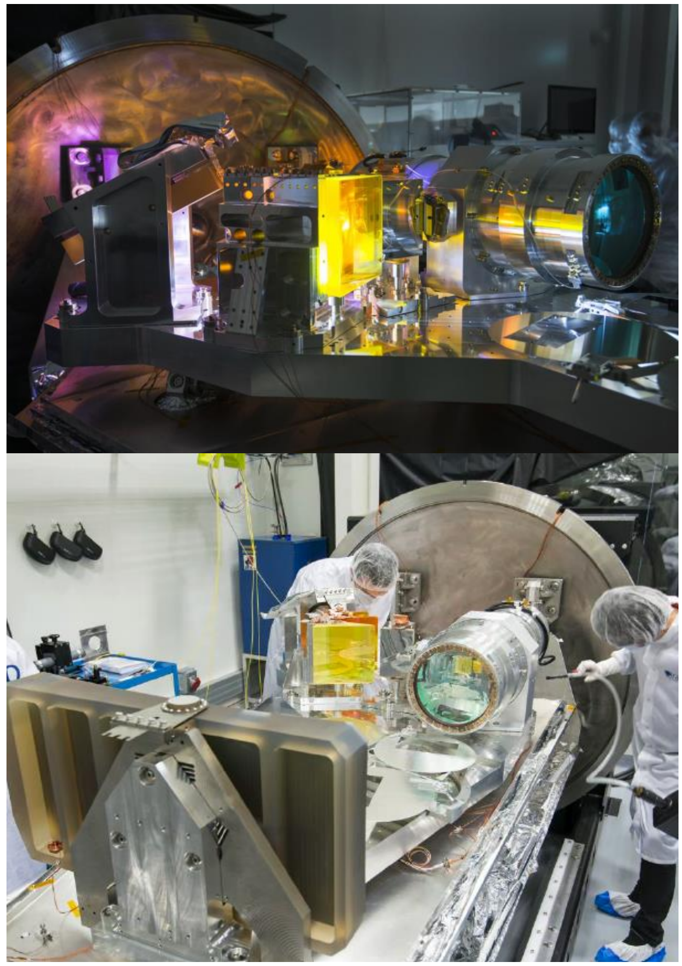


Figure 12 – The opto-mechanical bench of SPIRou's spectrometer is shown prior to being sealed, pumped, and cooled.

Image quality was evaluated using a H2RG in Toulouse on loan from the SPIRou partners at the University of Montreal and demonstrated excellent focus and overall instrument line shape from SPIRou's spectrometer. Excellent bench temperature stability was also demonstrated during cold tests, easily meeting the required <2 mK rms variations over 24 hr periods. Since even minute temperature variations can lead to changes in the spectrometer optical layout that impact the ambitious 1 m/s velocity sensitivity of SPIRou, extreme temperature stability is absolutely essential. Lab tests indicated the instrument should meet its overall 1 m/s velocity sensitivity target once the H4RG is installed in Hawaii due to greater line sampling (complete echellogram coverage) and higher spectral resolution (smaller pixels in the H4RG) compared to H2RG based tests. Polarization cross-talk between SPIRou's channels showed significant cross-talk (5-10%) which was traced to the feed optics in the Cassegrain unit. New optics were therefore ordered which will be installed after the instrument is delivered to Hawaii.

At the end of an extremely busy 2017 integrating SPIRou in the lab, the international team responsible for its design and ultimately the core of its science legacy ended the year on a high note, with the instrument packed into 13 large crates and shipped to Maunakea, its new home for many years in the future. We look forward to commissioning SPIRou and early science results in 2018.

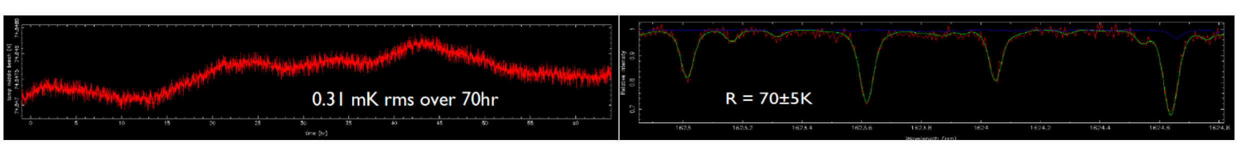


Figure 13 – Important tests conducted on SPIRou in the lab include (left) temperature stability of its spectrometer over time and (right) a spectrum of the sun demonstrating it is meeting its spectral resolution requirement.

SITELLE Status

Overall 2017 was another good year for the world's only optical imaging FTS in use at a major ground based observatory. Previous problems with intermittent loss of Modulation Efficiency (ME) were not seen in latter observing runs, including high declination targets where this problem was most prevalent. This was in part due to a new algorithm for measuring ME which allowed it to be sampled at the start position of each scan. Other improvements made to SITELLE in 2017 include -

- A broader-band UV source was installed to allow a correct phase map to be obtained for the SN1 filter. The original UV diode proved to have a narrower emission band than anticipated.
- A new filter wheel mount was machined to allow the filter wheel to be moved an additional 6 cm away from the telescope focal plane. This was done to improve the quality of the flats and other calibration images which showed in-focus features from dust on the filters. This change has been in place since the September run.
- A spare calibration green HeNe laser was purchased as a precaution following intermittent behavior of the original laser during the June 2017 run. This intermittency only appeared during engineering testing and had no impact on observations.

The bulk of the engineering troubleshooting for SITELLE in 2017 was invested in resolving the reduced image quality in the periphery of both of its cameras' fields of view. Reduction of deep, through-focus images taken in November 2016 showed that the image quality at the edge of the fields departs from that expected from Zemax optical modeling. Both cameras are equally affected. In order to debug the blurred images at the edges of the field, the problem was broken up into its base components: 1) telescope; 2) collimator; 3) interferometer; 4) camera(s). For the telescope image quality test, Cassegrain guider cameras were used to measure the image quality through focus across the field. This did not reveal anything out of the norm. In order to test the collimator and camera a Fizeau interferometer was borrowed from Subaru. Tests were conducted both in a warm lab (Waimea) and the cold summit. Those tests demonstrated significant wavefront errors in the field periphery and, to zero order, suggest a link to what is observed when SITELLE is used on the telescope. Efforts at the end of 2017 included continued interferometric testing at the summit in parallel with evaluating possible sources of error within the cameras. This work is being done in consultation with the original designers of the SITELLE optical system and will proceed into 2018. In any case the vast majority of SITELLE's field is unaffected by these aberrations making it possible for a variety of research to be completed.

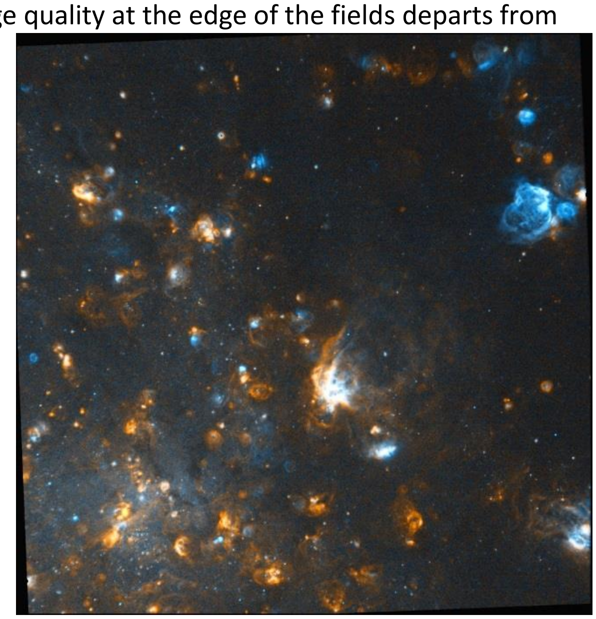


Figure 14 - SITELLE's SN2 filter combined image of the nearby galaxy M33. The center of the galaxy is located near the lower left corner of the image. Red was used for the H-β emission line and blue for the [OIII]5007 emission line. Star forming regions of different metallicities, ages, and masses are easily identified (large red and blue emission line regions). Some planetary nebulae are also scattered in the field (small blue dots of a few pixels radius). Photo credit Philippe Amram.

MegaCam Performance Improvements

Overhead Time Savings

During the 17A and 17B semesters the Instrumentation Group took on the goal to lower the overheads on MegaCam exposures. The faster reading procedures described in previous reports were implemented at the start of the 17A semester, resulting in significant improvements as explained below.

The results of this improvement can be cast in terms of cumulative observing time savings. During 2017 through the August run there were 20364 exposures taken with MegaCam in queue mode. The savings of 4 seconds per integration from reading MegaCam faster during this time in 2017 resulted in a total of 22.6 hours of additional observing time.

In semester 17B the Instrumentation Group continued to improve MegaCam's efficiency by upgrading the hardware responsible for reading CCDs and saving image files. This work included upgrading MegaCam's detector host computer (dethost). The new dethost reduces the time to transfer the MegaCam image to disk during readout by an additional 3 seconds, bringing the total overhead reduction to 7 seconds.

The overhead was further reduced by 1 second per integration by optimizing shutter operations. The shutter PLC control system had a 2 sec wait time to allow the electronics to stabilize before moving the shutter. Tests showed that a delay of only 0.7 sec was required. The delay was set to 1 second to provide some margin. This change was implemented on September 11, 2017 and *brought the overall average overhead savings to about 8 seconds per exposure.*

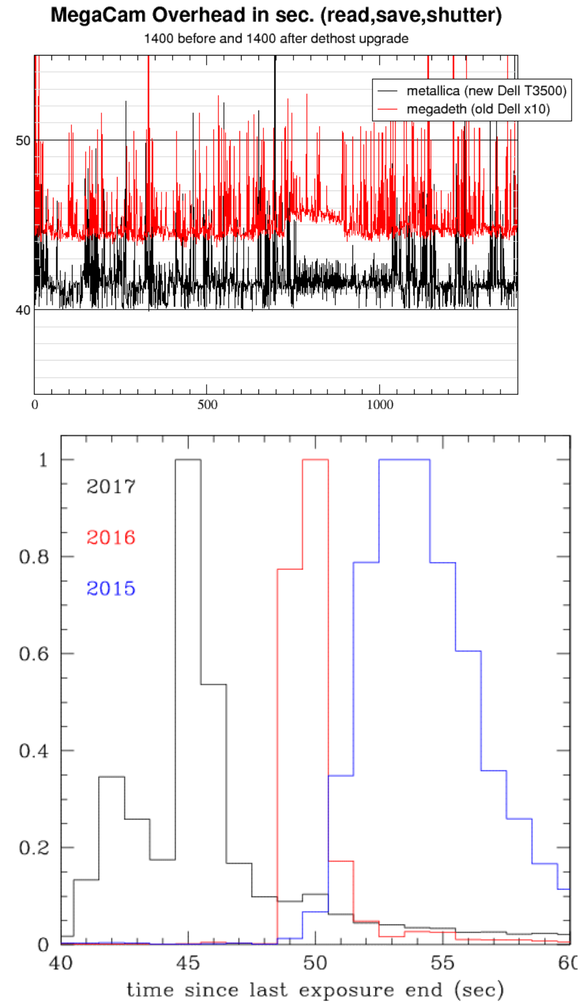


Figure 15 – Top: The x-axis shows the number of exposures tested and the y-axis gives the total overhead time before (red) and after (black) upgrades, including reading, saving and shuttering. Bottom: Histograms (as of Sept 18, 2017) of dead time between all exposures archived at CADC during 2015 (blue), 2016 (red) and 2017 (blue). Figure courtesy S. Gwyn.

These efficiency increases can be seen in Figure 15 (courtesy of Stephen Gwyn). MegaCam data at the CADC archive through September 18, 2017 was used to make this plot. The bimodal distribution in the 2017 data is due to the two phase deployment of (1) a faster readout time and (2) faster data storage, FITS header generation, opening/closing of the shutter, and moving to a new target.

Improved Reliability

The “SLOT OCCUPIED” fault, which happens when the PLC detects a filter in a supposedly empty slot of the jukebox during the filter unloading process, continued to occur despite changes to the jukebox PLC system. The fault has been happening about once a run and costs 20 minutes to recover. We added a slight delay to let the RFID sensor settle before checking the slot, thinking that the problem was due to a race condition in the filter system PLC but the problem persisted. Changing the RFID hardware did not solve the problem either. It seemed to be an intermittent latch-up issue with the RFID sensor when it transitions from a “valid filter” to “no filter” state. Rather than developing a new RFID system, we decided to use a Hall Effect proximity sensor to check the empty slot. The proximity sensor is a more robust solution. It is a simple switch that senses a magnetic perturbation caused by a local conductor - in this case the aluminum filter frame. The sensor is tied directly to an input in an I/O module in the PLC system rather than through a serial communication interface, like the RFID sensor. Off-telescope tests were successful and the change implemented in October 2017.

Spare Readout Boards

A purchase order was placed for the assembly of three more readout boards to supplement the one working spare in the MegaCam inventory, bringing the spares total to four. This amount is needed to drive the two MegaCam controllers and delivery is anticipated in early 2018, leaving MegaCam with a complete set of spare readout boards.

Shutter Timing

A timing system was added to MegaCam on Jun 08, 2017, to record the absolute times when the shutter opens and closes during an exposure. The system is comprised of a Raspberry PI and signal buffer and is synchronized to NTP with an absolute accuracy of 10 msec. The FITS data headers provided to MegaCam users will include the UTC time when the shutter opens and closes for each exposure.

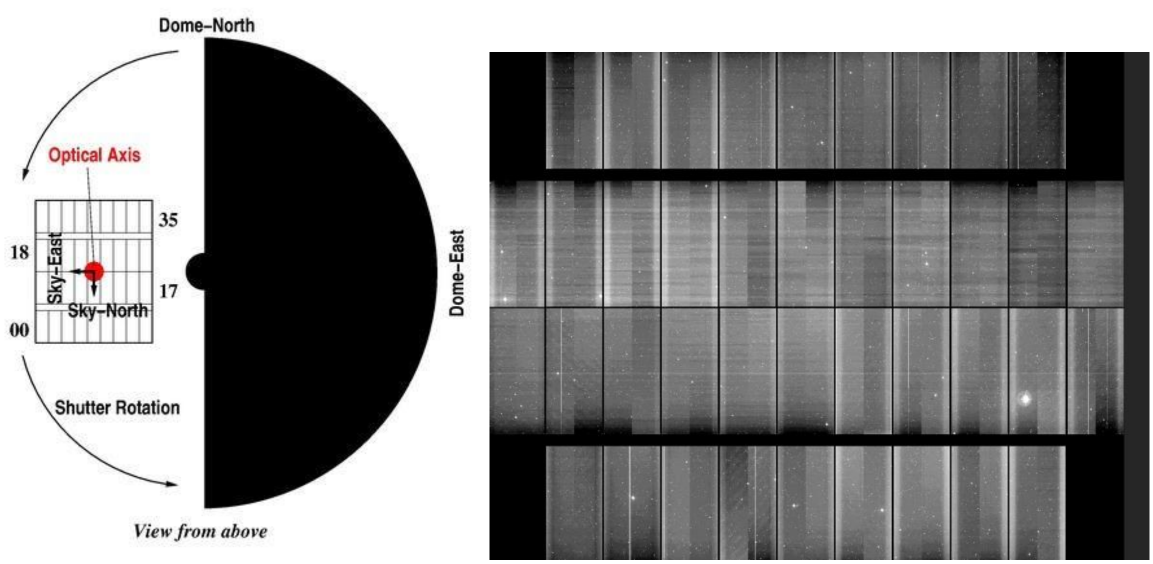


Figure 16 - Left: Schematic of MegaCam shutter. Right: MegaCam Exposure binned by a factor of 24 to illustrate the occasional noise patterns visible on CCDs in the second row.

The CCDs in the second row appear to be affected by a pattern of periodically brighter (by 1 or 2 ADUs) rows. This issue has been resolved by cleaning up the noise in the MegaCam environment. Disabling two of the four fans used to cool and maintain the environment temperature at 1 C has all but eliminated the noise. The noise has not appeared in the images since the two fans were turned off and two fans are sufficient to maintain the MegaCam environment temperature.

MegaCam Image Quality Monitoring

As part of our regular monitoring of MegaCam image quality we identified three types of image quality anomalies on data taken with narrow-band filters (low sky background). The first anomaly identified is shown in Figure 16 – occasionally the second row of CCDs have horizontal noise running across the CCDs.

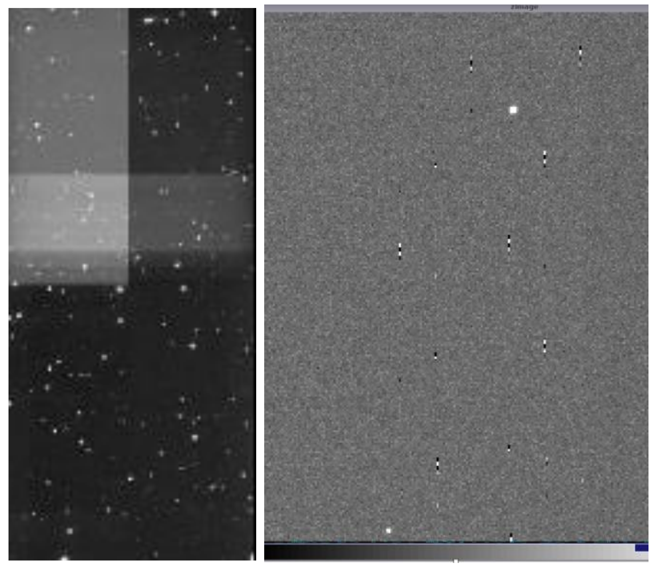


Figure 17 – Left: A binned image of Chip 12 displaying the increase in background across several rows. Less than 1% of images are affected by this issue. Right: Vertical 2-4 pixel features we coined raindrops. These affect ~50% of MegaCam images and have been present in the data since MegaCam was commissioned. Their frequency has not increased over time and they are uniformly distributed across the focal plane.

The second anomaly appears occasionally on chip 12 as a few ADU increase in background. In several runs this problem was seen in a bit less than 0.7% of the images taken with MegaCam. Based on an analysis of data from 10 nights randomly chosen over 4 runs, it does not appear that the frequency of this issue is increasing with time.

The third anomaly consists of symmetric alternating vertical features comprised of positive and negative signal, presumably injected into data during readout. These features appear to have been present since the instrument's commissioning, but we recently re-discovered them while investigating the features described above. They appear in about 50% of all images, but because they are tiny (3-4 pixels) and obviously are not sources, PIs have not flagged them as a significant problem.

Exposure Time Calculator & Sky Coverage

The MegaCam exposure time calculator was updated for 18A proposals to allow users to estimate the required exposure times based upon magnitudes or flux values. This new capability is available for narrow band filters only.

Since its deployment MegaCam has imaged 24% of the entire sky and 34% of the sky visible from Maunakea. Staff members A. Petric, N. Flagey, and M. Wilson worked briefly with an intern over part of the 2017 summer to investigate the potential of presenting the archived MegaCam data in a way that's more conducive to citizen science and transit-science research. Stephen Gwyn from CADC and Jean-Charles Cuillandre have been consulted and expressed potential interest in the project. Petric, who is the UH resident astronomer at CFHT, will apply for NSF support to hire a postdoc for two years to help with this effort.

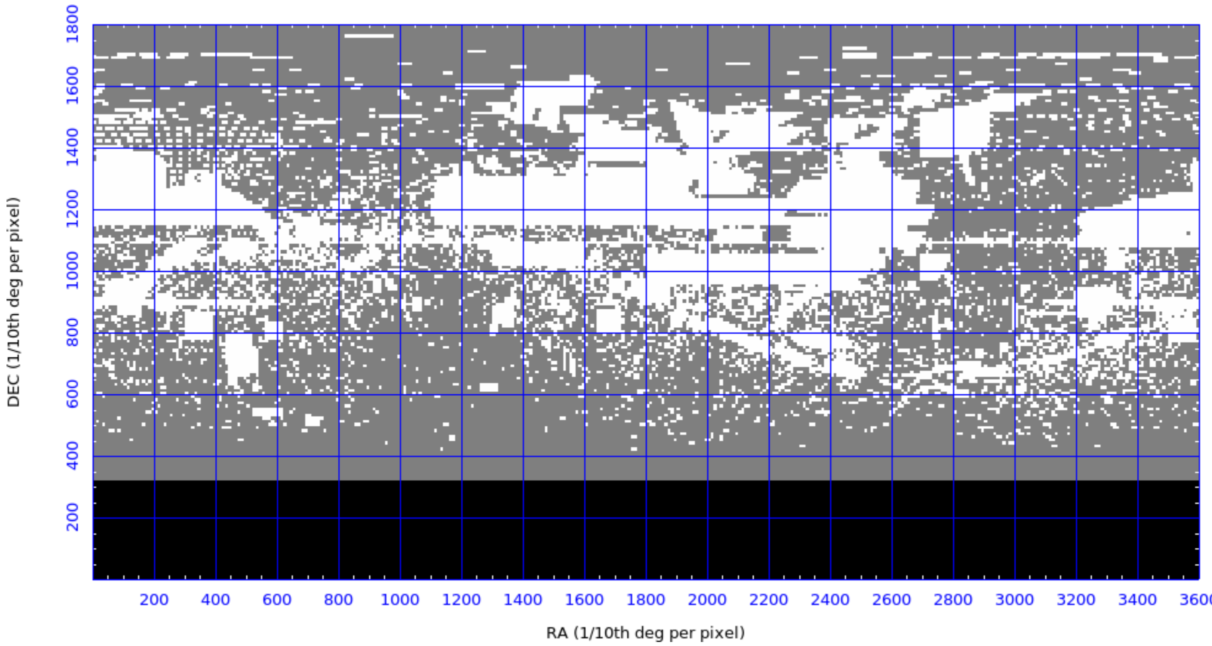


Figure 18 – Lifetime sky coverage of MegaCam images.

WIRCam Repairs

WIRCam operated without major issues over the past year, with one notable exception. On the night of 3 September 2017 there was a failure of the lower filter wheel which holds all of the broad-band filters. The night was salvaged by observing with a single filter only as this did not require further moves of the filter wheel. A more thorough investigation took place the next day.

During this investigation, it was determined that the problem was internal to the cryovessel and that it would not be safe to continue operating the filter wheel for the rest of the run. Operation was continued for one more day using a single filter, after which, the run was aborted, ESPaDOnS was put on the telescope and WIRCam was removed for repairs.

After warming, WIRCam was disassembled completely in order to access its filter wheels. On opening up the filter wheel assembly, it was found that the outer bearings of the lower filter wheel had failed. The outer bearings of the filter wheels are composed of 50 sapphire balls, 5 mm in diameter, riding on gold-coated steel races inserted into the aluminum wheel and filter housing. The balls are separated by Teflon ball spacers.

Most of the sapphire balls in the lower filter wheel were found to be at least partially broken with the remaining whole ones likely compromised. Given the progression of the wheel failure it is likely that the initial failure was due to one or two of the balls breaking and the fragments of these balls caused the other balls to break during movements associated with the troubleshooting. There was no indication of what caused the initial failure, so the assumption is that it was from wear over the 13 year usage of the instrument.

Figure 19 – Top: Removing detectors from WIRCam and lowering WIRCam to the floor of the aluminizing room for final disassembly. Bottom: Disassembly of WIRCam in the aluminizing room and the filter wheel assembly by itself.

On the positive side, the fragments from the broken sapphire balls did not migrate into the rest of the instrument, so all optics, filters, and the upper filter wheel were free of sapphire pieces. Nonetheless, as a precaution, all mechanical parts were thoroughly wiped down before reassembly. 100 spare sapphire balls were provided with WIRCam, so it was decided to replace both bearings sets (upper and lower filter wheels). The used balls from the upper wheel were kept for further engineering inspection. While two complete sets of spare bearing races exist at CFHT, only the lower races were replaced as the upper races were undamaged. The Teflon ball spacers were reused for both wheels, after cleaning.

The inner bearings of the filter wheels, composed of stainless steel balls and stainless steel races, were completely undamaged by this failure and both upper and lower inner bearings could be reused. The entire filter wheel assembly, including the upper wheel, was thoroughly cleaned with all traces of sapphire that could be seen removed. Several wipes of all potentially contaminated surfaces was done to hopefully remove all of the sapphire fragments that could potentially cause other ball failures.

ESPaDOnS/GRACES

ESPaDOnS/GRACES continues to function at a high reliability level. GRACES operations restarted in 2017 after a pause caused by work on the GMOS instrument at Gemini. On ESPaDOnS, there has been an incident of note (described below), however, it does not appear to have impacted the quality of the data.

An unidentified contaminant condensed onto the surface of the detector. The data quality did not appear to be adversely affected by the contaminant as it is stable and flat fielding appears to remove

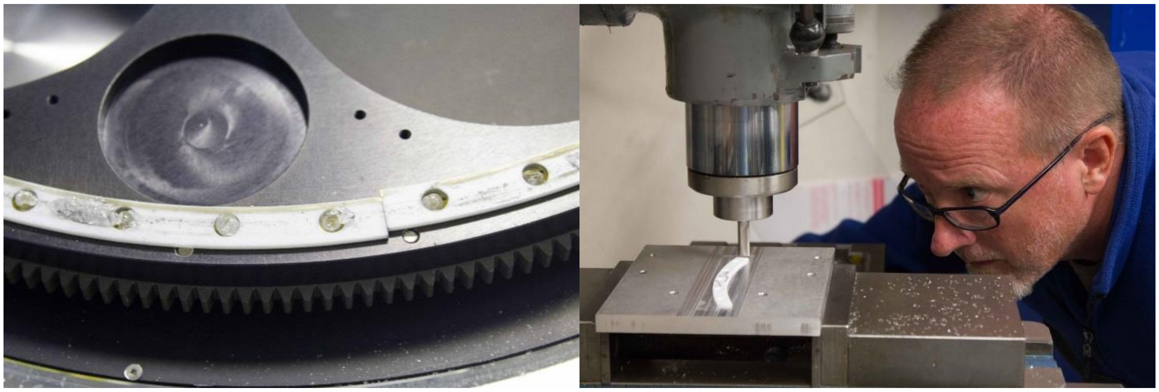


Figure 20 – Left: Image showing some of the damaged sapphire balls in the lower filter wheel prior to removal. Right: Careful machining of new Teflon spacers.

the signature from the data. Nonetheless, it was cosmetically objectionable and needed to be addressed. This contamination can be traced back to 21 May 2017, when ESPaDonS suffered a loss of cooling power to the PolyCold system used to cool the detector, resulting in the detector warming up in the middle of the night. Because ESPaDOnS was not on the telescope that night, it was decided to allow the detector to warm up to room temperature and troubleshoot the system the following day.

Investigation of the cooling system warm showed that the static pressure of the refrigerant in the system was significantly lower than it should have been. The system was recharged and the cooling was turned back on after a short pump on the detector cryostat

Due to time constraints imposed by the observational schedule cooling the instruments was started as soon as possible. At 4 mTorr, the vacuum level at the start of cooling was higher than normal as typically one would not start cooling until 0.1 mTorr. This was not considered an issue since the cryostat had not been opened. Generally in this case, the cryopump (getter) is the coldest point in the system, so all the contaminants should be absorbed there.

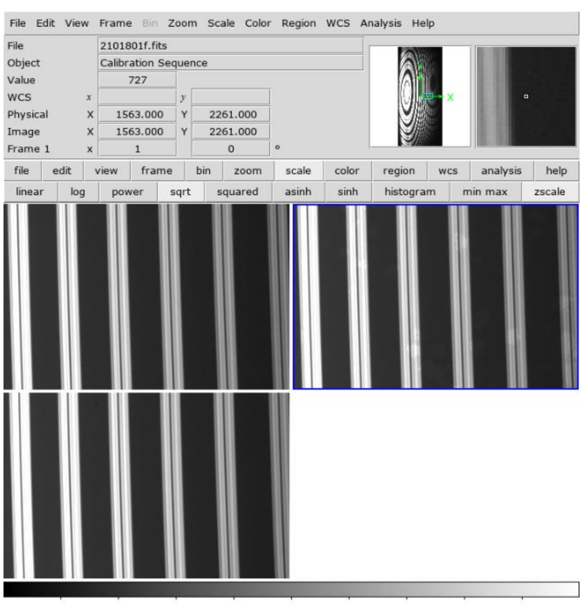


Figure 21 - ESPaDOnS flat-field images from before (upper left), during (upper right), and after (lower left) the "splotches" were visible.

The cooling system worked fine after this, but it was noted in August 2017 that images since 25 May had unusual “splotches” and dark rings in places. Since the appearance of spots in the data was concerning, the dewar was removed from the instrument and the detector was inspected on 29 August 2017. The surface of the detector was seen to have large areas near the upper and lower edges that appeared to be a coating degradation. There were also areas near the top and bottom of the chip with a rainbow coloration suggesting a thin film coating in that region. The most likely culprit for the rainbow was water. The cause of the apparent coating degradation was not clear.

At that point the engineering team began a program to mitigate the contamination by back filling with nitrogen, warming and pumping on the dewar. The results are promising as can be seen in the accompanying figures. We believe with more

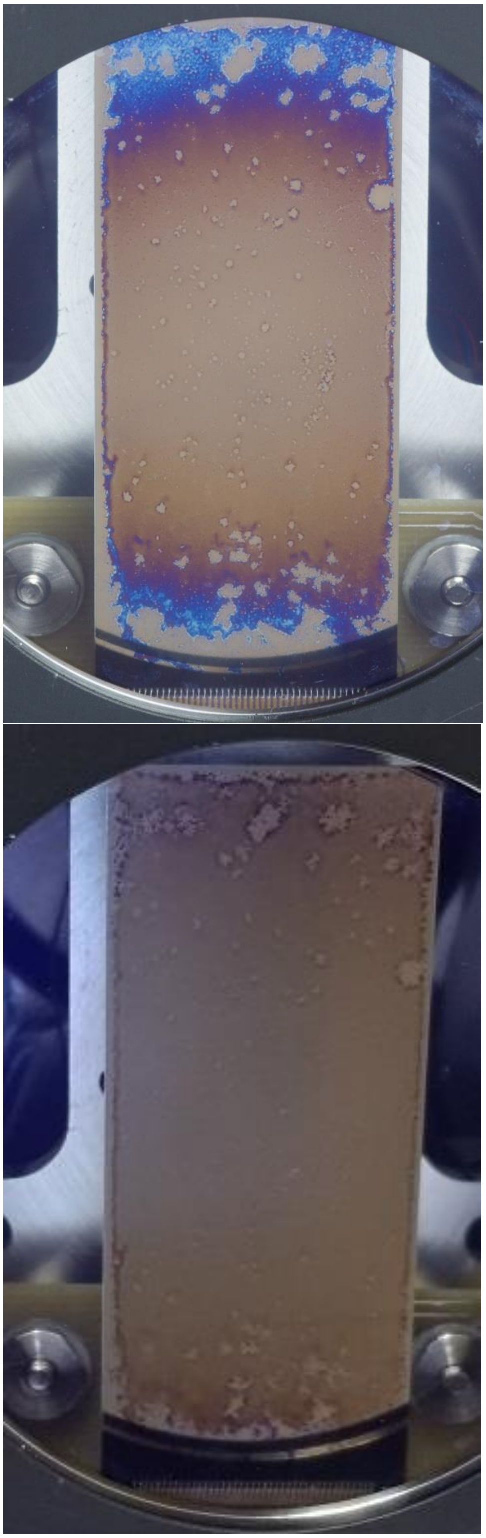


Figure 22 – Before (top) and after (bottom) pumping on the dewar, as described in the report, left a significant reduction in surface contamination.

aggressive and longer pumping, the detector will be returned to its nominal state. This was started during the break between the November GRACES run and the December ESPaDOnS run, with promising results shown in Figure 22. There is no plan to open the dewar or physically clean the detector as the risks of such procedures far outweigh the benefits, given the negligible impact to science data of the remaining splotches.

Other Activity in the Engineering Group

RBUSS Replacement

Replacement of RBUSS, the hardware that TCS uses to communicate with the remote control stations mounted on the telescope is progressing well. The control stations mainly control the telescope horizontal and vertical balance weights. Eliminating the RBUSS removes obsolete hardware and is a step in the eventual replacement of the VxWorks VME-based TCS controller. Integration and testing of the first fully assembled unit on the telescope was successful. PCB assembly and cable fabrication for the other two units along with the high-level software development remain. We anticipate completing the project in 2018.

Cassegrain CCD Guider

The hardware portion of the Cassegrain guider replacement project was completed. A mount for the new CCD camera, which replaces the TV camera, was fabricated and tested on the telescope. The CCD camera was actually used to gather optical aberration data on the secondary during an engineering night as part of the SITELLE image quality investigation. The high-level software interface development is still in the works but has been superseded by other higher priority tasks.

Building Cooling – Upper Chiller Repairs

The building chiller system which provides cold glycol fluid to the 5th level floor cooling, the telescope hydraulic system, and various smaller equipment throughout the building was repaired. For some time the upper chiller was unreliable and would not operate normally so we have been running on the lower chiller without a redundant back up. Changes to the upper chiller condenser (increasing the air volume available) and modifications to the refrigerant/oil level have resulted in a normally operating system. In fact the repaired chiller now operates colder than the lower chiller.

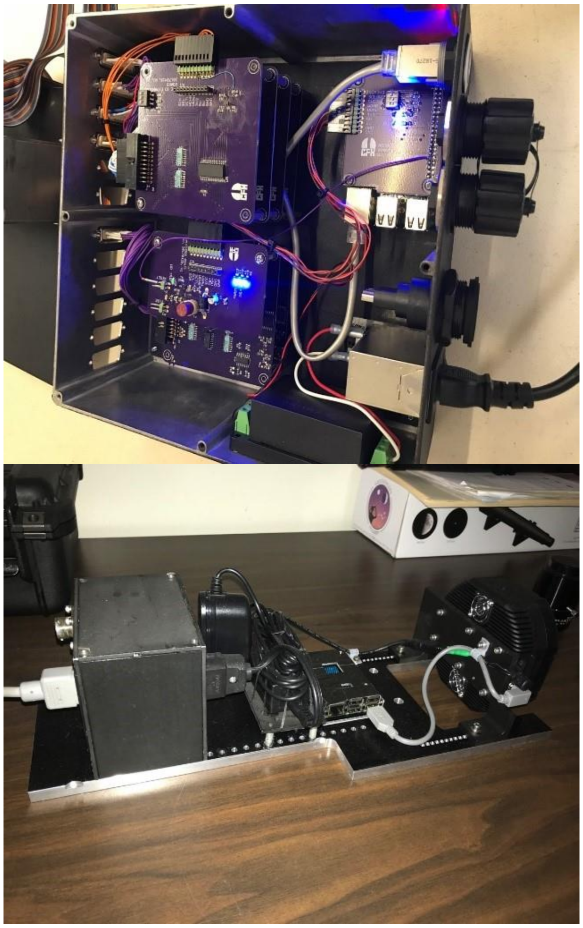


Figure 23 – Top: TCS RBUSS replacement hardware is shown. Bottom: New TCS Cassegrain CCD guide camera and mount, ready to be deployed on the summit, is shown.

The next steps to finish the upgrades to the building chiller for improved reliability and better monitoring include installing a new motor/pump combo with a higher capacity to meet ever increasing demands. Installation of a new electronic switch to provide remote control, and addition of an amp meter or similar device to know when the motor is on and how it is performing is also planned.

Pneumatic Dry Air system – Capacity Limits

The pneumatic dry air compressor system reached the maximum amount of pressure it can supply, hence no additional dry air services can be accommodated in the future. The oldest of the two air compressors will require significant repairs. Rather than replacing failing components for aging compressors, which amount to ~40% the cost of a new unit, most likely a new unit will be purchased and the old unit retired in 2018.

Dome Shutter Metrology

A half measurement of the dome rail profile was performed using a laser tracker on loan from the LBT and a custom fixture for following the rail with help from an API applications engineer who brought an active motorized target.

The measurements were taken but the software required to read and manipulate the data is cost prohibitive. We have tried various partner academic initiations but have not been able to find someone with the software to help us. A consultant who has the necessary software and may be willing to convert our data to a form which could be analyzed in house has been identified. Quotes for this work will be explored in 2018 so the data can be used for future shutter adjustments.

Bridge Crane Access Improvement Project

The bridge crane access improvement project has been slowed by the departure of the safety specialist however progress continues on the conceptual design. After the review of a conceptual design, the insulation panels behind the bridge crane were removed which allowed more room for the ladder and platform which will be needed to make the upgrade possible. The current preliminary design simplifies the access system by using a single vertical ladder with a platform at the top. The preliminary design work will continue with a review to follow.

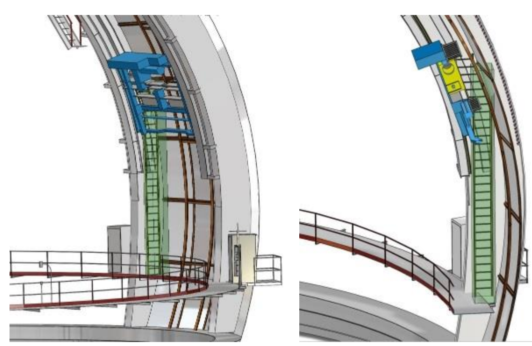


Figure 24 – Bridge crane access conceptual designs.

MSE Report

Summary and Overview

The Conceptual Design Phase of MSE was substantially completed in 2017 after a tremendously successful series of subsystem reviews and a pending Systems review by a high profile external panel. This phase has seen the emergence of a new partnership involving Canada, France and Hawaii working alongside Australia, China and India. The first drafts of a new Master Agreement to carry MSE through at least the Preliminary Design Phase is an essential and welcome development that indicates the shared interests of, and commitments to, this group. The Project Office has demonstrated remarkable ability, agility and determination in bringing together diverse teams to work on MSE, in developing the MSE system design and all associated high level documents, and in supervising and managing all the sub-system design.

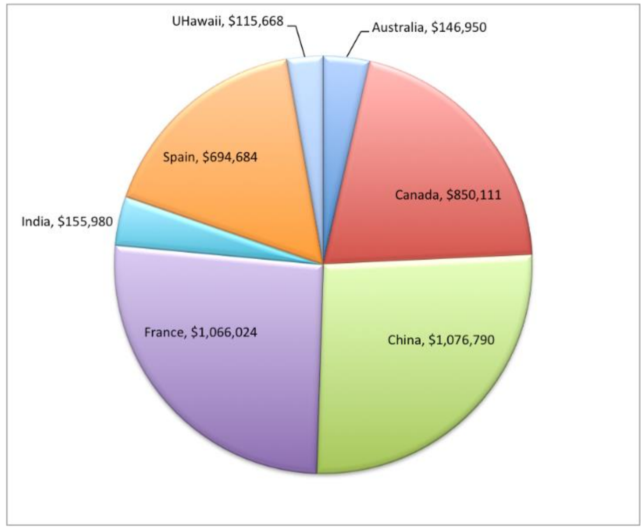


Figure 25 - The distribution of in-kind contributions among the MSE partners through 2016. Here, contributions from CFHT Corp are distributed among Canada, France and Hawaii (0.425:0.425:0.15), and contributed effort is valued at $120/hr.

Going forward, the model that worked well for MSE in the Conceptual Design Phase is not scalable to Preliminary Design Phase. The cost for a Preliminary Design is a quantum step greater than Conceptual Design, and together with that increased cost will come an increased level of engineering and procedural formality. MSE's new Management Group was prescient in requesting the development of a pre-construction Master Agreement among all the participants in this project, for this document now sets the stage for that growth in the project. As the document reaches final approval in 2018, it will provide a clear roadmap to the onset and funding distribution of the Preliminary Design Phase. It will be a roadmap that strives to move the project ahead as quickly as possible within the bounds of resources available at CFHT and the MSE partners. To capitalize on the 2020 national decision points that many partners and potential partners have on their calendars, MSE seeks construction funding in that timeframe – and to do so will mean a Preliminary Design phase that is substantially complete by 2020. Achieving this, and the stepped up resources needed, will certainly cause CFHT and each MSE partner to consider the value to our communities of MSE science beginning in the mid-to-late 2020s, and possibly cause them to make challenging decisions on science funding priorities.

Partnership and Governance

2017 saw the new governance structures for MSE, the MSE Management Group (MG) and their advisory group, the MSE Science Advisory Group (SAG), take charge of the direction of the project. A central thrust by MG throughout the year has been the effort to develop a master agreement ("Statement of Understanding") for all participants in the pre-construction work in MSE. This agreement will be between CFHT Corp and each of the participants in MSE. The purpose of this agreement is to establish among all the signatories their expectations of each other and CFHT. The agreement recognizes CFHT Corp's special status as the executive agency for the MSE project, and the obligations and limitations of that role.

The agreement defines, and grants limited authority to, an MSE Collaborative Board that will control the project, and it states the minimum contribution a participant needs to make to retain their status as a participant in the agreement. Perhaps the most important function the agreement serves is to set out the anticipated (but not binding) contribution each participant intends to make to complete the pre-construction work.

Science

The science activity for MSE in 2017 has been focused on understanding performance characteristics, operations concepts and data requirements to enable the science described in the Detailed Science Case and captured by the Science Requirements. Most of this effort has directly contributed to the development of the Level 1 documentation and was submitted for review at the end of 2017.

The MSE Systems Scientist took the lead in developing the operational concept of the MSE facility. This work is encapsulated in the Level I document, the Operations Concept Document (OCD). It describes all aspects of operations of this unique facility, including survey selection, phases of operations, observation definitions, queue scheduling, observing procedures, data reduction, calibration, data products and archiving, nighttime and daytime operations.

This work has been critical in identifying key areas of development. One of the most fascinating relates to effective queue scheduling. While many of the science data challenges of survey facilities relate to the back end (data processing and reduction), we anticipate the major science software challenge of MSE to be the front end. Specifically, how do you efficiently schedule spectroscopic observations of literally millions of targets distributed across the entire sky, when a single pointing observes some 4000 science targets chosen from multiple surveys, and single surveys can be expected to consist of thousands of pointings each with thousands of targets? All while taking into account current and anticipated observing conditions, as well as constraints such as the need to have reasonably balanced target brightnesses selected across the field of view. This area will be a focus of much of the coming conceptual design effort in the Program Execution Software Architecture (PESA), to be developed in 2018.

Science Development

Looking to the future, in addition to general science support of the MSE Project Office, we anticipate re-engaging the science team of MSE, and seeking to expand the science team through a range of activities. Specifically, after the conceptual design studies of 2017, we have the opportunity to revisit some of the driving science cases in the Detailed Science Case in light of this new information. Indeed, since the original release of the DSC, we have been approached by several groups that are seeking to augment the DSC with new science not originally considered. Some of the brand new science opportunities that have emerged in the past few years relate to gravitational waves.

Engineering

Subsystem Conceptual Designs

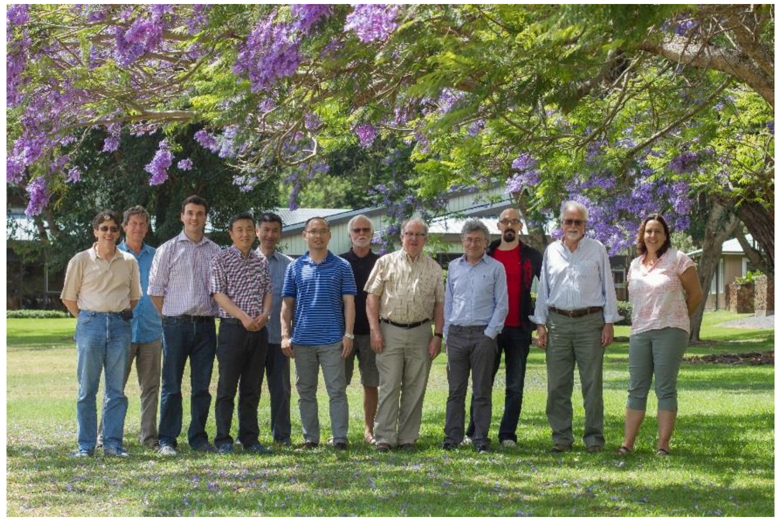


Figure 26 – Members of the review team that assessed the proposed design of the MSE high resolution spectrometers are seen in front of CFHT's Waimea office.

The first half of 2017 was dominated by an intense series of subsystem conceptual design reviews. We were successful at coordinating the reviews to minimize wear and tear on our few PO staff, with most of the reviews taking place in Waimea, and only two travel forays during the period to complete the remaining four reviews. The quality of subsystem design work was found to span a wide range, from work packages that needed more work to those that clearly exceeded the standards of a conceptual design.

In all cases, the conceptual design work addressed objectives drafted by the PO early in the project; objectives that were made on the basis of "informed engineering judgment" of the functional and performance requirements needed of that subsystem, and made without a rigorous analysis to support the requirements at that time. In every case, the contracted and contributed designs made within the MSE partners responded very well to the design challenge, providing a concept as well as a development plan for that subsystem, which have served the PO well to subsequently define the system, both in performance and in cost.

The conceptual design for the Observatory Building and Facilities remains scheduled for 2018. The conceptual designs for M1, the science calibration system, the telescope optical feedback system and the program execution software system have not yet been completed; progress on the designs on those less critical subsystems has been let slip due to limited effort available in the PO to lead those.

Fiber Position System Selection

A key subsystem that is at the heart of MSE's operational capabilities is the fiber positioner system (PosS) together with its Fiber Position Metrology System (FPMS). During the conceptual design phase, three groups provided independent PosS designs, based on different technologies offering different capabilities and performances. The designs of AAO (Australia), USTC (China) and UAM (Spain) were reviewed by a single panel in May, and the details of each design were incorporated into Flagey's observing efficiency model to assess the relative merits. Ultimately, the observing performance, technical merits, team performance, and cost were folded together into the PO's proposal to MG on the way forward for Preliminary Design Phase (PDP).

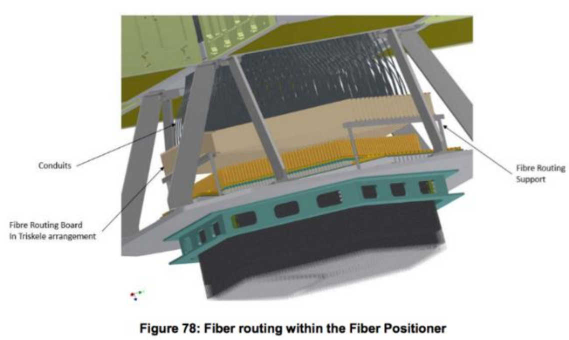


Figure 27 – AAO's Sphinx Fiber Positioner, as presented in the CoDR report.

Subsystem	Major Findings/Recommendations	MSE Project Office Action
Telescope Structure by IDOM	Design fully meets requirements; the proposed telescope structure reaches preliminary design level in some areas.	Confirm the inner pier structural interface capacity to support the telescope azimuth track and lateral restrain central structure
Enclosure by Empire Dynamic Structures	Design exceeds mass budget and the review panel provided mass reduction strategies for implementation at early preliminary design phase.	Confirm the outer building structural interface capacity to support the enclosure
High Resolution Spectrograph by NIAOT	Explore optical designs with different dispersion element options and off-axis collimator to accommodate native fiber output at f/2 exit beam.	Develop instrument simulator to trade design choices on the quality and effectiveness of science product
Fiber Positioner Systems/Fiber Position Metrology System by AAO, USTC and UAM	Three competed designs were reviewed. The review panel has clear preference for AAO which is judged to have the lowest programmatic risk. The review panel also acknowledged the USTC system had reached conceptual design level and some areas of AAO design is at preliminary design level.	Conduct the quantitative analyses to compare the Echidna and phi-theta designs in terms of: a) target allocation efficiency, b) system injection efficiency including contributions from the positioners and metrology system, and c) survey efficiency; provide PO recommendation based on overall programmatic evaluation
Fiber Transmission System by HAA	Design not mature enough to proceed to preliminary design phase, specifically an end-to-end fiber design concept is missing and a delta-CoDR is recommended.	Develop an end-to-end (telescope to spectrograph detector) simulator to allow the effects of technical choices affecting FRD stability, radial velocity and sky subtraction
Observatory Execution Software Architecture by CFHT	Design solution of using the CFHT software as a starting point is a good way to reduce cost and risk. However, comprehensive design requirements should be provided as part of the review.	PO to coordinate design requirements development with design team
Top End Assembly by DT-INSU	More work is needed to complete CoDR, e.g. lens mounting design based on optical tolerance budget, and missing service cable wrap concept for the instrument derotator; therefore a delta-CoDR is recommended.	Review the telescope central obscuration constraint which causes design choices that are impractical, e.g. WFC lens barrel in multiple stack-up pieces. Establish enclosure geometry along with its servicing platform and crane to ensure safe access to top end assembly components.
Low/Moderate Resolution Spectrograph by CRAL	Design is assessed as overly risky. Plan delta-CoDR with alternative lower risk optical designs to reduce number aspheres and allow more space for opto-mechanical packaging.	Reassess the scientific priority for H-band mode given the complexity of the spectrograph and high cost estimate presented.

Table 2 – Subsystem reviews completed in 2017

System Development

The latter half of the year saw a marked change in the project, with most subsystems completing their design tools while the PO processed the results of the subsystem reviews, developed system-wide budgets and modeling tools, and with those tools evaluated the overall system performance. The main product of this intense period of work was a suite of documents that rigorously connect the Science Requirements to the defining “Level 1 Documents” describing the system architecture, system operations, and state the overall system requirements. The requirements expressed in these documents will be used to define the work for each of the subsystems during preliminary design phase.

Models and analyses of integrated system performance give us confidence that the system will comply with almost all Science Requirements, but indeed it has also exposed a few notable problem areas where it does not. The integrated system fails to meet the required sensitivity in the two R=40,000 arms of the high resolution spectrograph. It fails to meet the required sensitivity in the H-band window of the low and moderate resolution spectrograph. And it fails, marginally, to meet the minimum resolution needed at all wavelengths in the low and moderate resolution spectrograph. Work to reconcile the design performance and the requirements will be an important task for the PO and the SAG following January’s design review, and will almost certainly result in some system-level design changes before moving to PDP.

Overall Project Development and Priorities

In 2018, the major thrusts for the MSE Project Office include -

- Bring the system design products to a readiness level to begin PDP,
- Complete the Conceptual Designs where that is not yet done,
- Increase the level of awareness of MSE in the current, and potential new, partnership,
- Support MG in their efforts to complete the master agreement and establish PDP funding.

Figure 28 – A CFHT CAD rendering of the exterior of MSE, seen in the iconic triangular shadow of Maunakea.

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 2017 Finances

CFHT continues to operate in a challenging economic environment of limited member agency contributions compounded with inflationary cost pressures. For 2017, member agency contributions were held flat from 2016 (see Table 3). Over 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$)		
	2017	2016
NRC	3,261,145	3,261,145
CNRS	3,261,145	3,261,145
UH	756,204	756,204
Total	7,278,494	7,278,494

Table 3 – Contributions from CFHT partners were held flat between 2016 and 2017.

Table 4 shows our 2017 Operating Fund expenditures on a comparative basis with 2016. In 2016 we had to draw funding from reserves to maintain a balanced budget. In 2017, our overall spending was below contributions and we were able to transfer the unspent amount of approximately $32k to reserves. This result was 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 Expenditure (US$)		
	2017	2016
Maunakea Facility and Operations	497,209	397,286
Base Facility and Operations	160,509	225,434
Services	258,568	327,537
Maunakea Support Services	132,001	95,241
Management & General	404,116	537,405
Staffing	5,576,064	5,582,668
Outreach	73,991	59,579
Instrumentation	91,470	72,384
Science	52,988	60,158
Transfer to (from) Reserve	31,578	(79,198)
Total	7,278,494	7,278,494

Table 4 – Operating expenditures broken down by cost categories.

In addition to member agency contributions, CFHT receives contributions from Associate Partners whose communities access CFHT facilities and help develop CFHT instrumentation. In 2017, contributions of $346,250 and $246,500 from the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) and the National Astronomical Observatory of China (NAOC), respectively were made. Funding received under these collaborative agreements is used to support instrument and project development costs, with the current focus on MSE. Efforts are ongoing to seek additional collaborative agreements and partnerships with agencies throughout the world.

Accounting Group Developments

In the spirit of continuous improvement, we implemented the following notable actions during the year:

- Rollout of new budget and planning system. Prior to the new planning system, budgets were manually prepared and rolled up in Excel worksheets, a very cumbersome and time intensive effort. The new system allows real time changes and monitoring, significantly reducing the amount of administrative overhead in budgeting and planning.

- Implemented a new Audit Committee charter. The new charter modernizes the financial oversight directed by the Audit Committee and improves overall governance. As part of this charter and associated oversight, CFHT completes its annual financial reporting obligations on a much faster time scale providing timelier reporting to the Board of Directors. This allows for more decision making when needed and streamlines the workflow of the Accounting Department.
- Streamlined the Accounts Payable (AP) and Procurement procedures. Several changes were made to speed the purchasing process, enhance internal controls and reduce redundant workflow in the administrative processes of both AP and Procurement. Changes include: increased purchasing limits for managers, greater utilization of procurement cards, and further automation of the approval workflow and data entry.
- Enhanced banking management. Several changes to our banking activities were implemented during the year: online wire transfer capabilities (previously done via phone and fax), implementation of vendor payments via ACH, direct deposit of employee reimbursements, and more robust cash management to improve returns on cash holdings.

Staff Safety

During 2017, we had zero OSHA recordable injuries. Near miss incidents and non-recordable accidents were addressed promptly to identify opportunities for improvement in our operating processes or training. Several safety initiatives were completed or undertaken during the year to mitigate potential hazards:

- A new process of using an overhead life line to mitigate fall hazards, both of people and equipment, was implemented during the CO_2 snow cleaning of the primary mirror.
- A guard rail system was installed on the 'blue platform' lift used in the observatory dome to reduce fall hazards when it is elevated more than four feet.
- The VFW Fokker man lift was taken out of service and replaced with newer equipment.
- Work continues to progress on improving the access and egress from the bridge crane.

- Jake Braden resigned as our Safety Specialist effective September 22, 2017. We appreciate all of Jake's contributions to improving our safety environment and culture. In considering how to add a new Safety Specialist in a capacity that meets our current safety needs, we engaged a part-time independent safety contractor. This model will allow us to maintain our focus on the safety program while we determine if a full time safety specialist may no longer be required.

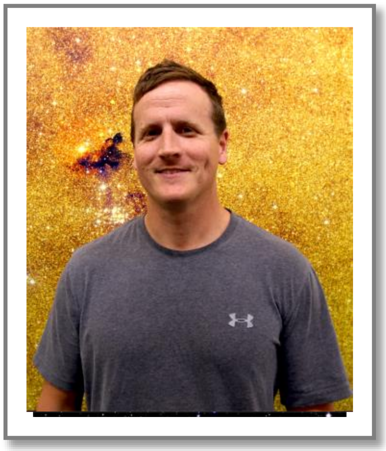
	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
Injuries	0	0	2	2	0	0	1	0	0	0
Illnesses	0	0	0	0	0	0	0	0	0	0
Lost work days	0	0	0	10.5	0	0	1	0	0	0

Table 5 – A decade of top-level statistics pertaining to safety are listed above.

Arrivals and Departures

We bid farewell to four of our staff 'ohana who chose to move on to their next adventures in life during 2017. In their places, we welcomed four more members into the CFHT family. 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

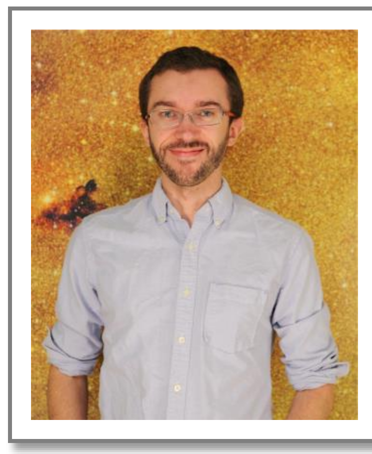


Jake Braden

Jake was our Safety Coordinator who joined CFHT in March of 2015. He resigned to pursue extended travel through New Zealand, Australia, and Southeast Asia. Though his time with us was short his emphasis on onsite safety management and training programs made a meaningful impact to improving our safety awareness and culture.

Peter Forshay

After 12 years as a Remote Observer, Peter left CFHT to take a position with the Space Telescope Science Institute to support the launch of the James Webb Space Telescope. Peter participated in many significant changes at CFHT during his time here, most notably the transition to our remote observation model.

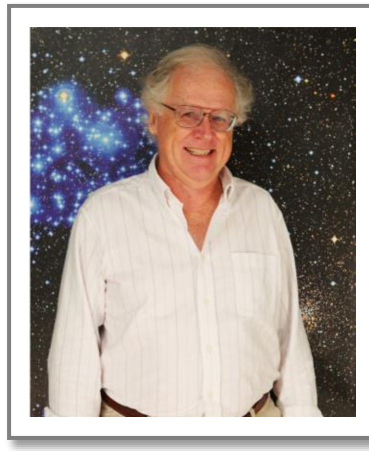


Blaise Kuo Tiong

Blaise has been with CFHT since April 2014 in the position of IT System Administrator. Blaise resigned to pursue a PhD in astronomy from Macquarie University in Australia. While we are always sad to see a member of CFHT depart, we anticipate and look forward to seeing Blaise again as a researcher. We are pleased to report that we were able to promote an employee from within the organization, Ferd Babas, to fill Blaise's vacancy.

Derrick Salmon

After 39 years at CFHT, Derrick decided it was time to retire from his position as the Director of Engineering. With a career that spans nearly the entire existence of CFHT, it is safe to say that Derrick witnessed and participated in more change than anyone else at CFHT. Words cannot express the positive impacts and lasting legacy of his contributions. Fortunately, we see Derrick quite frequently as he contributes his time and expertise to the MSE project.



Welcome

Callie Crowder

Callie is a recent graduate of the University of Hawaii at Hilo with degrees in Astronomy and Physics. She joined CFHT as a Remote Observer, filling the vacancy left by Peter Forshay. We are excited to be able to find outstanding young applicants from the local community. Callie supported herself through college working at the Maunakea Visitor Information Station for four years and so is already deeply connected to the Maunakea community. Upon joining CFHT, she immediately dove into several volunteer activities helping with our outreach and educational programs. Her enthusiasm for astronomy and helping local youth is contagious.

Eric Dela Rosa

Prior to joining CFHT as a System Administrator, Eric was employed locally at Parker School. Eric grew up on Hawaii Island and attended Hawaii Community College. While there, he was one of the early participants in the Akamai Internship program working in the CFHT instrumentation group. Now 10 years later, we are privileged to hire him as a full time employee. We are very proud to be able to see the benefits of the Akamai Internship program resulting in career opportunities and benefiting the astronomy community. Eric is married with a 15 year old daughter and brand new 2 month old son. Eric is excited to build his career in astronomy while being able to remain close to home.

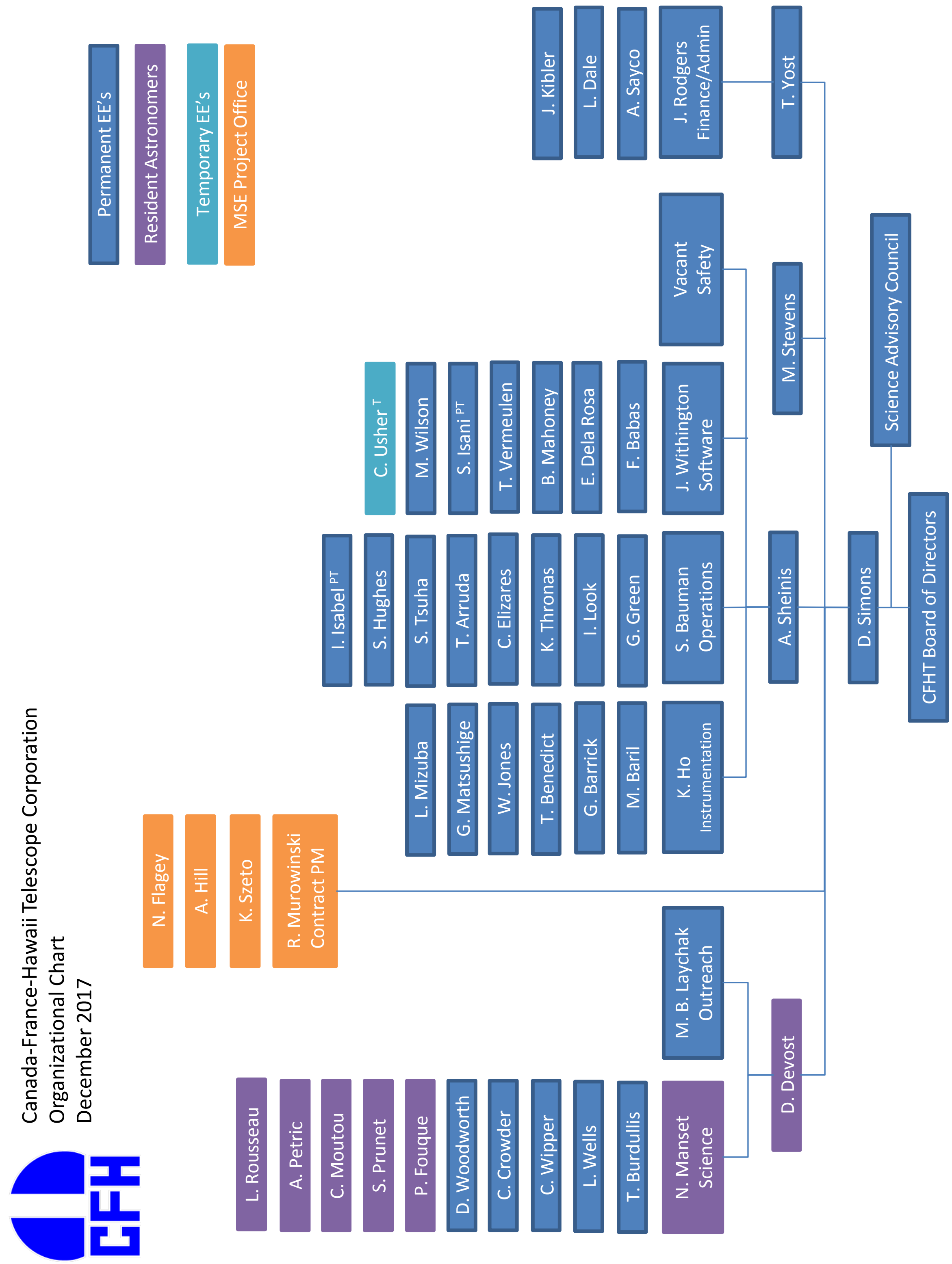
Jennifer Kibler

Jennifer originally began working for CFHT as a temporary employee. Her strong work ethic and cheerful attitude made her a must have employee. She joined the Administration group in early 2017 as a Financial and Administrative Support Specialist working in the front office. She is responsible for Accounts Payable and a variety of administrative support activities throughout the observatory. Jennifer is a recent graduate from UNLV with a degree in accounting, having just moved to Hawaii with her husband Matt. Jennifer is actively involved in several of our improvement initiatives and we look forward to her continued growth with the observatory.

Andy Sheinis

Andy was appointed Director of Engineering, replacing Derrick Salmon after his retirement. Prior to joining CFHT, Andy was the Head of Instrumentation at the Australian Astronomical Observatory, where he led the Instruments AAO developed for Australia, ESO, and Gemini among others and where he served as the Australian representative on the Giant Magellan telescope SAC as well as the MSE Management Group. Prior to AAO, Andy was a faculty member at the University of Wisconsin. He earned a Ph.D. in Astronomy and Astrophysics and an MS in Optical Physics. Andy is excited to return to Hawaii, having previously worked at the University of Hawaii Institute for Astronomy. Andy is married to Cietta, a Marriage and Family Therapist, and has a 12-year-old son, Arlo, who is currently attending HPA and playing baseball for the Waimea Rustlers. Andy and his family are happy to have recently purchased a home in Waimea.

Organization Chart



Staff List at the End of 2017

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

Outreach Report

It was another incredibly busy year in CFHT's outreach program, which is now functioning statewide through the Maunakea Scholars program, and internationally through various conferences and media outlets. We begin this section with a summary of our international activities, then segue to our numerous efforts in Hawaii to nurture and deepen our relationship with our local community.

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.

CFHT continued to partner with Discover the Universe on two major initiatives. We held our third annual teacher's workshop at the June 2017 CASCA meeting. The workshop was free of cost to participants and focused on hands-on activities they can use in their classrooms. We had excellent participation from astronomers Matt Russo from CITA, Christa Van Laerhoven from UBC, and Phil Langill from University of Calagary who all attended and/or presented. We were approached by the organizers of the 2018 CASCA meeting who would like to see the workshops continue. We plan on two workshops in Victoria, one for elementary and one for secondary teachers. We are working with the local organizers to include authentic First Nations content.

Using the "Discover the Teacher" network, CFHT connected via video conference with Canadian classrooms. We spoke with three English speaking schools in Edmonton. We are also a lesson partner with "Exploring By the Seat of Your Pants" run by a teacher in Guelph, Ontario. The program aims to "connect classrooms to science, adventure and conservation". As a lesson partner, CFHT participates in webcasted Google Hangout talks that are then archived on YouTube and available to teachers.

We attended the Eureka! Festival in Montreal. CFHT shared a booth with the University of Montreal and the Centre for Research in Astrophysics of Quebec (CRAQ) to talk about the 2017 solar eclipse. Mary Beth Laychak gave a talk on CFHT as part of the conference. The festival was very well attended as the organizers estimate over 100,000 people visited over its three day duration.

Figure 29 – The CFHT and CRAQ booth at the Eureka! Festival in Montreal.

In 2018, we plan to continue the efforts listed above with emphasis on expanding the reach of the programs. One lesson is that for the time being we are best suited to plugging into an already existing network of teachers such as Discover the Universe or Exploring by the Seat of Your Pants. We plan to further develop CFHT's outreach website to include teacher resources like lesson reviews, links to activities and CFHT generated content. Putting these resources online along with our menu of talks is the first step towards recruiting educators ourselves.

We currently have two CFHT photo displays in Canada - one at NRC/HAA in Victoria and the other at David Dunlap Observatory in Toronto.

Outreach in France

Last summer, 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.

CFHT and Société Française d'Astronomie & d'Astrophysique (SF2A) hosted the first ever outreach lunch at an SF2A meeting. Mary Beth Laychak spoke for twenty minutes about CFHT's work with local media and communicating with journalists. The rest of the session was a discussion about how to incorporate more public outreach into the French astronomical community. The session was very well attended. CFHT offered some suggestions based on our work in community engagement. We hope to work with SF2A on a similar lunch or session during the 2018 meeting.

CFHT plans to work with the SPIRou team on their planned SPIRou outreach display. We can provide video footage of the instrument's arrival at CFHT and funding. We aim to share the display in Hawaii as well.

We were contacted by Thierry Botti from the OSU Institut Pythéas about having a video presentation to students during the "Fête de la science à Marseille". Claire Moutou volunteered and talked about CFHT, SPIRou, exoplanets and SITELLE from the Remote Observing Room on October 13, 2017. The event was streamed on Facebook Live and posted on the CFHT Facebook page.

Outreach in Hawaii

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 ~6500 people over the course of the year.

Figure 30 – The Honoka'a Maunakea Scholars at the summit.

As part of CFHT's effort to reach local school students, we have several projects in the works with Hawaii schools. We 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 classroom building being built at Waimea Middle school. These connections give CFHT a prominent role in the local educational community.

2017 continued the expansion of the North Hawaii Journey Through the Universe program. We partnered with Honoka'a Elementary, Intermediate and High School, Waimea Elementary School and Paauilo to visit with over 1100 students during Journey week. Staff from the Keck Observatory and UH's Institute for Astronomy joined our efforts. We are in talks to add Laupaehoehoe school in 2018.

CFHT continues to provide support for local K-12 students working on science fair projects. We have a student working towards creating a small database on our website with CFHT archival data appropriate for students to use for science fair projects along with suggested science fair topics. This database will be accessible to students worldwide and we hope to translate the page into French. We are also in the process of piloting a CFHT housed lending library for Hawaii Island teachers.

At the high school level, CFHT and Gemini partnered to create the "Maunakea Scholars" program, an opportunity for local high school students to work with astronomy mentors on archival Gemini images before proposing their own projects using CFHT. In our inaugural year, three classes were awarded about one night of CFHT time. The projects submitted exceeded our expectations. The winning three were titled - " Validating or Redefining Mischaracterized Unconfirmed Exoplanets", "Quasars and What They are Made of", and "Exploring Star-Formation in the Hosts of Radio Quiet Quasars".

Figure 31 – MOU signing ceremony at UH. Front row - Hawaii state superintendent Kathryn Matayoshi, Doug Simons and UH President David Lassner. Back row - Ben Boe, Maissa Salama (MKS mentors), Spencer Young (MKS student) and Kelly Blumenthal (mentor).

For the 2016-2017 school year, Maunakea Scholars dramatically expanded. We worked with five schools - Waiakea and Honoka'a on Hawaii Island as well as Nanakuli, Kalani and Kapolei high schools on Oahu. We added Subaru, Gemini, EAO and Robo-AO as participating telescopes and hosted eight mentors (seven from UH Manoa, six graduate students). 'Imiloa garnered funding to provide cultural and Polynesian wayfinding presentations to the students and communities of all five schools.

In the 2017-2018 school year, the Maunakea Scholars program expanded again. We worked with ten schools on four islands - Hawaii Island, Maui, Molokai, and Oahu. We added Keck, IRTF and the Las Cumbres Observatory and created a website: www.maunakeascholars.org. In May 2017, the Maunakea Observatories, the Hawaii State Department of Education and the University of Hawaii signed an MOU to further expand the program. The MOU calls for the establishment of a working group, headed by CFHT, to facilitate the expansion of the program, to evaluate its effectiveness and bolster its cultural foundations.

CFHT sponsored three major community events this year: Manufacturing Day on October 6th, the Waimea Solar System Walk held on October 24th and the Winter Star Party on December 2nd. Manufacturing Day was a new event, spearheaded by Greg Green. It was held in conjunction with National Manufacturing Day. We invited local school students and the general public to tour our facility. Greg set up machining, spectroscopy, weather sensing, 3D printing and design demonstrations. The event pulled in participation from other community manufacturers and was selected by Innovate Hawaii as their feature Hawaii event on the National MFD FaceBook live feed. The event received coverage on statewide 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 250 people participated in the walk, which received coverage on the state television news broadcasts and in Hawaii Island newspapers. The costume contest added last year was just as successful this year.

Eight of the Maunakea Observatories, ‘Imiloa, and the University of Hawaii continued the Kama’aina 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 meals at HP, environmental and cultural briefings. Staff from the Maunakea Visitor Information Station, ‘Imiloa, and the Maunakea Observatories support each guided tour. CFHT plays an active role in the organization and coordination of the tours. The program is very successful with all reservations booked within five minutes each month and stellar post-visit reviews.

AstroDay Hilo is a Hawaii Island tradition occurring every May for the past 16 years. This year the Maunakea Observatories expanded the event to West Hawaii for the first time on November 4th. We estimate 2000 people attended. Astro Day West Hawaii received statewide coverage on television and Hawaii 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 followers grew from ~1530 in November 2016 to ~2100 by the end of 2017. Posts are made daily Monday-Friday and focus on good news coming out of CFHT with emphasis on the staff, science, instrumentation and outreach.

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 Hawaii State Department of Education. Our followers have increased from ~390 in 2016 to ~610 in 2017.

Media Presence

2017 brought several very large news releases. In June, a team from UH headed by Mike Liu announced the lower mass limit on stars at 70 Jupiter masses. The team used WIRCam for over a decade to study brown dwarf binary pairs. The announcement warranted a spot in the summer AAS press conference line up, a first for a CFHT discovery.

The discovery of the interstellar object ‘Oumuamua generated incredible attention at the end of November. The team led by Karen Meech at UH had a Nature paper on the object and garnered the front page of the Honolulu Star Advertiser. CFHT was mentioned in the articles. We are currently exploring other story ideas to maintain interest in the object and the work done by UH asteroid hunters using CFHT.

Astronomy received a public boost on November 12th with the publishing of a 40 page astronomy-centric insert in the Hawaii Tribune Herald. The insert, "Stars Over Maunakea" heavily featured CFHT staff and content. Claire Moutou provided an interview about exoplanets, Doug Simons wrote the introduction and conclusion and the Maunakea Scholars program was the focus of an article. The insert also included a list of major discoveries from Maunakea, profiles on the HP and road crew staffs, the Visitor Information Station and other programs run by the Maunakea Observatories. The Thirty Meter Telescope funded the publication of the insert in the West Hawaii Today in late 2017.

In addition to these large stories, CFHT programming like the Solar System Walk, Maunakea Scholars, Astro Day West, Manufacturing Day, the Waimea Christmas parade/CFHT star party and Astro Day have received television and written newspaper coverage over the course of the year. *Hawaii astronomy has received more positive news coverage in 2017 than any other year to this point.*

CFHT also contributes a monthly column for the North Hawaii News called "Across the Universe". The North Hawaii News was integrated into 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.

Figure 32 – Maunakea Scholars interview on the morning news. L-R- Billy V, local TV personality, Mary Beth Laychak and Justin Fernando, Maunakea Scholars student.

2017 Publications Including CFHT Data

Overall, 85 facility papers were published during this period including 78 archival papers and 58 papers based on CFHT cataloged data. In total for the year, 217 unique papers were published. This is the largest number of papers published in a single year during CFHT's ~40 year history. It is a real tribute to our community, making CFHT one of the most scientifically productive observatories in history.

Facility papers (85)

Moutou C., et al. 2017 SPIRou input catalogue: activity, rotation and magnetic field of cool dwarfs, MNRAS 472 4563

Rebassa-Mansergas A., et al. 2017 The white dwarf binary pathways survey - II. Radial velocities of 1453 FGK stars with white dwarf companions from LAMOST DR 4, MNRAS 472 4193

Youakim K., et al. 2017 The Pristine survey - III. Spectroscopic confirmation of an efficient search for extremely metal-poor stars, MNRAS 472 2963

Hill C. A., et al. 2017 Magnetic activity and radial velocity filtering of young Suns: the weak-line T-Tauri stars Par 1379 and Par 2244, MNRAS 472 1716

Grier C. J., et al. 2017 The Sloan Digital Sky Survey Reverberation Mapping Project: Hα and Hβ Reverberation Measurements from First-year Spectroscopy and Photometry, ApJ 851 21

Hsu L.-Y., et al. 2017 The Hawaii SCUBA-2 Lensing Cluster Survey: Are Low-luminosity Submillimeter Galaxies Detected in the Rest-frame UV?, ApJ 850 189

Han C., et al. 2017 OGLE-2016-BLG-0613LABb: A Microlensing Planet in a Binary System, AJ 154 223

Tudorica A., et al. 2017 Weak lensing magnification of SpARCS galaxy clusters, A&A 608 A141

Shen L., et al. 2017 The properties of radio galaxies and the effect of environment in large-scale structures at z ˜ 1, MNRAS 472 998

Lemaux B. C., et al. 2017 Chronos and KAIROS: MOSFIRE observations of post-starburst galaxies in z ˜ 1 clusters and groups, MNRAS 472 419

Ahmed A., Sigut T. A. A. 2017 Rotational mixing in Be stars: nitrogen abundances for a sample of Be stars from the MiMeS survey, MNRAS 471 3398

Starkenburg E., et al. 2017 The Pristine survey - I. Mining the Galaxy for the most metal-poor stars, MNRAS 471 2587

Meech K. J., et al. 2017 CO-driven Activity in Comet C/2017 K2 (PANSTARRS), ApJ 849 L8

Spengler C., et al. 2017 Virgo Redux: The Masses and Stellar Content of Nuclei in Early-type Galaxies from Multiband Photometry and Spectroscopy, ApJ 849 55

Webb K. A., et al. 2017 Constraining the Dust Opacity Law in Three Small and Isolated Molecular Clouds, ApJ 849 13

Landstreet J. D., et al. 2017 Monitoring and modelling of white dwarfs with extremely weak magnetic fields. WD 2047+372 and WD 2359-434, A&A 607 A92

Shultz M., et al. 2017 The pulsating magnetosphere of the extremely slowly rotating magnetic β Cep star ξ^1 CMa, MNRAS 471 2286

Neiner C., et al. 2017 Discovery of magnetic A supergiants: the descendants of magnetic main-sequence B stars, MNRAS 471 1926

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MAUNAKEA SPECTROSCOPIC EXPLORER

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