2016 CFHT Annual Report

Table of Contents

Front and back covers: CFHT's new dome vents are evident in the front cover photo, taken by Jean-Charles Cuillandre, and the back cover photo taken by Sean Goebel. Both photos were recorded in 2016 and capture the beauty of CFHT's site on Maunakea. The upper ridge of Maunakea, which is home to CFHT, Gemini-N, UH 2.2m, UKIRT, and Hoku Kea is arguably one of the best sites for astronomy on Earth.

Director's Message

With the completion of my first 5-yr term as CFHT Director, thinking retrospectively beyond 2016 comes naturally. Looking back, my immediate reaction is how fast that time has blazed by – an indication of the incredible number of events, challenges, and accomplishments we have all made in CFHT's wonderful global community. Some things did not come as much of a surprise since they were already planned or underway when I started as Director, like the completion of SITELLE and our new dome vents. Also, given the track record of innovative operations and the staff's insatiable desire to improve, achievements like SNR QSO, a cascade of efficiency gains with MegaCam, and progress with a project called ngCFHT came as no great surprise. Even though I did not predict any of these in detail when I started, they each reflect CFHT's working culture of continual improvement, refusing to be satisfied with the status quo.

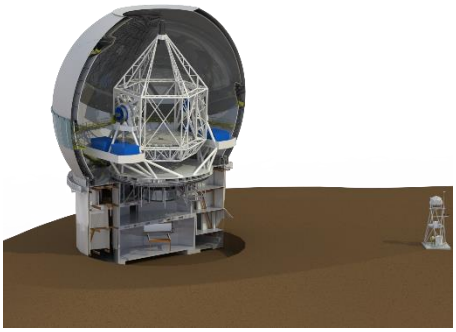


Figure 1 – The proposed successor to CFHT, the Maunakea Spectroscopic Explorer (MSE), is shown in this CAD rendering. If built, it will surely be one of the most scientifically productive machines in astronomy for decades.

What surprised me most over the past 5 years had to be the eruption of conflict over TMT that spilled over into doubts about the future of Hawaii astronomy in general. When we launched the MSE Project Office in March 2014, I anticipated spending large amounts of time building local community support and international funding support for the project. Six months later, with the protests at TMT's ground breaking on Maunakea, everything changed and it became clear that we had to start at a much lower level to build the foundation upon which not only MSE but the future of Hawaii astronomy would be built well into the 21st century. The years since then have been exhausting, tumultuous, emotional, and exciting at one time or another and I am taking away from these years in my career memories that are unique, to say the least, for any astronomer. Building a future for a good portion of 21st century astronomy in a complex setting like Hawaii, with its beautiful and powerful culture, a people struggling to find a unified voice and identity through everything from the awakening of their nearly lost language to nation building, has demanded of me far more than an understanding of telescopes and differential equations. It required going back to truly core aspects of the human experience, understanding and valuing our diverse belief systems and human constructs.

Through it all, CFHT has been visible in the quest for a resolution to the Maunakea conflict. Thanks to seemingly countless interviews I learned early on the techniques of "bridging" and "deflecting" tough questions from journalists, some predisposed to over simplifying or dramatizing the conflict. Case in point, I recall distinctly an interview in the early summer of 2015 by a Hawaii newspaper journalist. We were sitting in a coffee shop, me with a large cup of scorching hot coffee, blending with the summer heat of downtown Honolulu. The lengthy interview started with what is now a familiar first question – "do you mind if I use this?", as he placed a small voice recorder on the table between us. The bleary-eyed journalist asked probing questions, taken aback at my assertion that good things can emerge from these major conflicts. I had no idea what good could come from it, but it was a hard lesson in life that I believed would be proven even in this seemingly hopeless situation. He looked at me in disbelief, not unlike an interviewer I encountered live on the radio weeks earlier when I refused to accept that this is a hopeless battle between science and religion. "There is no way out of this – right?" Such a mindset is self-perpetuating, self-destructive, and needs to be countered with a very different vision for the path forward. Not a "blue sky" vision that is detached from reality, but a vision that is grounded in a deep

understanding and appreciation of how we came to this point, and what it is going to take to move forward. That means not just trying to resolve the TMT conflict, or renew the Master Lease for the Maunakea Science Reserve, but to change the sociological "culture" in Hawai'i so that such a conflict over Maunakea doesn't happen again. Culture change is always hard and requires relationship building at a grass roots level. In this case, it also means inverting the paradigm of outreach and literally bringing the community into the "homes" of the observatories, in our offices in Hilo and Waimea, and in our observatories on Maunakea. This approach requires a long-term commitment from the observatories – one that will sustain a long-term relationship with the community. New initiatives like the Kama'āina Observatory Experience (KOE) and the Maunakea Scholars program flip the paradigm. KOE brings the local community into the observatories to experience a day of learning about the cultural, environmental, and scientific dimensions of Maunakea. In parallel, Maunakea Scholars from several high schools across Hawaii use the most powerful telescopes in the world to pursue their own research projects. The audacity of high school students using machines that can reach back across most of the history of the universe speaks for itself. CFHT also championed the Maunakea Fund in 2016 and played a lead role in developing and supporting EnVision Maunakea. The Maunakea Fund provides funding for the advancement of diverse cultural, environmental, and scientific interests in Maunakea. EnVision Maunakea is a novel program that creates safe spaces for community discussions about the future of Maunakea. Recurring themes and key interests are being documented through this program, leading to a unique and compelling community based vision for the future of the centerpiece of the Hawaiian archipelago – Maunakea. Only time will tell what emerges from these initiatives – perhaps these are some of the good things that emerged from what started as a hopeless conflict.

When I started as CFHT's Director back in 2012, I recall hearing frustrated murmurings from some on the staff – "it's hard living in the shadows of giants". I chuckled to myself – "aperture envy" which I did not share after 18 years at Gemini but I did not take lightly this tacit frustration as I forged my relationship with CFHT's staff. Given what we have all accomplished in recent years, with visionary projects like MSE, that will be built not with just steel and glass but visionary community engagement, CFHT has much to be proud of. In the evening, when I am on CFHT's catwalk, taking in another spectacular 14,000 ft sunset and I see Maunakea's enormous shadow cast on the horizon into space, I know CFHT's shadow is part of that. These days, I think CFHT's shadow is just as long as the other "giant" observatories. In fact, maybe a bit longer.

Figure 2 – Sunset on Maunakea in which the tallest mountain on earth projects its shadow, which contains CFHT's shadow, into space (photo courtesy Jean-Charles Cuillandre).

Science Report

Newborn Giant Planet Grazes its Sun

For the last 20 years the giant planets known as hot Jupiters have presented astronomers with a puzzle. How did they settle into such small orbits, down to 0.01 Jupiter radii? An international team of astronomers including two CFHT resident astronomers, Claire Moutou and Lison Malo, discovered a newborn hot Jupiter, orbiting a star that is only 2 million years old. The discovery that hot Jupiters can already be present at such an early stage of star-planet formation represents a major step forward in our understanding of how planetary systems form and evolve.

For this discovery, the team monitored V830 Tau, located in the Taurus stellar nursery, some 430 light-years away. Over the 1.5 months of the campaign, a regular 4.9 day wobble in the radial velocity of the host star revealed a giant planet almost as massive as Jupiter, orbiting its host star at a distance of only 0.05 AU. This discovery demonstrates for the first time that such bodies can be generated at very early stages of planetary formation and likely play a central role in shaping the overall architecture of planetary systems. The team used ESPaDOnS, Narval and GRACES to monitor V830 Tau for a total of 47 hours. GRACES was used to monitor the star using light from the Gemini North telescope when the instrument was unavailable at CFHT. Using all three telescopes was essential for monitoring regularly V830 Tau throughout the campaign and for detecting its giant planet.

Theoretical work indicates that such planets can only form in the cold and icy outer regions of the protoplanetary disc in which both the central star and surrounding planets are born. Some, however, migrate inwards without falling into their host star, thus becoming hot Jupiters. Planet formation models offer two competing explanations of how and when this migration of hot Jupiters occurred. Either it happened early while these planets were still forming, or much later, with some planets being kicked closer to their stars due to the interaction of multiple planets, or both. This discovery demonstrates that the first, earlier option is taking place; it revives the long-running debate about how and when this migration occurs, and brings us one step forward in our understanding of how planetary systems form.

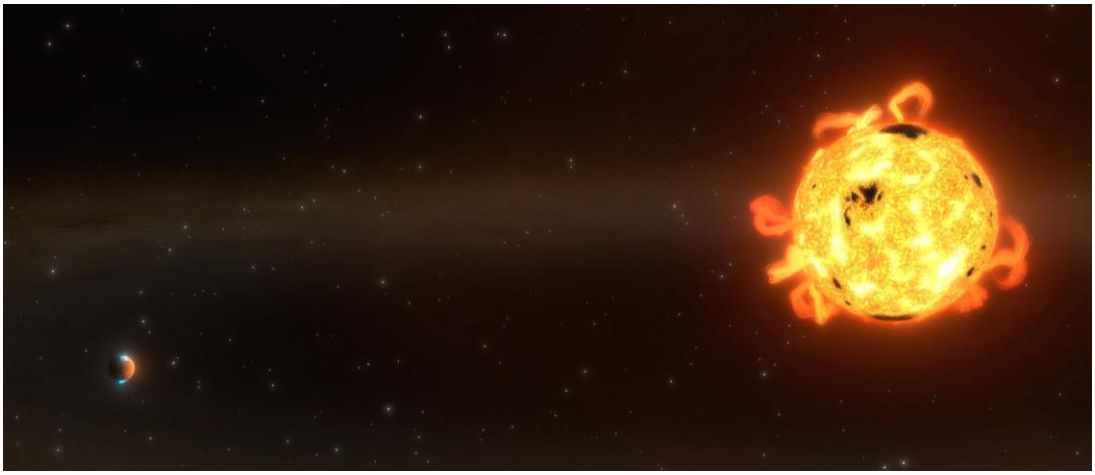


Figure 3 – An artist's view of V830 Tau and the newborn giant planet like the one recently discovered. Infant stars are very active making the detection of planets around them challenging. This image was created by a student artist from Hawaii (credit Michael Ho).

Unique Fragment Returns After Billions of Years of Cold Storage

A unique object that appears to be made of inner Solar System material from the time of Earth's formation and preserved in the Oort Cloud for billions of years was found using CFHT, ESO's VLT and PANSTARRS. This comet brings clues about the origin of the Solar System and is the first object to be discovered that is on a long-period cometary orbit, but that has the characteristics of a pristine inner Solar System asteroid.

Lead author Karen Meech of the University of Hawaii's Institute for Astronomy and her colleagues concluded that the comet C/2014 S3 was formed in the inner Solar System at the time the Earth was forming, but was ejected at a very early stage. Their observations indicate that it is an ancient rocky body, rather than a contemporary asteroid that strayed out. As such, it is one of the potential building blocks of the rocky planets, such as the Earth, that was expelled and preserved in the deep freeze of the Oort Cloud for billions of years.

Comet C/2014 S3 was discovered using PANSTARRS and was immediately labelled as unusual, as it does not have the characteristic tail that most long-period comets have when they approach the Sun. As a result, it has been dubbed a "Manx comet", after the tailless cat. Observations in the days after the discovery suggested that its colors might be interesting, so follow-up multifilter observations were obtained in October 2014 using CFHT followed by spectra in November 2014 using the VLT in Chile.

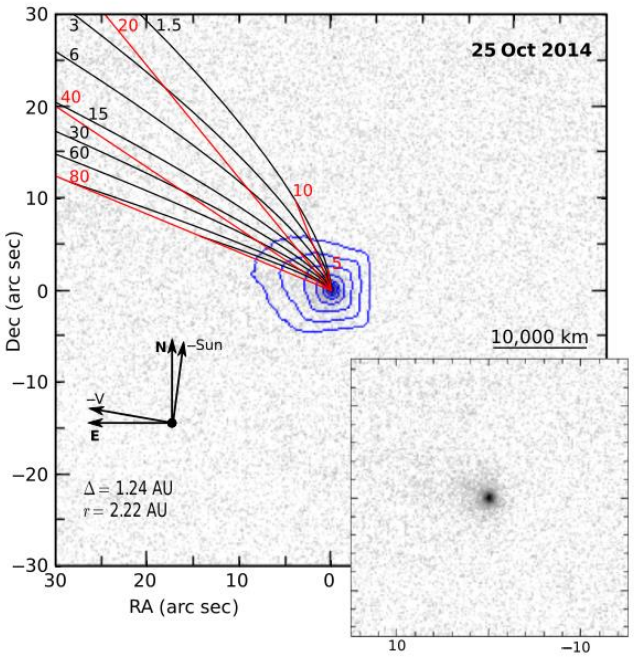


Figure 4 - CFHT image of C/2014 S3 (PANSTARRS) obtained in October 2014. The background stars have been processed out of these composites. The comet was at heliocentric distances (r) of 2.11 and 2.22 AU, moving outward from its perihelion at 2.05 AU on 13 August 2014. The syndynes (black; grain sizes are expressed in micrometers) and synchrones (red; positions noted in days before the observations) map out the expected position of the dust released from the nucleus under the influence of solar radiation pressure. Different lines indicate the locus of dust of different sizes released at different times; the marked change between the two epochs reflects very different viewing geometries. The blue isophotes are equally spaced on a logarithmic scale. The insets are at the same scale as the main images. The arrows indicate the directions of North and East and of the antisolar and negative of the heliocentric velocity vectors (−V). Dec, declination; RA, right ascension; D, geocentric distance. Credit: Karen Meech, University of Hawaii, CFHT.

Careful study of the light reflected by C/2014 S3 indicates that it is typical of asteroids known as S-type, which are usually found in the inner asteroid main belt. It does not look like a typical comet, which are believed to form in the outer Solar System and are icy, rather than rocky. It appears that the material has undergone very little processing, indicating that it has been deep frozen for a very long time. The very weak comet-like activity associated with C/2014 S3, which is consistent with the sublimation of water ice, is about a million times lower than active long-period comets at a similar distance from the Sun.

A number of theoretical models are able to reproduce much of the structure we see in the Solar System. An important difference between these models relates to what they

predict about the objects that make up the Oort Cloud, particularly regarding the relative numbers of icy and rocky objects it contains. This first discovery of a rocky object from the Oort Cloud is therefore an important test of the different predictions of the models. The authors estimate that observations of 50–100 of these Manx comets are needed to distinguish between the current models, opening up another rich vein in the study of the origins of our Solar System.

A New Dwarf Planet Discovered with CFHT

An international team of astronomers discovered a new dwarf planet, designated 2015 RR245 that orbits partly in the Kuiper belt and is roughly 700 kilometers in diameter. It has one of the largest orbits known for a dwarf planet and was discovered using CFHT as part of the ongoing Large Program entitled the Outer Solar System Origins Survey (OSSOS).

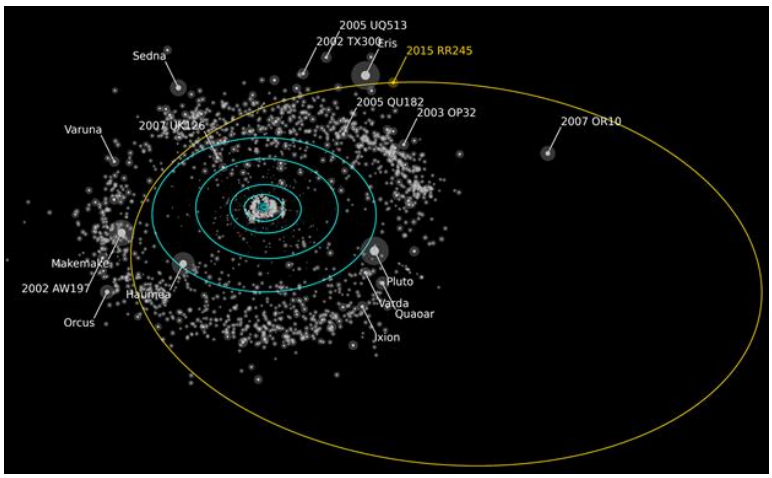


Figure 5 - Rendering of the location and orbit of RR245 (yellow line). Objects as bright or brighter than RR245 are labeled. The blue circles show the projected orbits of the major planets. The Minor Planet Center describes the object as the 18th largest in the Kuiper Belt. Credit: Alex Parker, OSSOS team.

Icy worlds beyond Neptune trace how the giant planets formed and then moved out away from the Sun and allow researchers to piece together the history of our Solar System. The vast majority of dwarf planets like 2015 RR245 were destroyed or thrown from the Solar System in the early chaos that ensued as the giant planets moved out to their present orbits: RR245 is one of the few dwarf planets that has survived to the present day — along with Pluto and Eris, the largest known dwarf planets. 2015 RR245 now circles the Sun among the remnant population of tens of thousands of much smaller trans-Neptunian worlds, most of which have unknown orbits. RR245 is travelling towards its closest approach at 34 AU, which it will reach around 2096 and its orbital period is about 700 years.

RR245 is the only dwarf planet found by OSSOS, which has discovered more than five hundred new trans-Neptunian objects. Projects like OSSOS are only possible due to the exceptional observing capabilities of CFHT. The unique site coupled with the wide-field capabilities of MegaCam and the flexibility of queue scheduling are optimal for such discoveries. RR245 may be one of the last large worlds beyond Neptune to be found until larger telescopes, such as LSST, come online next decade.

Structure of the ISM Revealed on Unprecedented Scales

This third quarter press release also uses the wide field capabilities of MegaCam but this time, the capabilities of the instrument allow high-resolution low surface brightness measurements in conjunction with data obtained from space with Planck and WISE to reveal the structure of the diffuse interstellar medium over several square degrees with unprecedented sensitivity.

The team of researchers derived the statistical properties of interstellar turbulence over a wide range of scales, from 0.01 to 10 pc. The main innovation of this work is the use of a large optical telescope (CFHT) to study the structure of the interstellar medium at high resolution and on a large area on the sky, something that is very challenging to obtain with observations done in the infrared. The mapping of these interstellar cirrus clouds located within a few hundred parsec from the Sun can be done because interstellar dust grains scatter starlight. This scattered light has been detected for decades by optical telescopes but here, it is the first time that is exploited scientifically to study the structure of interstellar clouds which are composed of faint filamentary structures of various sizes. The result obtained benefits from specific image processing and data acquisition techniques developed in the context of the MATLAS Large Program at CFHT that aimed at detecting faint diffuse emission around galaxies.

One advantage of the high angular resolution provided by MegaCam on CFHT is to eventually reach the angular scale at which turbulent energy dissipates. Understanding the exact process by which kinetic energy is dissipated and heats the gas is essential. It is key in the formation of dense structures that lead to the formation of stars. For instance, recent studies based on Herschel observations of molecular clouds have revealed the presence of filaments with widths of 0.1 pc that seem constant whatever their mass. This observational fact has been attributed to the energy dissipation process, namely ambipolar diffusion (friction between neutrals and ions). The present study shows that the dissipation scale in the interstellar medium is smaller than 0.01 pc which brings important constraints on the exact process responsible for this dissipation.

These results emphasize the fact that scattered light from cirrus, an important source of pollution for deep imaging destined to mapping diffuse structures around massive galaxies, is carrying potentially precious information about the nature of the physical processes involved in the evolution of matter in our own galaxy.

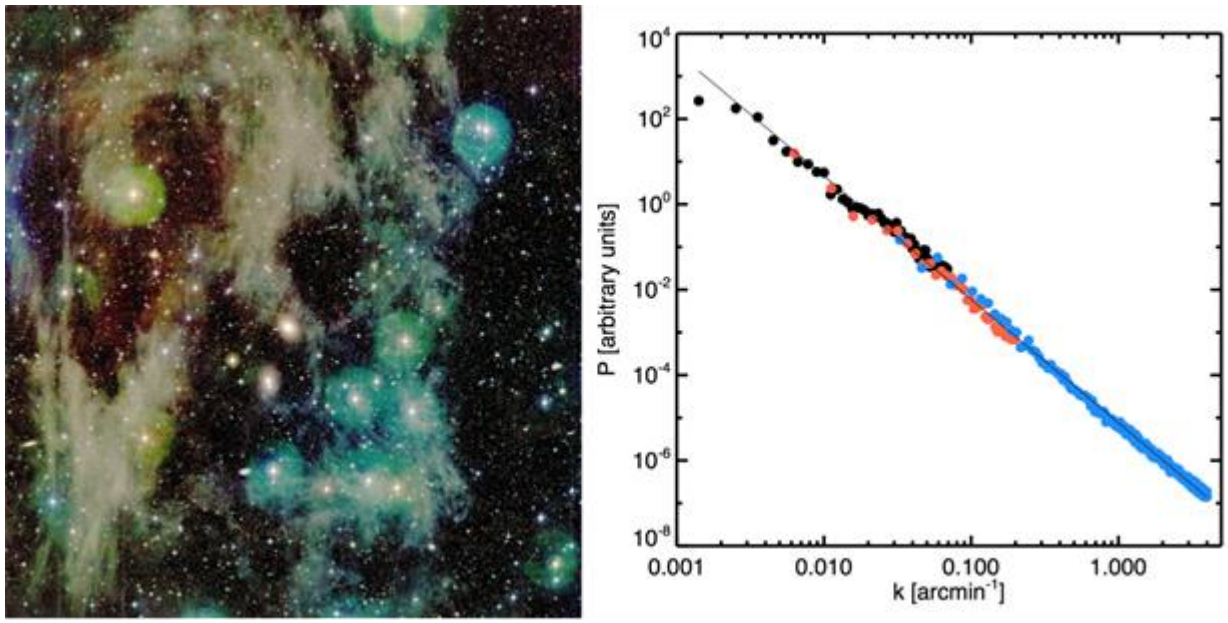


Figure 6 - Left: Optical images in true colors of the cirrus field obtained with MegaCam on CFHT. (Image Credits: MATLAS collaboration, Pierre-Alain Duc). Right: Combined power spectrum : black is Planck radiance, red is WISE and blue is MegaCam. The units of the y axis are arbitrary; each power spectrum was scaled in order to match the others. For each power spectrum, we show data points corresponding to scales larger than the beam and where the power is above the noise component. The data points shown here are noise subtracted and divided by the beam function. The best fit gives P(k) ~ k^(2.9±0.1). (Figure from Miville-Deschênes et al. 2016).

A New Look at the Largest Known Disk Galaxies

A Canadian and French team of researchers from the Laboratoire d'Astrophysique de Marseille, NRC Herzberg and Queens University studied Malin 1, a nearby galaxy that was discovered in the eighties and is known to contain an extremely large disk of gas and stars. The new observations of Malin 1, a prototype giant low surface brightness galaxy, allowed the team to obtain new results in contradiction with one of the hypotheses concerning the formation of this type of galaxy.

Despite their large mass, because they are diffuse and have a low surface brightness, galaxies like Malin 1 are difficult to detect and are still poorly understood. They could represent a significant percentage of the galaxies in the universe because they could be easily missed in surveys. It is thus important to study them and understand their formation and evolution. This is now possible owing to large aperture telescopes, modern detectors and observing techniques that allow deeper observations of low surface brightness objects.

This paper presents for the first time deep images obtained at 6 different wavelengths, from the FUV to the near-infrared. The optical data was obtained as part of the Next Generation Virgo Survey (NGVS) large program using MegaCam on CFHT. Originally this campaign was planned to study the Virgo cluster but it also supports the study of background objects like Malin 1. The NGVS images offer a new view of this spectacular galaxy, the largest galactic disk known, with a diameter exceeding 250 kilo-parsec.

Figure7 – Combination of 4 NGVS images of Malin 1 obtained with MegaCam. The scale of the figure gives an indication of the size of the galaxy. In comparison, the Milky Way has a diameter of ~30 kpc. Image Credit: Samuel Boissier/A&A/ESO/CFHT.

The team of researchers extracted from these data radial luminosity and color variations. The colors strongly depend on the galaxy's star formation history. Comparing observations with predictions from various numerical models allowed the team to estimate for the first time the history of star formation in the giant disk of Malin 1. Their analysis suggests that the giant disk has been in place for several Gyr, and that star formation proceeded at a normal long-term pace despite the very low disk density.

This result is important as it contradicts a scenario proposed recently predicting that these giant galaxies are formed during violent interactions. Moreover, in the context of the cosmological formation of galaxies, numerous mergers and gravitational interactions should have perturbed the disk of Malin 1. The formation of such a structure and its survival for a very long time presents a challenge for simulations of galaxy formation.

Engineering Report

SITELLE

This novel instrument is capable of interferometric imaging down to UV wavelengths and was used in 2016 for a number of interesting research programs. With its 10 arcmin field of view SITELLE is ideal for recording emission line spectra of complex/diffuse fields, providing measurements of velocity fields, chemical compositions, energy states, electron densities, etc. Measurements of dynamics, metallicities and star formation activity across entire galaxies in a single scan will be commonplace with SITELLE. Figure 8 shows one of the more impressive images recorded with SITELLE in 2016 of a nebula in which various emission lines exhibit the well-defined sinc-function instrument line shape characteristic of FT spectrometers at R~5000. Delivered spectral resolution depends on source brightness, scan parameters and observing conditions but for many objects this type of spectral resolution is feasible and is easily high enough to reveal interesting physics of emission line fields.

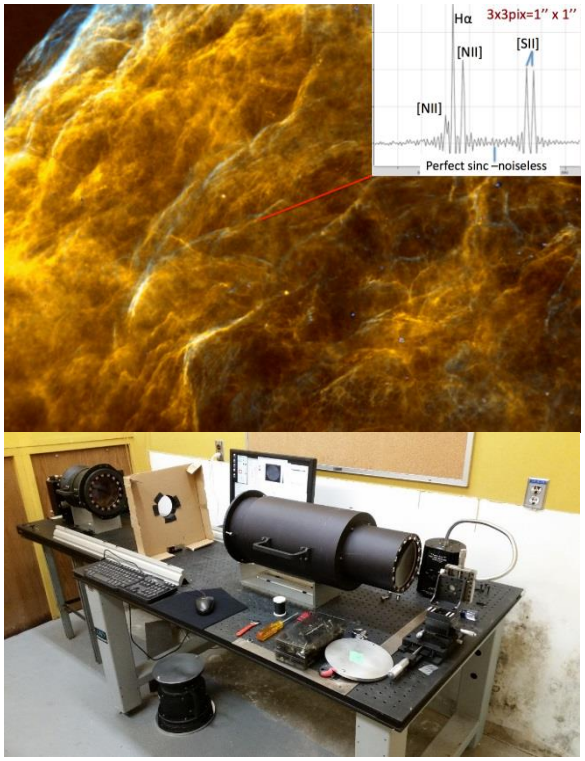


Figure 8 – Top: Emission line spectra from an observing run in March 2016 show both excellent image quality and exquisite FTS instrument line profiles. Bottom: Collimator and camera optics installed on a lab bench for testing off the instrument.

From an engineering perspective, the main challenges with SITELLE in 2016 included achieving reliable modulation efficiency during scans requiring large optical path differences and good image quality across the entire field. While SITELLE is yielding outstanding science, improvements in these areas are needed for SITELLE to reach its performance potential. Work on improving SITELLE's off-axis image quality included removing the camera assemblies and measuring transmitted wavefronts that could be compared to model performance. These tests revealed field dependent aberrations but the source within the optical assemblies remains to be identified. No matter what the cause, the reduced image quality affects only the outer ~20% of the field of view, so in most cases does not impact observations significantly. Work on modulation efficiency improvements includes injecting a tilt in SITELLE's scan mirror that increases linearly with optical path difference. That change significantly improved modulation efficiency. In addition, one of the scan system actuators failed in 2016 and had to be replaced. Despite these technical challenges, which thus far have marginally impacted science operations with SITELLE, this amazing instrument continues to produce stunning results that over time will add in important ways to CFHT's science and instrumentation legacies.

SPIRou

Anticipation builds with the advancement of SPIRou's assembly at IRAP in Toulouse, France. SPIRou is likely the most complex and expensive instrument ever built for CFHT, with a scientific promise to match. It is a fiber-fed YJHK spectropolarimeter with R~70K spectral resolution and ~1 m/s velocity stability – a unique combination of capabilities in astronomy. Key to SPIRou's use in a major exoplanet survey from Maunakea is its ability to measure and disentangle radial velocity measurements from the magnetic activity that is commonly found in the low mass (M type) stars that SPIRou will preferentially observe. The previously mentioned work with ESPaDOnS used to identify a hot Jupiter in close orbit to a low mass, magnetically active star, is an important step in developing the techniques required to make such measurements with SPIRou.

Figure 9 – Top: The Cassegrain feed for SPIRou is shown in the lab at IRAP. Middle: The cryo-bench ready to be enclosed in SPIRou's large vacuum jacket is shown. Bottom: Mounting the parabolic mirror used in double pass in the spectrometer optical assembly is shown.

Some of the technical progress made with SPIRou in 2016 includes ASIAA completing their development of the SPIRou guide camera. This subsystem feeds a fast tip/tilt compensator in the pre-fiber Cassegrain optics, providing optimal centration of the PSF at the fiber entrance pupil. The Cassegrain unit was successfully tested in a cold chamber at IRAP and is now mostly complete. In addition the calibration unit, which is a temperature stabilized Fabry Perot etalon that produces a multitude of emission lines which serve as a velocity fiducial, was also delivered to IRAP in 2016. The cryo-bench and associated vacuum jacket was completed at HAA in Victoria, Canada, after testing was completed to verify its baseline performance, without the spectrograph optics installed. After arrival in IRAP key tests were performed that demonstrated milli-kelvin temperature stability under thermal load conditions similar to what will be experienced when the cryo-bench is populated with the spectrometer's optical assembly. One of the most challenging optical elements in SPIRou is the image slicer, which is being manufactured by Winlight. That component was completed and coated in late 2016. The science detector for SPIRou will be a Teledyne H4RG sensor that is currently being fabricated as a contribution from CFHT to the project. That is on track for a delivery in late 2017 to Hawaii where it will be integrated with the instrument. In the meantime engineering grade H4RG and H2RGs are being used to support lab I&T work to ensure that the opto-mechanical assembly meets a variety of performance requirements before it is shipped to Hawaii. CFHT continued to prepare the Coude room to house SPIRou, as well as upgrade cooling systems and develop software needed to operate SPIRou remotely from Waimea. Overall, great progress in 2016 for the next major instrument slated to join WIRCam, MegaCam, SITELLE, and ESPaDOnS on Maunakea at CFHT.

MegaCam

The bulk of the upgrade effort made on MegaCam in 2016 was dedicated to speeding up its array controller. This was part of a number of improvements intended to boost overall MegaCam observing efficiency in advance of the launch of the next round of Large Programs in 2017A. This included investment in >$500K in new filters which have significantly higher throughput and larger formats allowing all 40 MegaCam CCDs to be used for the first time. Combined with significantly improved delivered image quality due to the retrofit of dome vents, and SNR QSO which iteratively adjusts integration times to reach a predefined SNR, these improvements are leading to potentially weeks of additional observing time each year for CFHT's community.

Work on speeding up MegaCam's controller in the first half of 2016 focused on hardware upgrades and developing a deeper understanding of firmware and limitations built into the overall system. This analysis indicated that the overarching speed limit in the system stems from the SHARC Digital Signal Processors (DSPs) built into the MegaCam array controller. Replacing those DSPs and associated Analog to Digital Convertors would amount to essentially rebuilding the entire controller and was beyond the scope of the upgrade. Nonetheless, within the performance envelope of the DSPs, room for increased readout speed with little-to-no effect on noise performance was identified.

Beyond controller limitations, faster readouts inevitably lead at some point to increased noise from the output amplifiers in the CCD 42-90 detectors used in MegaCam. One manifestation of that increased amplifier noise is in the form of readout oscillations or "waves" that lead to periodic bias offsets during the initial column readouts that can be as large as 40 – 50 ADU. Historically this has been handled by first clocking 50 fake pixels to stabilize the system before prescan and actual pixel readout occurs, leading to a 40.8 second total readout time for the focal plane. The upgraded system now skips the readout of fake pixels at the expense of injecting repeatable oscillations in the first 128 columns of each detector, which typically have ~10 ADU amplitudes. Because these oscillations or "waves" are repeatable bias offsets, they are automatically subtracted with a master bias through the standard MegaCam data reduction pipeline. Figure 10 below shows the before/after master bias substraction of this new readout mode. This new readout mode allows full focal plane readout in 33.9 sec, or a reduction of 6.9 sec per readout compared to methods used to date with MegaCam. Though this may not sound like much given how often MegaCam is readout over the course of a year, as CFHT's most popular instrument, this ~15% boost in readout speed adds up over time, particularly in high cadence observations needed by large surveys like the CFIS Large Program launched in early 2017. Detailed on-sky tests confirmed that this new faster readout mode has no significant effects on data quality. Other upgrades under consideration include upgrading the window in MegaCam to Fused Silica with a high performance broadband coating. Again, all of this leads to steady performance gains for CFHT's most popular instrument.

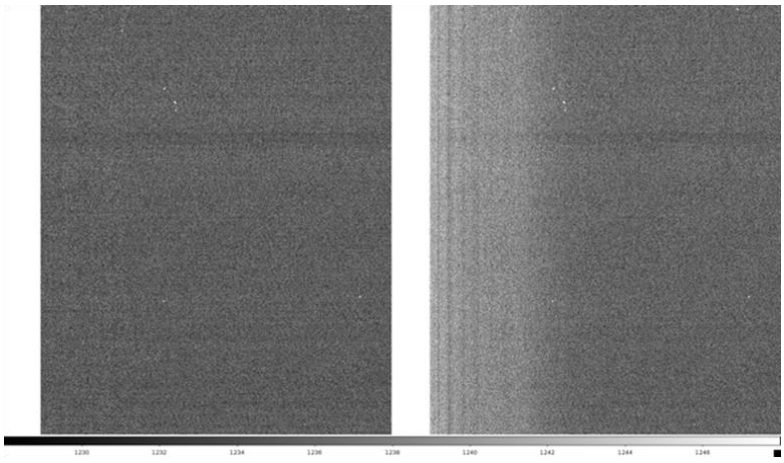


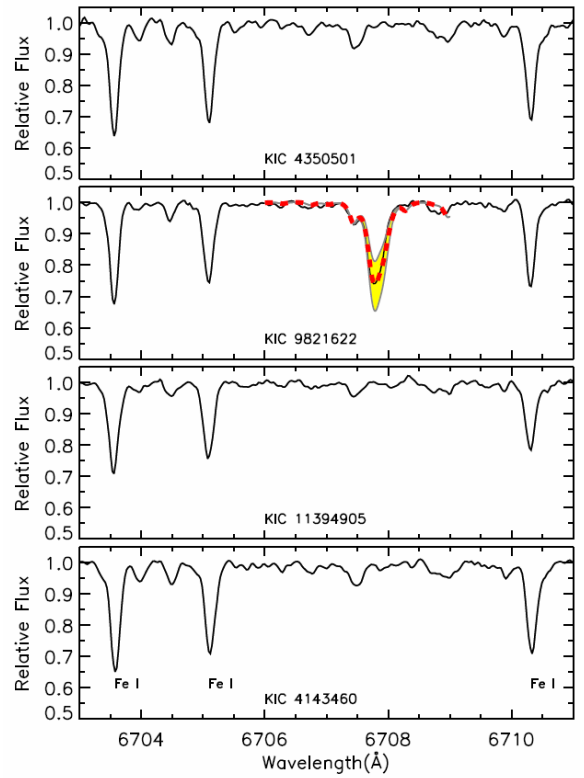
Figure 10 – Image after subtraction of a master bias image (left) and a raw bias image (right). Notice the removal of residual "waves" in bias in the columns initially read out.

GRACES

Gemini Remote Access to ESPaDOnS (GRACES) was fully operational in 2016, with considerable demand from the Gemini community for this innovative research tool that stems from exceptional inter-observatory collaboration. The demonstrated performance and demand of GRACES led to discussions in 2016 to extend the duration of the collaborative agreement between Gemini and CFHT for GRACES, as well as the opportunity for CFHT's community to use Gemini time allocated via the GRACES program through Gemini's queue based observing system. This should increase the flexibility and hopefully demand for GRACES exchange time. Under the terms of this agreement, CFHT makes ESPaDOnS (GRACES) available when ESPaDOnS is otherwise not being used for CFHT based observations. In exchange, the CFHT community receives observing time using either Gemini telescope and any instrument at the exchange rate of 15% of the time GRACES is used. Time is "banked" at CFHT and enough is now available that a steady stream of 3-4 nights of Gemini time per semester should be available to CFHT's community.

Though GRACES does not support spectro-polarimetry, it does offer R~40K spectroscopy using a 2-fiber (object + sky) mode, or R~68K resolution in single fiber (object only) mode. Both modes extend several magnitudes deeper than what is possible at CFHT. Target acquisition is supported via GMOS at Gemini-N which loads a special cassette into its slit mask assembly that holds the GRACES fiber pick-off assembly. Targets are first imaged with GMOS and precision offsets executed to move objects into the fiber entrance pupil after the GRACES fiber assembly has been moved into the GMOS focal plane. Guiding is performed through the standard on-instrument wavefront sensor in GMOS.

This demonstration of fiber-fed instrumentation connecting CFHT and Gemini is in principle extensible to other observatories across the summit since most of the losses are incurred at the fiber entrance/exit interfaces, not the fiber itself (except for blue wavelengths of light). We look forward to seeing other instruments shared across Maunakea like this in the future.



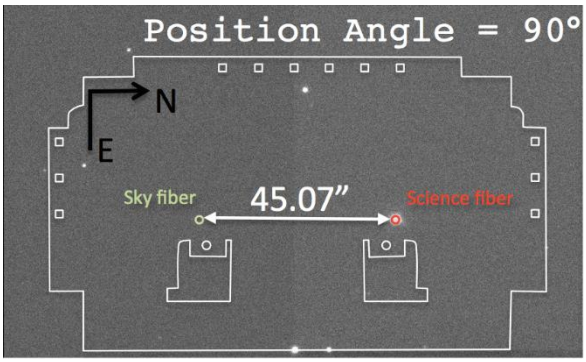


Figure 11 – Above: The "finishing touches" on the GRACES program were made in 2016 with these artistic additions to the outside of the thermal enclosure used to contain ESPaDOnS. Middle: Some of the first research published via GRACES is shown in the form of spectra of four massive and young [α/Fe]-rich red giant stars (Yong et al. 2016). Bottom: Sky/Object fiber entrance geometry of GRACES at the GMOS input at Gemini-N.

Facilities Development

f/8 Secondary Mirror

The f/8 secondary mirror support system was upgraded during 2016 to improve performance and reliability. One consequence of this upgrade is improved point spread functions at the telescope's Cassegrain focus, which occasionally produced triangular shaped stellar images, reducing throughput in ESPaDOnS. The problem was traced to excessive bending forces being placed on the back of the secondary mirror, which is normally held in place through a combination of mechanical defining posts and vacuum pressure on the front face of the mirror. Engineering a solution to the passive secondary mirror mechanical control system, which dates back to the original design of the telescope, was achieved through the use of load cells retrofitted into the assembly. These were used to fine tune the vacuum regulators so the secondary mirror maintains positive contact load on its defining pads over the sky but not to the point of deforming the mirror and producing triangular images. The vacuum (or "cosine") regulators were adjusted to give a relatively flat force curve with telescope zenith angle. The force curve now shows a maximum load per pad of 10 kgf and a variation of ~ 2kgf per fixed pad from 0 to 80 degrees zenith angle. Given that the mirror support vacuum and bending forces on the glass are on the order of 5000 Newtons, small residual force changes are not unexpected but remain within operating margin.

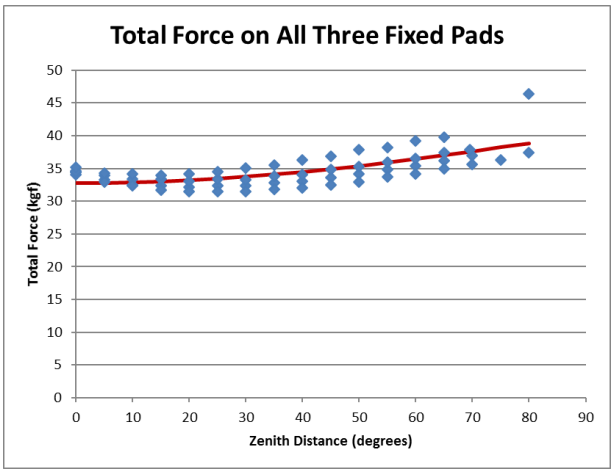


Figure 12 – The summed force over all three fixed pads of the f/8 secondary support system at various telescope angles. The different branches in the data are for telescope motions to the North, South, East and West. The solid line is the predicted force based on fits of the pressure and vacuum data to cosine curves.

Other upgrades include digital readouts that show load cell forces in the control room and the Waimea remote operations room. The vacuum pumps have been upgraded and the facility dry air supply, in combination with a Venturi pump, yield a more stable, reliable, and responsive f/8 support system than we have probably ever had. While additional minor upgrades are anticipated, this type of on-going system upgrade of "legacy" hardware on the telescope is needed to sustain optimal performance.

Preventative Maintenance Program

The new preventative maintenance (PM) program is being used regularly and increasingly by the Operations Group as they become familiar with it. PM task information is now being performed and entered into the PM software program when a particular PM task is due. Other tasks not yet scheduled but on the task list are being added as time permits. The PM tasks have also been incorporated into the Technical Operations Meeting (TOM) schedule which will improve planning and provide resources available for support and/or upgrade projects. The ability to review and create reports of completed work tasks is being developed and will improve overall visibility of the observatory maintenance systems. This important new tool in our summit systems has grown increasingly important as core systems in the observatory age and demand greater scrutiny to maintain uptime.

Query Results

Description	Location	System	Status	Work Type	Priority	Due/Comp
Basement AHU	Basement	Building Exhaust	Completed	Mechanical	High	Sep 14, 2016
Generator	1st Floor	Diesel Generator	Completed	Mechanical	High	Sep 14, 2016
Generator load test	1st Floor	Diesel Generator	Completed	Electrical	High	Sep 14, 2016
water pumps and storage tank	Basement	Water System	Completed	Mechanical	High	Sep 14, 2016
WeldingShop PM	1st Floor	Machine Shop	Completed	Mechanical	Low	Sep 14, 2016
Air Compressor #2 "6-Month Service Cycle"	Basement	Dry Air System	Completed	Mechanical	Medium	Sep 14, 2016
Diesel pump room	Basement	Diesel Generator	Completed	Mechanical	Medium	Sep 14, 2016

Figure 13 – An example of a database query for tasks completed on Sep 14th, 2016 using the new preventative maintenance tool on the summit.

Telescope Hydraulic Upgrade Project

A new oil dehydration system has been installed and functionality tests are being performed to determine the run-time required to remove specific water levels from the telescope hydraulic fluid. The system comes equipped with a water % sensor which dictates the amount of saturation in the fluid passing through the system.

Since the current hydraulic oil filters are no longer manufactured, a new particulate filtration system was selected and ordered as a replacement and upgrade. The new filters have dirty filter sensors to warn when filter replacement is due. It will be installed on circuit one of the hydraulic system after the low pressure pump to support fit and functionality tests. Once testing is finished, the remaining filtration components will be ordered and installed to complete the upgrade. Given the importance of having a reliable hydraulic system to operate the telescope, this work is crucial to sustain CFHT's operational performance.

Figure 14 – The new HYDAC water removal system for the summit hydraulic supply is shown.

Telescope Declination Pin Upgrade

The telescope declination pin was reworked and its actuation mechanism and position sensing circuit were upgraded. The work eliminated a problem due to the declination pin not moving when commanded which occurred intermittently during insertion and removal of the pin. The upgrade also moved the telescope parked position closer to true zenith. During past removal of the primary mirror at aluminizing shutdowns, poor alignment between the telescope and the mirror cart due to the past offset has caused fairly serious operational problems which should now be solved. This work was an Akamai student intern's project and is a great example of how interns in the Akamai program perform important tasks at the Maunakea Observatories.

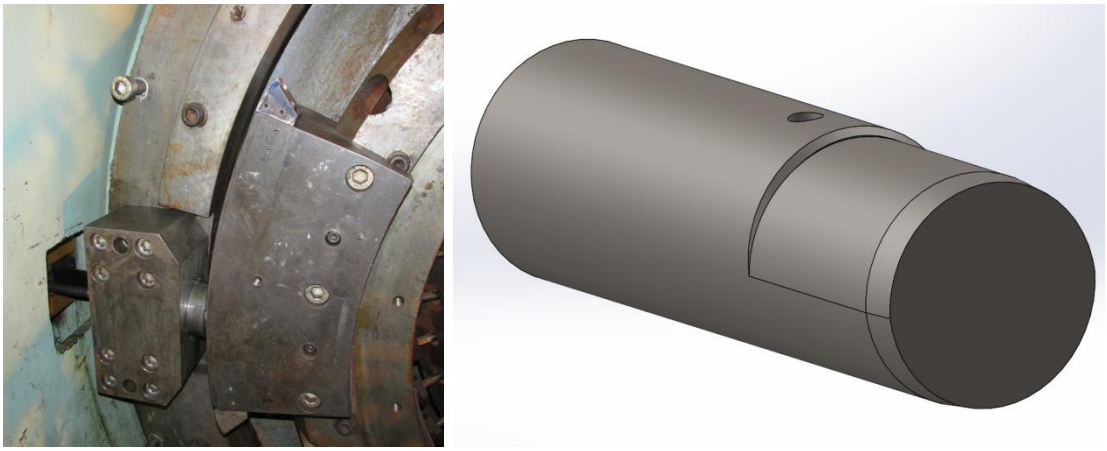


Figure 15 – Declination pin insertion mechanism (left) & new declination pin with relief to provide angular alignment (right).

QSO software

We have undertaken a project to update our PH2 tool and to develop an API for large program teams that want to develop their own software to manage their programs. The changes are targeted specifically at assisting large and complex programs. The API can be used to get information about observing programs and to configure them using scripts to replace or compliment the graphical PH2 user interface. This could be useful for large or complex programs that require a lot of interaction with PH2. Eventually the API will serve as the foundation for an updated version of the graphical PH2 and PH1 web interface. We are working on three parts of this system in parallel:

- A data-exchange format

Currently this specification is in JSON, which is a popular human-readable data standard. We have a proposed format that can express every defined field of an observing program and we are working on a format for making changes such as deleting or adding a target or changing an instrument configuration.

- A database backend

We need to upgrade our database servers and are making sure the API will work with the new system.

- A new authentication interface

The API will include methods for authenticating users and transmitting data. The authentication system will provide self-service account management and the ability to assign roles to multiple users working on the same observing program.

The data-exchange specification was completed in late 2016 and in early 2017 we plan to start testing the API functions on the live system and working with large program teams to start integrating tools. We expect to release the API to all users in mid-2017 and to start releasing new web-based tools in late 2017. The usual web PH2 will continue to be available throughout this transition.

MSE Report

Spring of 2016 saw the release of "The Detailed Science Case for the Maunakea Spectroscopic Explorer" (DSC). This major milestone marked the culmination of a multi-year effort by the Science Team to identify the primary transformational science goals of a wide-field MOS facility, and to set such a facility within the international landscape of the 2020s and beyond. The DSC is approximately 200 pages long, with an additional 100 pages of appendices, and has nearly 180 co-authors. The essential summary of the project is contained within the first chapter and a 10 page "précis" document was also released at the same time as the DSC, providing a concise overview of the project.

The DSC was based around the development of "Science Reference Observations", that is, science programs that are transformational in their field and unique to MSE. These SROs therefore directly link the DSC to the Science Requirements Document (SRD). A third key document with significant science input is the Operations Concept Document (OCD) that the MSE Systems Scientist has been leading and is scheduled for completion in 2017. Among other topics, this document focuses on the implementation of the science programs at the telescope.

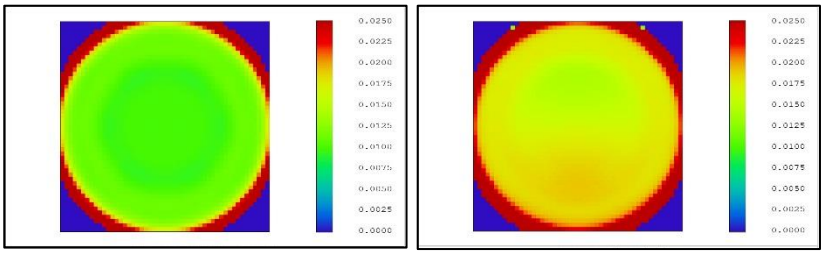


Figure 16 - RMS image quality maps for (left) ZD=0° and (right) ZD=50°. The asymmetry in the ZD=50° case is due to the ADC action.

The MSE Science Team continues to accrete new members, and we now have 103 members from across the international community (Australia – 16; Canada - 17; China - 8; France - 24; India – 10; Spain - 8; USA – 11; Others – 9). At the MSE All-Team Meeting in Madrid in the spring, a subset of this group met for discussions on science development after the completion of the DSC. As a result of this meeting and the confluence of other activities, the science focus for next year will be on survey development and implementation.

MSE's engineering world was a very productive one in 2016. Early in the year saw the formal design review validating the telescope optical design. The design was reviewed by a panel of five international members who were specifically charged to assess the rationale and maturity of the proposed widefield corrector design and to recommend risk mitigation strategies. The review panel endorsed the selected design but also recommended that we engage an independent consultant to liaise with vendors on the feasibility of the challenging fabrication task, leveraging their expertise and established methodologies in polishing and

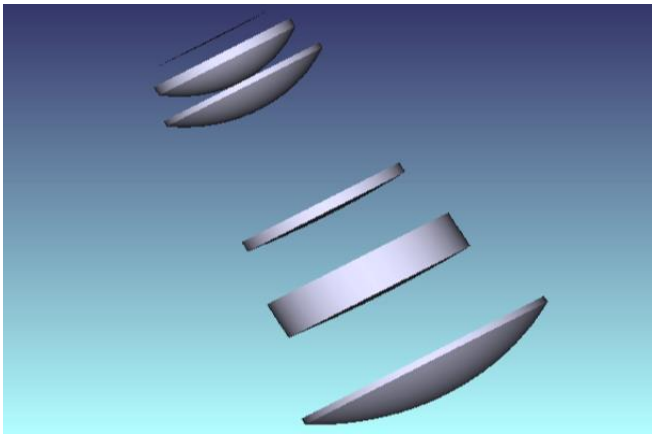


Figure 17 – Prime Focus Corrector and ADC for MSE.

optical testing – a recommendation that resulted in MSE engaging the optical consultant, Prime Optics in this role.

Independent of the work by our partner, Indian Institute of Astrophysics, on the primary mirror (M1) system conceptual design, the consultant Structural Design Solutions was contracted to assess the fabrication feasibility of the M1 segments by adopting the fabrication techniques developed for the E-ELT and TMT projects. Initial findings indicated the existing technologies are well suited for the MSE implementation, including the segment support system for individual segments and the overall segment alignment and global M1 figuring control.

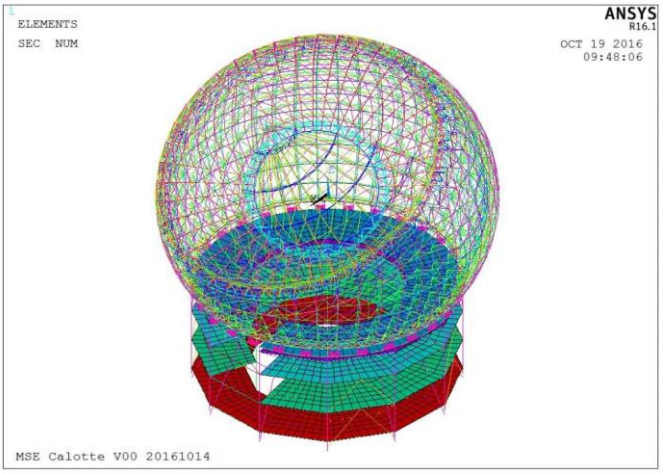


Figure 18 - EDS Calotte FE model.

Using the telescope optical layout, Empire Dynamic Structures (EDS) was contracted in Q1 2016 to develop a mutually compatible telescope and Calotte enclosure configuration in order to inform the conceptual designs of the Telescope Structure and Enclosure. This "pre-conceptual" configuration was based on a 10% maximum growth of the current building space envelope. In order to maximize the enclosure size while keeping the growth of the overall building height to within 10%, the optimal configuration requires removal of the current observing floor from the outer building. The EDS configuration became the starting point for the subsequent Telescope Structure and Enclosure conceptual designs.

In Q2 2016, two Call-for-Bids were issued: for the Enclosure and for the Telescope Structure conceptual designs. After evaluating the proposals submitted, EDS was again selected to continue the enclosure work and the Spanish firm IDOM was selected for the telescope work. Regular progress meetings through the latter half of the year provided both the PO and the contractor early guidance and feedback, as both firms work toward their conceptual design reviews planned for Q1 2017.

One of the design drivers in both efforts is a conservative mass allocation; necessarily conservative due to discrepancies in the soil bearing capacity values found in the historical CFHT design documents. To better understand the soil capacity – and whether the mass allocations might be relaxed - Fewell Geotechnical Engineering has been contracted to measure the soil bearing capacity by on-site core drilling at the CFHT site.

A contract has also been prepared with M3 Engineering to provide some of the conceptual design work needed to upgrade the current outer building enclosure pier and inner telescope pier for the new observatory, structurally and architecturally, and in a way that meets both the user requirements and the County-imposed Building Code regulations.

Engineering work within the MSE Project Office (PO) also continued to accelerate as the project moved through the conceptual design phase in 2016. A combined science and engineering meeting in Madrid last April underscored the importance of the PO's coordinated development of interface definitions and coherent design requirements among the observatory subsystems within the international engineering team. Happily, our ability to do so was bolstered in no small way by the newest addition to the PO staff.

Alexis Hill joined the team in August, bringing strong opto-mechanical and systems engineering experience to address the needs identified at the Madrid meeting. Her tireless attention to detail has already proven to be invaluable in coordinating the many and complex interfaces in the Top End Assembly; an area which brings together the wide field corrector, instrument rotator, hexapod, acquisition and guide systems, fibre positioners and fiber transmission system, and all in a restricted volume and with limited mass allowance.

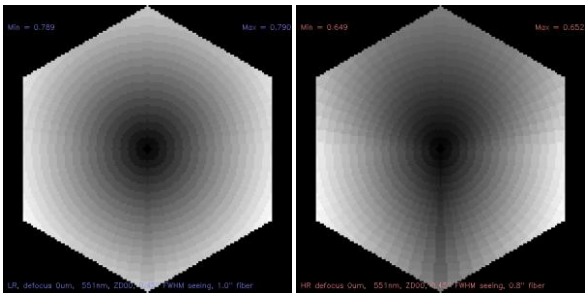


Figure 19 - Grey-scale maps of the injection efficiency as seen by the LMR spectrograph (left) and HR spectrograph (right), at the optimal position, across the entire field of view, with the telescope pointing at zenith, at 551nm, without defocus, with a seeing of 0.45" FWHM, and fibers of 1.0" diameter.

Central to maintaining a systems engineering approach to the design of MSE, of course, is the need for the PO to develop and maintain error budgets and performance models of the configured design, and this too has grown into an important activity through the Conceptual Design phase. The error budgets and models are used to understand MSE's ability to meet its highest level science requirements, and perhaps the most demanding and technically far reaching of those requirements is that for very high system sensitivity. MSE's high sensitivity over wide wavelength coverage is, more than any other science requirement, what will give us access to new discovery space - with its promise of rich scientific return. Accordingly, the priority in MSE's performance budget activities in 2016 has been to identify and characterize system parameters that affect a key element of the system efficiency: the fibre injection efficiency. The systems engineering team has developed a modular Integrated Time Calculator (ITC) framework and a detailed injection efficiency model that accounts for over twenty parameters within the baseline MSE design. As we move toward the numerous decisions that will need to take place at the end of the Conceptual Phase, this efficiency model will become an important tool in the decision process.

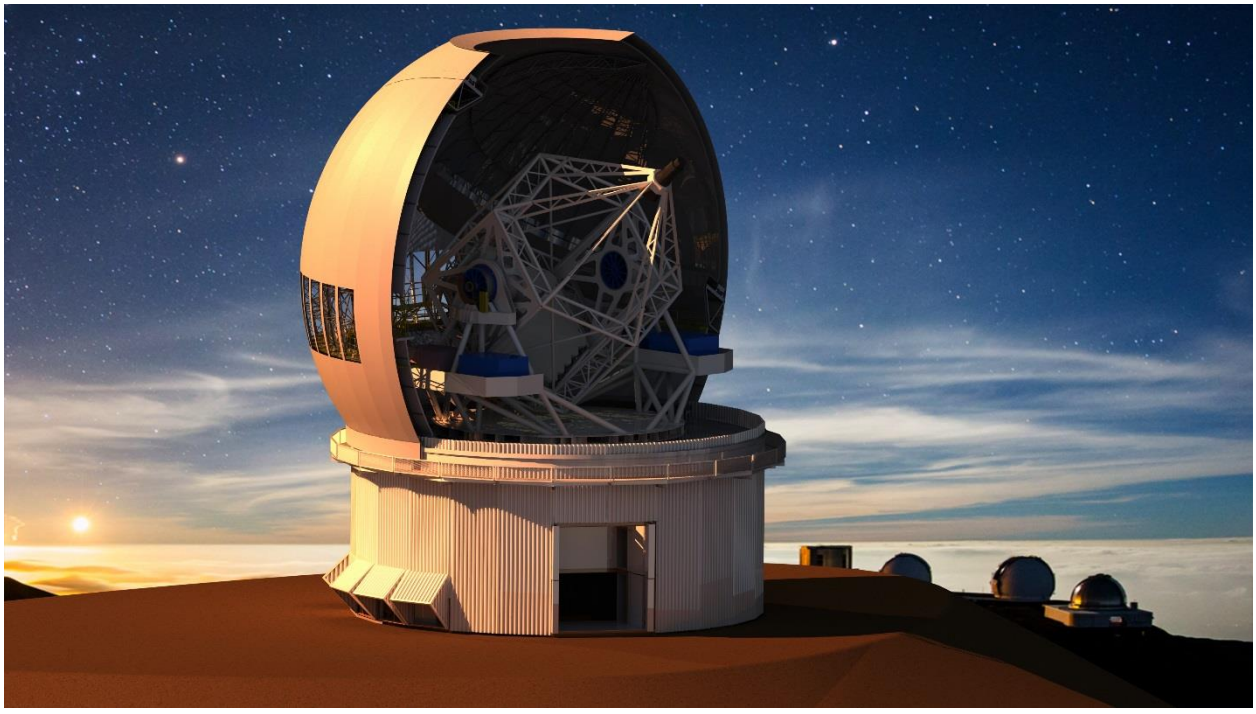


Figure 20 - MSE telescope structural model developed by IDOM.

Administration Report

Overview

For personal reasons Sheri Christopher, CFHT's Director of Finance and Administration, left CFHT in September 2016. Sheri did a fabulous job leading the Finance and Administration team, reorganizing and improving our business systems, and without a doubt leaving our F&A systems in better shape than she found them. As anticipated, Sheri proved to be a quick study and, together with Jane Rogers, who has taken on new responsibilities, successfully guided the F&A components of the 2015 Board meeting and a successful audit. Sheri led the recruitment of Arturo Sayco to increase our accounting capacity, and drove improvements to our accounting software (Financial Edge) and travel systems (Egencia). Rather than go through a full recruitment, the Executive Director instead approached an applicant (Tracy Yost – CFO at Parker Ranch) for the position since he previously received high marks through the same recruitment process that led to hiring Sheri. Tracy accepted CFHT's offer and started in August, allowing some transitional overlap with Sheri before her departure. Prior to working as Parker Ranch's CFO Tracy worked for Trueblue, Digimarc, PacificCorp, and Arthur Andersen, leaving Tracy with an impressive depth and range of skills in finance, human resources, and contract management. As CFO of one of the oldest and most well established businesses in Waimea for the past 5 years, Tracy brings a deep understanding of the Hawai'i Island business community.

Summary of 2016 Finances

After holding member contributions level for several years, the founding partners increased the agency contributions in 2016 by 1.6% (see Table 1). The increase was timely to alleviate the increasing cost structure of CFHT driven primarily by inflationary pressures in employee staffing. Over the years, CFHT has been able to effectively maintain a steady budget with an ongoing emphasis on efficiency gains and careful attention to expenditures. Typically, in years past, the organization has been able to transfer unspent budget amounts to the Reserve Fund. However, in 2016, approximately $80,000 was drawn from Reserves to maintain a balanced budget (see Table 2). For future years, CFHT will continue to work closely with its finance agencies to maintain stable and efficient operations.

Agency Contributions (US$)	2016	2015
NRC	3,261,145	3,211,145
CNRS	3,261,145	3,211,145
UH	756,204	744,610
Total	7,278,494	7,166,900

Table 1 - Contributions from CFHT partners increased by 1.6% between 2015 and 2016.

Operating Fund Expenditures (US$)	2016	2015
Maunakea Facility and Operations	397,286	395,745
Base Facility and Operations	225,434	308,808
Services	327,537	322,470
Mauankea Support Services	95,241	88,865
Management & General	537,405	428,155
Staffing	5,582,668	5,259,750
Outreach	59,579	59,070
Instrumentation	72,384	64,735
Science	60,158	78,409
Transfer to (from) Reserve	(79,198)	160,893
Total	7,278,494	7,166,900

Table 2 - Operating expenditures broken down by cost categories.

In addition to the member agency contributions, CFHT receives payments under collaborative agreements with other agencies as reimbursement for costs associated with their use of the CFHT facilities. In 2016, CFHT received $291,500 and $431,250 from the Academia Sinica Institute of Astronomy and Astrophysics of Taiwan (ASIAA) and the National Astronomical Observatory of China (NAOC), respectively. Additional collaborative agreements with the

Korean Astronomy and Space Science Institute (KASI) and the Brazilian Ministry of Science, Technology, and Innovation (MSTI) expired in 2015. Efforts are ongoing to renew the MSTI agreement and seek opportunities to partner with additional agencies.

Accounting Group Developments

In April, we migrated to a new corporate travel vendor, Egencia, to achieve cost savings and improve travelers' access to travel booking options. The accounting group successfully migrated to the most recent version of our provider ADP's online payroll system as well. The decision was made to migrate to this platform so that a new module required for compliance with the Affordable Care Act (ACA) regulatory requirements will be available to the accounting group, if CFHT passes the threshold for compliance (i.e., 50 FTEs). CFHT also rolled out the Advanced Budget Management (ABM) tool in 2016. The accounting group customized the tool's setup and reports and received end user training. Use of the tool will help streamline CFHT's annual budgeting process, moving the analysis out of a web of MS Excel spreadsheets to a module of CFHT's financial accounting software package. Some benefits of the tool include budget requests that can be input directly and with data aggregated, thereby reducing CFHT's reliance on error prone data entry and aggregation procedures. Further in the future when CFHT adopts a month-end close process, budget managers will be able to access complete budget data in real time.

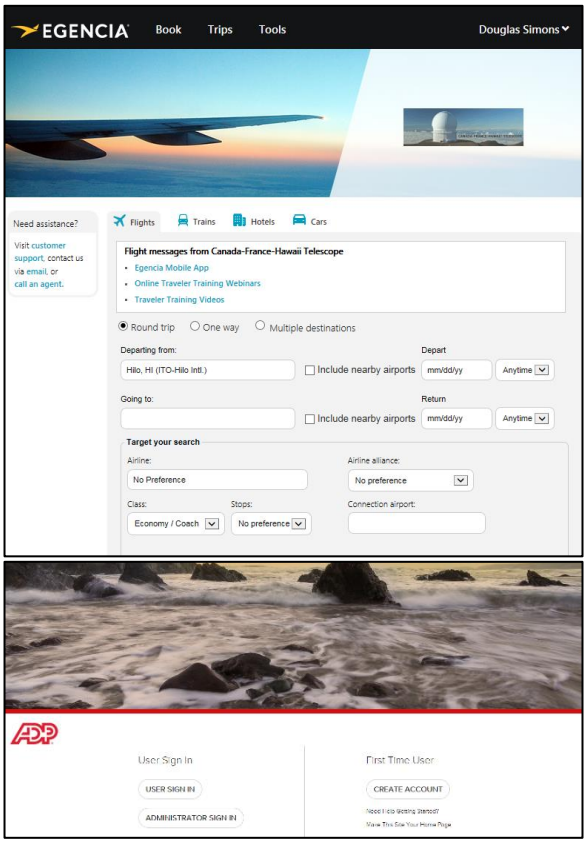


Figure 21 – Above, new travel software was implemented for the staff to use, replacing Concur. Below, a much newer version of the software used for payroll, tracking vacation/sick days, etc. was implemented as well.

Improvements to the accounts payable process have also been underway since earlier this year, when the group undertook changes to improve the accuracy, efficiency and timeliness of the processing of invoice payments. An interface is currently being implemented between our financial accounting software (Financial Edge) and our electronic document management system (PaperSave) to eliminate a manual and redundant process that required double data-entry by the accounting department for every invoice processed by the group. Our new Accountant, Arturo, who has assumed responsibility for the Accounts Payable process, has been evaluating our AP process with the Finance Manager and DFA to recommend improvements.

Staff Safety

During 2016, we had zero OSHA recordable injuries and zero lost-time injuries. Near miss incidents were addressed promptly. Some opportunities for improvement were identified in the procedures for mirror cleaning with CO_2, access and egress from the bridge crane, and procedures to be used during the 2017 summer shutdown and mirror coating. A guard rail system has been designed and is being fabricated for the "blue platform" to improve fall protection and OSHA compliance while working underneath the

telescope. Four new people completed the Emergency Medical Responder (EMR) training, a rigorous 6-day course that helps increase our internal medical response capabilities, and several staff renewed or completed the First Aid/CPR/AED/Oxygen-use class as well.

In 2017, we will continue to focus on fall protection rescue planning and general emergency readiness at the summit. Three employees were certified by Climb Aloha in a basic 3-day rope access and fall protection class that aims to improve our ability to work with rope systems; the goal of this effort is to improve self-rescue (rope descent) capability from the bridge crane or other elevated work platforms if mechanical failure occurs. Improvement in bridge crane access and egress continues to be a priority; the operations group is working on designing an access/egress system to suit the needs of all employees. Our training records system will be converted to a fully electronic system. When complete the information on employee training will then become available to supervisors and administrative staff.

	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007
Injuries	0	2	2	0	0	1	0	0	0	1
Illnesses	0	0	0	0	0	0	0	0	0	0
Lost work days	0	0	10.5	0	0	1	0	0	0	1

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

Arrivals and Departures

As was the case in 2015, in 2016 we said farewell to 3 departing staff members but this year we also welcomed 8 new CFHT ‘ohana members, yielding another net increase in our overall staff size by the end of the year. New staff filled positions that touch essentially all parts of CFHT, including engineering, science, administration, and the MSE Project Office. As we do each year, below we first pay tribute to those who left CFHT in 2016, then wish a welcome/aloha to our new staff members.

Farewell

Sheri Christopher

After some amazing accomplishment, Sheri left as CFHT’s Director of Finance and Administration in September 2016 in order to slow down and help support family needs at home. She was only with CFHT for a year and a half but accomplished many things in her short tenure that will have lasting impacts on the organization – she restructured the administrative functions, recruited a new accountant and improved many business processes. We will miss Sheri but do get to see her from time to time as she and her family are staying in the Waimea area.

Glenn Morrison

Dr. Glenn Morrison left his post as the UH Resident Astronomer in 2016 and moved to the Large Binocular Telescope Observatory in Arizona. Glenn was at CFHT for 11 years, having first assumed his post in 2005. During his time here, he worked on a wide range of instruments and projects. Glenn served as the queue observing coordinator for MegaCam, during which time the queue observing efficiency rating increased to 94%. Glenn was also an important member of the SITELLE development team and was central to the ASIVA project – an all-sky mid-IR camera that is used regularly by all Maunakea observatories. We wish Glenn all the best in his future academic and scientific endeavors.

Jim Thomas

After a distinguished 22 year career with CFHT, Jim retired from his position as software engineer in July 2016. We still see Jim frequenting the halls at CFHT as he often returns to visit former colleagues and share his expertise in software engineering and control systems. Over his career at CFHT, Jim worked on dozens of instruments and telescope control systems from AOP to Megacam and the TCS. Jim and his wife Diana still currently reside on the Big Island.

Roger Wood

Roger retired as our "Jack of all Trades" in April 2016 after 33 years. He provided a myriad of support roles, ranging from fleet maintenance, to building upgrades/repairs, to transporting equipment and supplies for CFHT all over the island. He will be remembered as someone who was positive and always had a kind word to share. During his time at CFHT, he proved himself able to expertly complete any project given to him. At last year's Christmas party, Roger offered sage retirement advice to all his former coworkers, "before you retire, make sure you have something else to do." Roger and his wife Susan live in Honoka'a and remain active in the community.

Lison Malo

Lison Malo left CFHT in 2016, after holding the Canadian Resident Astronomer position since January 2014. She received her PhD from the Université de Montréal in 2014 and immediately joined CFHT out of graduate school. Lison's research interests include young low mass stars, brown dwarfs, the kinematics of stellar groups and young exoplanets. While at CFHT, Lison was involved in several scientific collaborations. Lison was the science lead of GRACES, a 270 m fiber link between Gemini and ESPaDOnS at CFHT. She also served as the Project Scientist for OPERA, an open source pipeline for ESPaDOnS. She regularly coordinated nighttime observations and participated in outreach activities, always with a positive and cheerful attitude. Lison returned to her Alma Mater, the Université de Montréal, to work on a new instrument called the Near Infrared Planet Searcher (NIRPS). We wish Lison the best of luck in her new adventure!

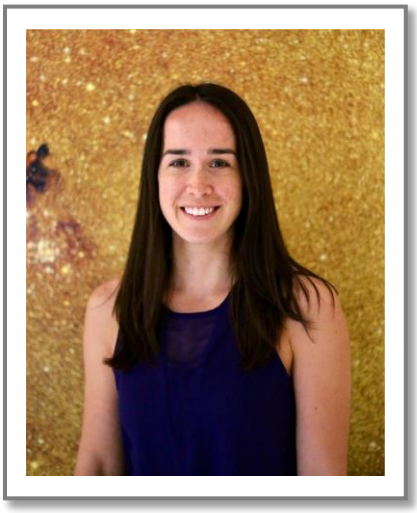
Welcome

Alexis Hill

Alexis joined our MSE Project Office in August 2016 as a Project Engineer. Alexis brings an incredible depth of experience combining mechanical engineering and project requirements management. Prior to joining CFHT, Alexis worked at NRC-Herzberg for 10 years. Projects that she has participated in previously include the Gemini Planet Imager (GPI), where she designed the superstructure and various opto-mechanical subsystems; Gemini High Resolution Optical Spectrograph (GHOST) and the TMT Narrow Field Infrared Adaptive Optics System (NFIRAOS). On the NFIRAOS project, she served as the technical authority for the enclosure, large optical subsystems, and managing interfaces. Alexis is a graduate of the University of Victoria with a degree in Mechanical Engineering. As a recent transplant to Hawaii she had to trade in her curling broom for roller skates and is now playing for the local roller derby team.

Steve Hughes

Steve joined CFHT in January 2016 as our electrician, replacing Larry Roberts who left in 2015 to return to the mainland. Steve has over 30 years of experience in electrical construction and maintenance, 10 of which included owning his own contracting business. Prior to relocating to the Island for this position, he was employed by the Colorado Rockies Major League Baseball team and helped to maintain Coors Field in Denver. Steve and his wife Barbara moved to the Island with two of their three children – Mike is 15 years old and participates in football, basketball, and baseball; Madison is 13 and also attends HPA and is a cheerleader. Their third daughter Nicole is a real estate agent in Colorado. The family enjoys hiking, skiing and snowshoeing when in Colorado and goes to the beach as often as possible here in Hawaii.



Laurie Rousseau-Nepton

Dr. Laurie Rousseau-Nepton is CFHT's newest Resident Astronomer, having been recruited at the end of 2016, replacing Dr. Lison Malo. She is a recent graduate from Université Laval in Québec where she developed her expertise in instrumentation and galaxy evolution. Her teaching experience has focused on the basics of astronomical observations using different instruments. While spending a significant amount of time at the Mont Mégantic Observatory, she worked with the SpIOMM prototype instrument which is the predecessor of SITELLE, CFHT's Imaging Fourier Transform Spectrograph. She participated in SITELLE's development and looks forward to sharing her SITELLE expertise with the scientific community. Laurie enjoys running, hiking and hunting moose. She is excited about her move to Hawaii and looks forward to exploring the Island, albeit without the moose.

Andreea Petric

Dr. Andreea Petric was appointed as the new UH Resident Astronomer and assumed her role in July, 2016, replacing Dr. Glenn Morrison. Andreea received her PhD from Columbia University with a thesis on X-ray scattering halos and was a postdoctoral fellow at Caltech working on IR and millimeter observations of interacting galaxies and galaxies hosting Active Galactic Nuclei (AGN). Her current research focuses on optical and near-IR observations of the impact of AGN on the interstellar medium of their host galaxies and the fate of molecular gas in merging galaxies. She has been a mentor for the Maunakea scholars program since its inception. Andreea taught Galaxies and Cosmology, and Quantum Mechanics at UH Hilo. In her role at CFHT, she will teach Basic Astronomy at the North Hawai`i Education and Research Center in Waimea in addition to making regular class room visits both on the Big Island and Oahu. On her personal time, Andreea has committed herself to marathons and triathlons.

Arturo Sayco

Arturo joined CFHT in April 2016, assuming the newly created role of Accountant that was created as part of the Administrative Department restructuring. Prior to CFHT, he worked for the State Compensation Insurance Fund in San Francisco, California for over 13 years where he held positions of Senior Financial Analyst, Senior Internal Auditor, Budget & Reporting Manager, and most recently Corporate Planning Manager. Arturo relocated to Hawai'i early in 2016 with his partner for family reasons. He grew up in the Philippines where he received a Bachelor in Accountancy, cum laude, from the Polytechnic University of the Philippines, Manila, and passed his CPA. In his free time Arturo enjoys the culinary arts, travel, and hiking.

Kahea Thronas

In March 2016 Kahea replaced Roger Wood as our new Facility and Vehicle Maintenance Specialist. Before joining CFHT Kahea worked for West Hawaii Concrete performing batch plant and vehicle maintenance, and subsequently owned his own vehicle repair business in Waimea. His responsibilities at CFHT include maintenance oversight of the company's vehicle fleet, general maintenance of the Waimea facilities, and support for the observatory as needed. Kahea is from the Big Island and holds a Bachelor's degree from UH Hilo in agriculture. His wife Amanda is the program director at Mala'ai: The Culinary Garden of Waimea Middle School. They have a 4 year old son, Felix Kanoa, and together enjoy traveling and learning new things. Kahea is an avid bike commuter and loves to ride to work.

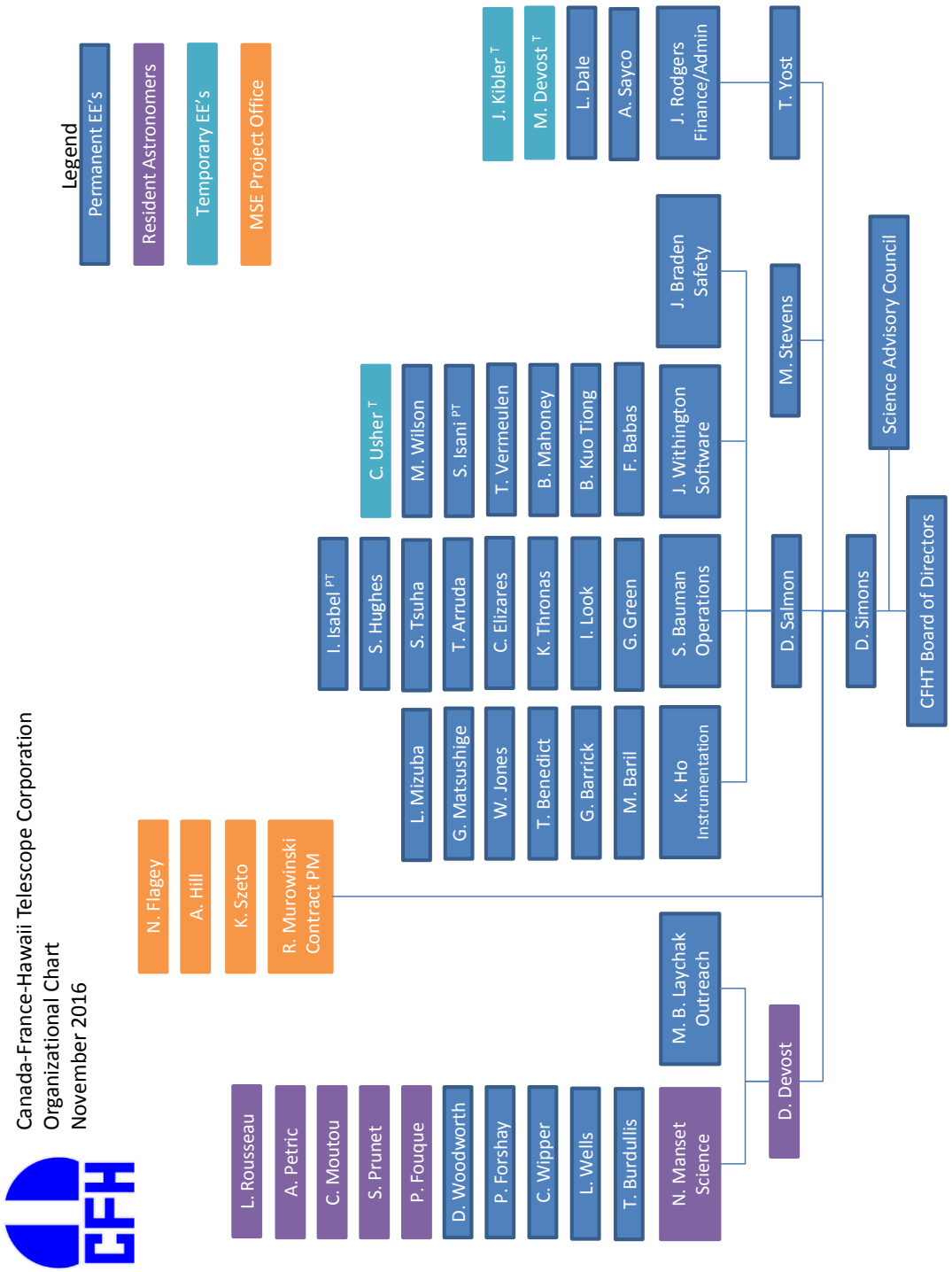
Matt Wilson

After receiving his Masters in Electrical Engineering from Rensselaer Polytechnic Institute in 2008, Matt started his own company. After many highs and lows, the company was closed in 2010 and he joined a startup, named Square. Over his 6 years at Square, Matt's favorite memories are inventing new financial products and building several highly available, distributed, transactional systems. Having accomplished what he wanted at Square, Matt came to CFHT in September of 2016 with a passion for science and a desire to get to the stars! In addition to the new job, he recently married. He and his wife Aubrey purchased a home in Waimea and are enjoying life and work on the Big Island. Matt is fully immersing himself into the CFHT culture, having already been Santa Claus at his first CFHT Christmas party.

Tracy Yost

Tracy joined the CFHT 'ohana in August 2016, replacing Sheri Christopher as the Director of Finance and Administration. Prior to joining CFHT, Tracy worked as Chief Financial Officer for Parker Ranch, also in Waimea. With over 20 years of experience, he brings an extensive depth and breadth of skills spanning finance, human resources, process improvement, contracts and business management. He holds a BS and MA from Utah State University. Tracy and his wife Heather live in Waimea and have three children – Megan, who just spent a year and half in Romania and is now finishing her college studies on the mainland with a major in linguistics; Joshua, who is in his sophomore year of college at Utah State University; and Erica, who is attending Parker High School in Waimea.

Organization Chart



Staff List at the End of 2016

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
Braden, Jake	Safety Specialist	**Prunet, Simon**	Resident Astronomer
Burdullis, Todd	QSO Operations Specialist	**Rodgers, Jane**	Finance Manager
Dale, Laurie	Administrative Specialist	**Sayco, Arturo**	Accountant
Devost, Daniel	Director of Science Operations	**Salmon, Derrick**	Director of Engineering
Elizares, Casey	Summit Operations Manager	**Szeto, Kei**	MSE Project Engineer
Flagey, Nicolas	MSE Systems Scientist	**Simons, Doug**	Executive Director
Forshay, Peter	Remote Observer	**Stevens, Mercédes**	Assistant to the Exec Director
Fouque, Pascal	Resident Astronomer	**Thronas, James Kahea**	Vehicle/Facility Maint. Specialist
Green, Greg	Mech Designer/Instr. Maker	**Tsuha, Seizan**	Mechanical Technician
Hill, Alexis	MSE Project Engineer	**Usher, Christopher**	Software Programmer
Ho, Kevin	Instrument Manager	**Vermeulen, Tom**	System Programmer
Hughes, Steve	Electrician	**Wells, Lisa**	Remote Observer
Isabel, Ilima	Custodian	**Wilson, Matt**	Computer Software Eng.
Isani, Sidik	Software Engineer	**Wipper, Cameron**	Remote Observer
Jones, Windell	Instrument Engineer	**Withington, Kanoa**	Software Manager
Kuo Tiong, Blaise	System Administrator	**Woodworth, David**	Remote Observer
Laychak, Mary Beth	Outreach Program Manager	**Yost, Tracy**	Director of Finance and Admin.
Look, Ivan	Mechanical Design Engineer		

Outreach Report

CFHT's outreach program had another busy year in 2016 as our outreach networks across our diverse community continue to expand. Summarized here are the international and local dimensions of our outreach program, describing everything from teacher training workshops in Canada to supporting a science documentary captured by a French film crew on the summit of Maunakea, to just about everything in between.

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 second annual teacher's workshop at the June 2016 CASCA meeting. The workshop was free of cost to participants and focused on hands-on activities they can use in their classrooms. Nobel Laureate Art McDonald spoke with the teachers, the highlight of the afternoon for many of them. At the CASCA meeting, we were approached by the organizers of the 2017 CASCA meeting who would like to see the workshops continue.

Using the Discover the Teacher network, CFHT offered to connect via videoconference with Canadian classrooms. We had three English and several French speaking schools register. We'll be scheduling those visits soon.

CFHT participates in educational video conferences with Canadian schools. We are 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 and available to teachers on the Exploring website.

In 2017, we plan to continue the efforts listed above with emphasis on expanding the reach of the programs. One lesson from the telecons 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.

CFHT continues to partner with the Friends of the Dominion Astrophysical Observatory. CFHT's outreach program manager gave a workshop to Canadian teachers and was the guest speaker at Hawaii Night at the DAO in October.

We currently have two CFHT photo displays in Canada- one at HAA in Victoria and the other at David Dunlap Observatory in Toronto. The DDO display opened in Summer 2016 and has been viewed by ~2500 people.

In 2017, we plan to return to Eureka! Festival in Montreal, partnering with Lison Malo at the University of Montreal.

Outreach in France

Last year, Claire Moutou filmed a segment for the exoplanet episode of the upcoming television series "Sur Les Routes De La Science". The series follows two science journalists as they travel the world meeting scientists working on "science's biggest questions". The film crew traveled to Hawaii in August for several days of filming on Maunakea including two at CFHT. The show aired November 13, 2016 in France. A short trailer of the episode was posted in 2016.

The 2016 CFHT User's Meeting was held in Nice. At the conclusion of the meeting, the CFHT image display was donated to Observatoire de la Côte d'Azur. We continue to have an image display at Pic du Midi. We will continue the tradition of French CFHT image displays by hosting one at the 2017 SF2A meeting with the images donated to a Parisian location after the meeting.

In 2017, we plan to continue creating new networks into the French community. When we further develop CFHT's outreach website we will work towards translating its content into French to make our website more broadly applicable to our international community.

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 ~4500 people over the course of the year.

As part of CFHT's effort to reach local school students, we have several projects in the works with Big Island and Hawaii schools. We have partnered with Honoka'a Intermediate and High Schools to create after school programming.

2016 marked the inaugural year of Journey Through the Universe North Hawaii. We partnered with Honoka'a Elementary, Intermediate and High School to visit with 730 students during Journey week. In 2017, we will be adding Paauilo and likely Waimea Elementary Schools. The Keck Observatory staff will be participating with CFHT to visit the additional classrooms.

CFHT continues to provide support for local k-12 students working on science fair projects. We still have the goal of 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 will translate the page into French. We are also in the process of piloting a CFHT housed lending library for Big Island teachers. The library will go online in Spring 2017.

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. The three classes were awarded one night of CFHT time. The projects submitted exceeded our expectations and included "Validating or Redefining Mischaracterized Unconfirmed Exoplanets", "Quasars and What They are Made of", and "Exploring Star-Formation in the Hosts of Radio Quiet Quasars".

For the 2016-2017 school year, Maunakea Scholars has dramatically expanded. We are working with five schools- Waiakea and Honoka'a on the Big Island as well as Nanakuli, Kalani and Kapolei high schools on Oahu. We have added Subaru, Gemini, EAO and Robo-AO as participating observatories. We have 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.

Figure 22 – The 2016 Maunakea Scholars from Kapolei High School on Oahu and several teachers are seen here on the CFHT catwalk. An important part of the Maunakea Scholars program is to bring students up to see the telescopes they are using for their research projects.

Social Media

The CFHT FaceBook page grew from ~740 fans in November 2015 to ~1500 toward the end of 2016. 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 ~110 in 2015 to ~390 in 2016.

CFHT's online astronomy blog Hoku is updated twice a month. Cam Wipper writes the content. One post each month focuses on the night sky while the other tackles explaining a topic in astronomy. Cam started a series on Proxima Centauri b after the announcement of the planet's discovery.

Local Students

CFHT employed several outreach interns over the course of 2016. A student from UH Hilo's astronomy program reviewed the Perimeter Institute for Theoretical Physics' outreach kits targeted for high school students. She completed the kits by aligning them with Hawaii State Department of Education standards and suggesting modifications for local teachers. Her reviews will accompany the kits when teachers borrow them.

Currently CFHT has a high school student from Kanu O Ka Aina, a Waimea Hawaiian Immersion School, working as an intern. She is adding Hawaii place based content to the Universe Awareness program's Universe in a Box. The Universe in a Box is a kit designed for students aged 4-10 and covers basic movement of the sky, constellations, planets, etc. When completed, the kit and the additional Hawaiian activities will be available for local students to borrow.

The CFHT outreach program manager also mentored two local high school students and a middle school student. The high school students participated in the PISCES STARS program, which focuses on girls interested in pursuing a career in STEM. One student wants to be an engineer, the other an astronomer. The outreach program manager is working with them on school projects as well.

Community Events

CFHT sponsored two major community events this year, the Waimea Solar System Walk held on October 24th and the Winter Star Party on December 3rd. 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 300 people participated in the walk, which received coverage on the state television news broadcasts and in Big Island newspapers. We added a costume contest this year which was very successful. The grand prize family won a small telescope donated by Celestron.

Eight of the Maunakea Observatories, Imiloa and the University of Hawaii launched the Kama'aina Observatory Experience summit tours. Twenty-four Kama'aina (Hawaii residents) tour two observatories a month complete with lunch at HP, environmental and cultural briefings. Staff from the Visitor Information Station, Imiloa, and the observatories serve as guides for each tour. CFHT plays an active role in the organization and coordination of the tours. The program is very successful with all 24 openings reserved within ~5 minutes each month and stellar post visit reviews. We are discussing an expansion of the program.

CFHT continues to host summit tours for visiting astronomers and graduate students, local charities and educational groups. We have escorted an estimated 150 people to the summit this year, including a French film crew (see above), a BBC film crew for the show "Stargazing Live" with Brian Cox and several print journalists. We also supported a tour for a group of Canadian graduate students along with Stephan Courteau in May 2016.

Media Presence

2016 brought three very popular and widely picked up press releases. In June, the discovery of V830 Tau b by Jean-Francois Donati and his team was featured in Nature Magazine. The local Hawaii media picked up the story and Hawaii News Now morning show invited Lison Malo to appear on the show to discuss the discovery. Hawaii News Now has a viewership of ~40,000 people. Claire Moutou also spoke with Hawaii Public Radio about the discovery.

The discovery of dwarf planet RR245 by the OSSOS team in July was CFHT's largest press release. Major news outlets worldwide picked up the announcement. It was the top "News Pick" on Physics today for July 13th, made the New York Times and "Cherdak", a popular Russian science publication.

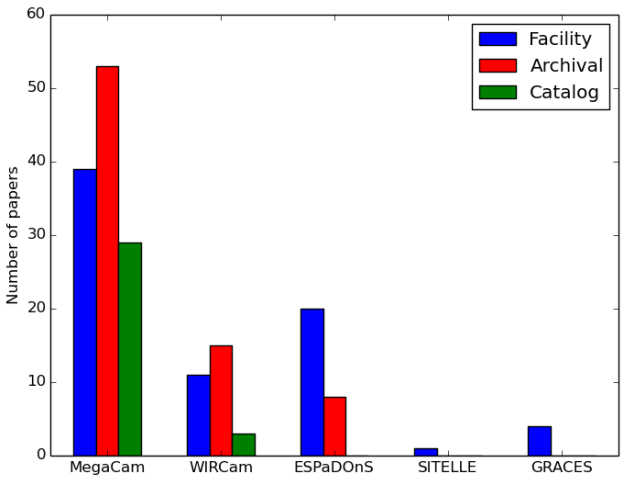
A press release on Malin 1 by Samuel Boissier and the NGVS team received considerable local Hawaii attention. It was featured in Pacific Business News and two Hawaii morning news programs- Hawaii News Now and KITV4.

In addition to these three large stories, CFHT programming like the Solar System Walk, Maunakea Scholars and Astro Day received television and written newspaper coverage over the course of the year. CFHT also contributes a monthly column for the North Hawaii News called "Across the Universe". The North Hawaii News was integrated into the West Hawaii Today, which has a readership of 18,000 people.

Figure 23 – Top and middle - Mary Beth Laychak appearing on live TV in back-to-back interviews to describe Malin 1 observations. Bottom, CFHT Resident Astronomer Lison Malo was interviewed live on TV about the discovery of a young hot Jupiter discovered at CFHT.

2016 Publications Including CFHT Data

Listed below are refereed papers published in 2016 that relied upon CFHT. There were 69 facility papers published during this period, 77 archival papers, and 49 papers based upon cataloged CFHT data, leading to a total of 189 papers published in 2016. The distribution between these types of papers is plotted to the right, according to instruments used. The CFHT community was prolific in 2016, leading to one of the largest number of annual publications in the history of CFHT.



Facility papers (69)

Flores-Cacho I., et al. 2016 Multi-wavelength characterisation of z ~ 2 clustered, dusty star-forming galaxies discovered by Planck, A&A 585 A54

Patel P., Sigut T. A. A., Landstreet J. D. 2016 Photoionization Models of the Inner Gaseous Disk of the Herbig Be Star BD+65 1637, ApJ 817 29

Sousa A. P., et al. 2016 CSI 2264: Accretion process in classical T Tauri stars in the young cluster NGC 2264, A&A 586 A47

Shankman C., et al. 2016 OSSOS. II. A Sharp Transition in the Absolute Magnitude Distribution of the Kuiper Belt's Scattering Population, AJ 151 31

Xin L.-P., et al. 2016 Multi-wavelength Observations of GRB 111228A and Implications for the Fireball and its Environment, ApJ 817 152

Wade G. A., et al. 2016 The MiMeS survey of magnetism in massive stars: introduction and overview, MNRAS 456 2

Ryabchikova T., et al. 2016 Accuracy of atmospheric parameters of FGK dwarfs determined by spectrum fitting, MNRAS 456 1221

Köhlinger F., et al. 2016 A direct measurement of tomographic lensing power spectra from CFHTLenS, MNRAS 456 1508

van der Burg R. F. J., et al. 2016 Prospects for high-z cluster detections with Planck, based on a follow-up of 28 candidates using MegaCam at CFHT, A&A 587 A23

Boselli A., et al. 2016 Spectacular tails of ionized gas in the Virgo cluster galaxy NGC 4569, A&A 587 A68

Stauffer J., et al. 2016 CSI 2264: Characterizing Young Stars in NGC 2264 with Stochastically Varying Light Curves, AJ 151 60

Ibata R. A., Lewis G. F., Martin N. F. 2016 Feeling the Pull: a Study of Natural Galactic Accelerometers. I. Photometry of the Delicate Stellar Stream of the Palomar 5 Globular Cluster, ApJ 819 1

Lokhorst D., et al. 2016 The Next Generation Virgo Cluster Survey. XIX. Tomography of Milky Way Substructures in the NGVS Footprint, ApJ 819 124

Sánchez-Janssen R., et al. 2016 The Next Generation Virgo Cluster Survey. VII. The Intrinsic Shapes of Low-luminosity Galaxies in the Core of the Virgo Cluster, and a Comparison with the Local Group, ApJ 820 69

Liu F., et al. 2016 The detailed chemical composition of the terrestrial planet host Kepler-10, MNRAS 456 2636

Folsom C. P., et al. 2016 The evolution of surface magnetic fields in young solar-type stars - I. The first 250 Myr, MNRAS 457 580

Bílek M., et al. 2016 Deep imaging of the shell elliptical galaxy NGC 3923 with MegaCam, A&A 588 A77

Takami M., et al. 2016 Stable and Unstable Regimes of Mass Accretion onto RW Aur A, ApJ 820 139

Harrington D., et al. 2016 Alpha Virginis: line-profile variations and orbital elements, A&A 590 A54

Moutard T., et al. 2016 The VIPERS Multi-Lambda Survey. I. UV and near-IR observations, multi-colour catalogues, and photometric redshifts, A&A 590 A102

Moutard T., et al. 2016 The VIPERS Multi-Lambda Survey. II. Diving with massive galaxies in 22 square degrees since z = 1.5, A&A 590 A103

Campbell E. K., et al. 2016 Gas Phase Absorption Spectroscopy of C+60 and C+70 in a Cryogenic Ion Trap: Comparison with Astronomical Measurements, ApJ 822 17

Toloba E., et al. 2016 The Next Generation Virgo Cluster Survey XVI: The Angular Momentum of Dwarf Early-type Galaxies from Globular Cluster Satellites ApJ 822 51

Higgs C. R., et al. 2016 Solo dwarfs I: survey introduction and first results for the Sagittarius dwarf irregular galaxy, MNRAS 458 1678

Maia F. F. S., Moraux E., Joncour I. 2016 Young and embedded clusters in Cygnus-X: evidence for building up the initial mass function?, MNRAS 458 3027

Conn A. R., et al. 2016 Major substructure in the M31 outer halo: distances and metallicities along the giant stellar stream, MNRAS 458 3282

Landstreet J. D., et al. 2016 Discovery of an extremely weak magnetic field in the white dwarf LTT 16093 = WD 2047+372, A&A 591 A80

Fotopoulou S., et al. 2016 The XXL Survey. VI. The 1000 brightest X-ray point sources, A&A 592 A5

Adami C., et al. 2016 The XXL Survey. VIII. MUSE characterisation of intracluster light in a z ~ 0.53 cluster of galaxies, A&A 592 A7

Ziparo F., et al. 2016 The XXL Survey. X. K-band luminosity - weak-lensing mass relation for groups and clusters of galaxies, A&A 592 A9

Ferrarese L., et al. 2016 The Next Generation Virgo Cluster Survey (NGVS). XIII. The Luminosity and Mass Function of Galaxies in the Core of the Virgo Cluster and the Contribution from Disrupted Satellites, ApJ 824 10

Yong D., et al. 2016 GRACES observations of young [α/Fe]-rich stars, MNRAS 459 487

Kitching T. D., et al. 2016 Discrepancies between CFHTLenS cosmic shear and Planck: new physics or systematic effects?, MNRAS 459 971

Moutou C., et al. 2016 The magnetic properties of the star Kepler-78, MNRAS 459 1993

Donati J. F., et al. 2016 A hot Jupiter orbiting a 2-million-year-old solar-mass T Tauri star, Natur 534 662

Volk K., et al. 2016 OSSOS III—Resonant Trans-Neptunian Populations: Constraints from the first quarter of the Outer Solar System Origins Survey, AJ 152 23

Heinis S., et al. 2016 The Host Galaxy Properties of Variability Selected AGN in the Pan-STARRS1 Medium Deep Survey, ApJ 826 62

Hsieh T.-H., et al. 2016 IRAS 16253-2429: The First Proto-brown Dwarf Binary Candidate Identified through the Dynamics of Jets, ApJ 826 68

Battistelli E. S., et al. 2016 Galaxy clusters as probes for cosmology and dark matter, IJMPD 25 1630023

Miville-Deschênes M.-A., et al. 2016 Probing interstellar turbulence in cirrus with deep optical imaging: no sign of energy dissipation at 0.01 pc scale, A&A 593 A4

Kleyna J. T., et al. 2016 The Progressive Fragmentation of 332P/Ikeya-Murakami, ApJ 827 L26

Sikora J., et al. 2016 HD 35502: a hierarchical triple system with a magnetic B5IVpe primary, MNRAS 460 1811

Wright N. J., et al. 2016 Cygnus OB2 DANCe: A high-precision proper motion study of the Cygnus OB2 association, MNRAS 460 2593

Thomas G. F., et al. 2016 Exploring the reality of density substructures in the Palomar 5 stellar stream, MNRAS 460 2711

Lee-Waddell K., et al. 2016 The frequency and properties of young tidal dwarf galaxies in nearby gas-rich groups, MNRAS 460 2945

Rivinius T., Baade D., Carciofi A. C. 2016 Short-term variability and mass loss in Be stars. II. Physical taxonomy of photometric variability observed by the Kepler spacecraft, A&A 593 A106

Bannister M. T., et al. 2016 The Outer Solar System Origins Survey. I. Design and First-quarter Discoveries, AJ 152 70

Timmons N., et al. 2016 Multi-wavelength Lens Reconstruction of a Planck and Herschel-detected Star-bursting Galaxy, ApJ 829 21

Licitra R., et al. 2016 The Next Generation Virgo Cluster Survey. XX. RedGOLD Background Galaxy Cluster Detections, ApJ 829 44

Boissier S., et al. 2016 The properties of the Malin 1 galaxy giant disk. A panchromatic view from the NGVS and GUViCS surveys, A&A 593 A126

Méndez R. H., Kudritzki R.-P., Urbaneja M. A. 2016 The Two Central Stars of NGC 1514: Can They Actually Be Related?, ApJ 829 73

Bower G. C., et al. 2016 Variable Radio Emission from the Young Stellar Host of a Hot Jupiter, ApJ 830 107

Robert J., et al. 2016 A Brown Dwarf Census from the SIMP Survey, ApJ 830 144

Andrievsky S. M., et al. 2016 Oxygen, α-element and iron abundance distributions in the inner part of the Galactic thin disc - II, MNRAS 461 4256

McMonigal B., et al. 2016 The elusive stellar halo of the Triangulum galaxy, MNRAS 461 4374

Alexandersen M., et al. 2016 A Carefully Characterized and Tracked Trans-Neptunian Survey: The Size distribution of the Plutinos and the Number of Neptunian Trojans, AJ 152 111

Walker G. A. H., et al. 2016 Gas-phase Absorptions of C60+: A New Comparison with Astronomical Measurements, ApJ 831 130

Boucher A., et al. 2016 BANYAN. VIII. New Low-mass Stars and Brown Dwarfs with Candidate Circumstellar Disks, ApJ 832 50

Powalka M., et al. 2016 The Next Generation Virgo Cluster Survey (NGVS). XXV. Fiducial Panchromatic Colors of Virgo Core Globular Clusters and Their Comparison to Model Predictions, ApJS 227 12

Bannister M. T., et al. 2016 OSSOS. IV. Discovery of a Dwarf Planet Candidate in the 9:2 Resonance with Neptune, AJ 152 212

Walawender J., et al. 2016 Protostellar Outflows in L1340, ApJ 832 184

Lee Y.-M., et al. 2016 A Monte Carlo Study of Flux Ratios of Raman Scattered O vi Features at 6825 and 7082 Å in Symbiotic Stars, ApJ 833 75

Liu M. C., Dupuy T. J., Allers K. N. 2016 The Hawaii Infrared Parallax Program. II. Young Ultracool Field Dwarfs, ApJ 833 96

Martin N. F., et al. 2016 The PAndAS View of the Andromeda Satellite System. II. Detailed Properties of 23 M31 Dwarf Spheroidal Galaxies, ApJ 833 167

Wang W.-H., et al. 2016 The SXDF-ALMA 2-arcmin² Deep Survey: Stacking Rest-frame Near-infrared Selected Objects, ApJ 833 195

Zhao G., et al. 2016 Systematic Non-LTE Study of the -.6 ≤ [Fe/H] ≤ 0.2 F and G Dwarfs in the Solar Neighborhood. II. Abundance Patterns from Li to Eu, ApJ 833 225

Choi A., et al. 2016 CFHTLenS and RCSLenS: testing photometric redshift distributions using angular cross-correlations with spectroscopic galaxy surveys, MNRAS 463 3737

Jauzac M., et al. 2016 The extraordinary amount of substructure in the Hubble Frontier Fields cluster Abell 2744, MNRAS 463 3876

Martin T. B., Prunet S., Drissen L. 2016 Optimal fitting of Gaussian-apodized or under-resolved emission lines in Fourier transform spectra providing new insights on the velocity structure of NGC 6720, MNRAS 463 4223

Archival Papers (77)

Raichoor A., et al. 2016 The SDSS-IV extended Baryon Oscillation Spectroscopic Survey: selecting emission line galaxies using the Fisher discriminant, A&A 585 A50

Oldham L. J., Auger M. W. 2016 Galaxy structure from multiple tracers - I. A census of M87's globular cluster populations, MNRAS 455 820

More A., et al. 2016 SPACE WARPS- II. New gravitational lens candidates from the CFHTLS discovered through citizen science, MNRAS 455 1191

Licitra R., et al. 2016 The RedGOLD cluster detection algorithm and its cluster candidate catalogue for the CFHT-LS W1, MNRAS 455 3020

Davidzon I., et al. 2016 The VIMOS Public Extragalactic Redshift Survey (VIPERS). Environmental effects shaping the galaxy stellar mass function, A&A 586 A23

Kochukhov O., Wade G. A. 2016 Magnetic field topology of τ Scorpii. The uniqueness problem of Stokes V ZDI inversions, A&A 586 A30

van Uitert E., et al. 2016 Weak-lensing-inferred scaling relations of galaxy clusters in the RCS2: mass-richness, mass-concentration, mass-bias, and more, A&A 586 A43

Mathys G., et al. 2016 HD 18078: A very slowly rotating Ap star with an unusual magnetic field structure, A&A 586 A85

Zolotukhin I., et al. 2016 A Search for Hyperluminous X-Ray Sources in the XMM-Newton Source Catalog, ApJ 817 88

Mawatari K., et al. 2016 Discovery of a Damped Lyα Absorber at z = 3.3 along a Galaxy Sight-line in the SSA22 Field, ApJ 817 161

McMonigal B., et al. 2016 Major substructure in the M31 Outer Halo: the East Cloud, MNRAS 456 405

Davies J. I., Davies L. J. M., Keenan O. C. 2016 Probing the low surface brightness dwarf galaxy population of the virgo cluster, MNRAS 456 1607

McGreer I. D., et al. 2016 A Constraint on Quasar Clustering at z = 5 from a Binary Quasar, AJ 151 61

Madrid J. P., Donzelli C. J. 2016 The Abell 85 BCG: A Nucleated, Coreless Galaxy, ApJ 819 50

Dewangan L. K., et al. 2016 A Multi-wavelength Study of Star Formation Activity in the S235 Complex, ApJ 819 66

Rutkowski M. J., et al. 2016 Lyman Continuum Escape Fraction of Star-forming Dwarf Galaxies at z ˜ 1, ApJ 819 81

Beasley M. A., et al. 2016 An Overmassive Dark Halo around an Ultra-diffuse Galaxy in the Virgo Cluster, ApJ 819 L20

Paudel S., et al. 2016 SDSS J085431.18+173730.5: The First Compact Elliptical Galaxy Hosting an Active Nucleus, ApJ 820 L19

Cortesi A., et al. 2016 The SLUGGS survey: chromodynamical modelling of the lenticular galaxy NGC 1023, MNRAS 456 2611

Blake C., et al. 2016 RCSLenS: testing gravitational physics through the cross-correlation of weak lensing and large-scale structure, MNRAS 456 2806

Parsa S., et al. 2016 The galaxy UV luminosity function at z ≃ 2-4; new results on faint-end slope and the evolution of luminosity density, MNRAS 456 3194

Buddendiek A., et al. 2016 RCSLenS: a new estimator for large-scale galaxy-matter correlations, MNRAS 456 3886

Durret F., et al. 2016 Searching for filaments and large-scale structure around DAFT/FADA clusters, A&A 588 A69

Heinis S., et al. 2016 Of Genes and Machines: Application of a Combination of Machine Learning Tools to Astronomy Data Sets, ApJ 821 86

Harikane Y., et al. 2016 Evolution of Stellar-to-Halo Mass Ratio at z = 0 - 7 Identified by Clustering Analysis with the Hubble Legacy Imaging and Early Subaru/Hyper Suprime-Cam Survey Data, ApJ 821 123

Kim J.-W., et al. 2016 Discovery of a Supercluster at z ~ 0.91 and Testing the ΛCDM Cosmological Model, ApJ 821 L10

Applegate D. E., et al. 2016 Cosmology and astrophysics from relaxed galaxy clusters - IV. Robustly calibrating hydrostatic masses with weak lensing, MNRAS 457 1522

Gebran M., et al. 2016 A new method for the inversion of atmospheric parameters of A/Am stars, A&A 589 A83

Vida K., et al. 2016 Investigating magnetic activity in very stable stellar magnetic fields. Long-term photometric and spectroscopic study of the fully convective M4 dwarf V374 Pegasi, A&A 590 A11

van der Burg R. F. J., Muzzin A., Hoekstra H. 2016 The abundance and spatial distribution of ultra-diffuse galaxies in nearby galaxy clusters, A&A 590 A20

Martinet N., et al. 2016 Weak lensing study of 16 DAFT/FADA clusters: Substructures and filaments, A&A 590 A69

Lisenfeld U., et al. 2016 Molecular gas and star formation in the tidal dwarf galaxy VCC 2062, A&A 590 A92

Moutard T., et al. 2016 The VIPERS Multi-Lambda Survey. I. UV and near-IR observations, multi-colour catalogues, and photometric redshifts, A&A 590 A102

Moutard T., et al. 2016 The VIPERS Multi-Lambda Survey. II. Diving with massive galaxies in 22 square degrees since z = 1.5, A&A 590 A103

Leone F., et al. 2016 A Method to Calibrate the High-resolution Catania Astrophysical Observatory Spectropolarimeter, AJ 151 116

Konno A., et al. 2016 Bright and Faint Ends of Lyα Luminosity Functions at z = 2 Determined by the Subaru Survey: Implications for AGNs, Magnification Bias, and ISM H I Evolution, ApJ 823 20

Matthee J., et al. 2016 The CALYMHA survey: Lyα escape fraction and its dependence on galaxy properties at z = 2.23, MNRAS 458 449

Ishikawa S., et al. 2016 The very wide-field gzK Galaxy Survey - II. The relationship between star-forming galaxies at z ˜ 2 and their host haloes based upon HOD modelling, MNRAS 458 747

Li R., et al. 2016 Measuring subhalo mass in redMaPPer clusters with CFHT Stripe 82 Survey, MNRAS 458 2573

Pierre M., et al. 2016 The XXL Survey. I. Scientific motivations - XMM-Newton observing plan - Follow-up observations and simulation programme, A&A 592 A1

Adami C., et al. 2016 The XXL Survey. VIII. MUSE characterisation of intracluster light in a z ~ 0.53 cluster of galaxies, A&A 592 A7

Baran N., et al. 2016 The XXL Survey. IX. Optical overdensity and radio continuum analysis of a supercluster at z = 0.43, A&A 592 A8

Ziparo F., et al. 2016 The XXL Survey. X. K-band luminosity - weak-lensing mass relation for groups and clusters of galaxies, A&A 592 A9

Trujillo I., Fliri J. 2016 Beyond 31 mag arcsec⁻²: The Frontier of Low Surface Brightness Imaging with the Largest Optical Telescopes, ApJ 823 123

Roberts-Borsani G. W., et al. 2016 z ≳ 7 Galaxies with Red Spitzer/IRAC [3.6]-[4.5] Colors in the Full CANDELS Data Set: The Brightest-Known Galaxies at z ~ 7-9 and a Probable Spectroscopic Confirmation at z = 7.48, ApJ 823 143

Laigle C., et al. 2016 The COSMOS2015 Catalog: Exploring the 1 < z < 6 Universe with Half a Million Galaxies, ApJS 224 24

Koprowski M. P., et al. 2016 The SCUBA-2 Cosmology Legacy Survey: galaxies in the deep 850 µm survey, and the star-forming `main sequence', MNRAS 458 4321

Kamiński T., et al. 2016 An observational study of dust nucleation in Mira (o Ceti). I. Variable features of AlO and other Al-bearing species, A&A 592 A42

Paraficz D., et al. 2016 The PCA Lens-Finder: application to CFHTLS, A&A 592 A75

Sakstein J., et al. 2016 Testing gravity using galaxy clusters: new constraints on beyond Horndeski theories, JCAP 7 019

Hatfield P. W., et al. 2016 The galaxy-halo connection in the VIDEO survey at 0.5 < z < 1.7, MNRAS 459 2618

Harnois-Déraps J., et al. 2016 CFHTLenS and RCSLenS cross-correlation with Planck lensing detected in fourier and configuration space, MNRAS 460 434

Finn C. W., et al. 2016 On the connection between the metal-enriched intergalactic medium and galaxies: an O VI-galaxy cross-correlation study at z < 1, MNRAS 460 590

De Grandi S., et al. 2016 A textbook example of ram-pressure stripping in the Hydra A/A780 cluster, A&A 592 A154

Nantais J. B., et al. 2016 Stellar mass function of cluster galaxies at z ~ 1.5: evidence for reduced quenching efficiency at high redshift, A&A 592 A161

Ribeiro B., et al. 2016 Size evolution of star-forming galaxies with 2 <z < 4.5 in the VIMOS Ultra-Deep Survey, A&A 593 A22

Toshikawa J., et al. 2016 A Systematic Survey of Protoclusters at z ~ 3-6 in the CFHTLS Deep Fields, ApJ 826 114

Luhman K. L., Esplin T. L., Loutrel N. P. 2016 A Census of Young Stars and Brown Dwarfs in IC 348 and NGC 1333, ApJ 827 52

Chen Y.-T., et al. 2016 Discovery of a New Retrograde Trans-Neptunian Object: Hint of a Common Orbital Plane for Low Semimajor Axis, High-inclination TNOs and Centaurs, ApJ 827 L24

Battaglia N., et al. 2016 Weak-lensing mass calibration of the Atacama Cosmology Telescope equatorial Sunyaev-Zeldovich cluster sample with the Canada-France-Hawaii telescope stripe 82 survey, JCAP 8 013

Velasco S., et al. 2016 High spatial resolution optical imaging of the multiple T Tauri system Lk Hα 262/Lk Hα 263, MNRAS 460 3519

Hamren K., et al. 2016 Carbon Stars in the Satellites and Halo of M31, ApJ 828 15

Verdugo T., et al. 2016 Combining strong lensing and dynamics in galaxy clusters: integrating MAMPOSSt within LENSTOOL. I. Application on SL2S J02140-0535, A&A 595 A30

Straatman C. M. S., et al. 2016 The FourStar Galaxy Evolution Survey (ZFOURGE): Ultraviolet to Far-infrared Catalogs, Medium-bandwidth Photometric Redshifts with Improved Accuracy, Stellar Masses, and Confirmation of Quiescent Galaxies to z ˜ 3.5, ApJ 830 51

Bouwens R. J., et al. 2016 The Bright End of the z ˜ 9 and z ˜ 10 UV Luminosity Functions Using All Five CANDELS Fields*, ApJ 830 67

Alexeeva S. A., Ryabchikova T. A., Mashonkina L. I. 2016 NLTE carbon abundance determination in selected A- and B-type stars and the interpretation of C I emission lines, MNRAS 462 1123

Chen C.-C., et al. 2016 Faint Submillimeter Galaxies Identified through Their Optical/Near-infrared Colors. I. Spatial Clustering and Halo Masses, ApJ 831 91

Lee M. G., Jang I. S. 2016 Globular Clusters, Ultracompact Dwarfs, and Dwarf Galaxies in Abell 2744 at a Redshift of 0.308, ApJ 831 108

Herczeg G. J., et al. 2016 The Eruption of the Candidate Young Star ASASSN-15QI, ApJ 831 133

Belardi C., et al. 2016 The DECam minute cadence survey - I, MNRAS 462 2506

Rousselot P., et al. 2016 A long-term follow up of 174P/Echeclus, MNRAS 462 S432

Hildebrandt H., et al. 2016 RCSLenS: The Red Cluster Sequence Lensing Survey, MNRAS 463 635

Merritt A., et al. 2016 The Dragonfly Nearby Galaxies Survey. II. Ultra-Diffuse Galaxies near the Elliptical Galaxy NGC 5485, ApJ 833 168

Zhao G., et al. 2016 Systematic Non-LTE Study of the -.6 ≤ [Fe/H] ≤ 0.2 F and G Dwarfs in the Solar Neighborhood. II. Abundance Patterns from Li to Eu, ApJ 833 225

Dressler A., et al. 2016 Demonstrating Diversity in Star-formation Histories with the CSI Survey, ApJ 833 251

Smit R., et al. 2016 Inferred Hα Flux as a Star Formation Rate Indicator at z ~ 4-5: Implications for Dust Properties, Burstiness, and the z = 4-8 Star Formation Rate Functions, ApJ 833 254

Santos S., Sobral D., Matthee J. 2016 The Lyα luminosity function at z = 5.7 - 6.6 and the steep drop of the faint end: implications for reionization, MNRAS 463 1678

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Grazian A., et al. 2016 The Lyman continuum escape fraction of galaxies at z = 3.3 in the VUDS-LBC/COSMOS field, A&A 585 A48

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Arcavi I., et al. 2016 Rapidly Rising Transients in the Supernova—Superluminous Supernova Gap, ApJ 819 35

Gillis B. R., Taylor A. N. 2016 A generalized method for measuring weak lensing magnification with weighted number counts, MNRAS 456 2518

Hathi N. P., et al. 2016 The VIMOS Ultra Deep Survey: Lyα emission and stellar populations of star-forming galaxies at 2 < z < 2.5, A&A 588 A26

Chen C.-C., et al. 2016 The SCUBA-2 Cosmology Legacy Survey: Multiwavelength Counterparts to 10³ Submillimeter Galaxies in the UKIDSS-UDS Field, ApJ 820 82

Faisst A. L., et al. 2016 A Coherent Study of Emission Lines from Broadband Photometry: Specific Star Formation Rates and [O iii]/Hβ Ratio at 3 > z > 6, ApJ 821 122

Pons E., et al. 2016 Narrow-line X-Ray-selected Galaxies in the Chandra-COSMOS Field. I. Optical Spectroscopic Catalog, ApJ 821 130

Mountrichas G., et al. 2016 The clustering amplitude of X-ray-selected AGN at z ˜ 0.8: evidence for a negative dependence on accretion luminosity, MNRAS 457 4195

Grandis S., et al. 2016 Information gains from cosmological probes, JCAP 5 034

Lieu M., et al. 2016 The XXL Survey . IV. Mass-temperature relation of the bright cluster sample, A&A 592 A4

Shirokov S. I., et al. 2016 Large-scale fluctuations in the number density of galaxies in independent surveys of deep fields, ARep 60 563

Hatch N. A., et al. 2016 The structure and evolution of a forming galaxy cluster at z = 1.62, MNRAS 459 387

Rafiei Ravandi M., et al. 2016 The extended disc and halo of the Andromeda galaxy observed with Spitzer-IRAC, MNRAS 459 1403

Maltby D. T., et al. 2016 The identification of post-starburst galaxies at z ˜ 1 using multiwavelength photometry: a spectroscopic verification, MNRAS 459 L114

Iovino A., et al. 2016 A high definition view of the COSMOS Wall at z ~ 0.73, A&A 592 A78

Cassarà L. P., et al. 2016 Effect of the star formation histories on the SFR-M_∗ relation at z ≥ 2, A&A 593 A9

Driver S. P., et al. 2016 Measurements of Extragalactic Background Light from the Far UV to the Far IR from Deep Ground- and Space-based Galaxy Counts, ApJ 827 108

Rhee J., et al. 2016 Giant Metrewave Radio Telescope observations of neutral atomic hydrogen gas in the COSMOS field at z ˜ 0.37, MNRAS 460 2675

Liu J., Haiman Z. 2016 Origin of weak lensing convergence peaks, PhRvD 94 043533

Powalka M., et al. 2016 New Constraints on a Complex Relation between Globular Cluster Colors and Environment, ApJ 829 L5

Ownsworth J. R., et al. 2016 The evolution of galaxies at constant number density: a less biased view of star formation, quenching, and structural formation, MNRAS 461 1112

Shirasaki M., et al. 2016 Cosmological constraints on dark matter annihilation and decay: Cross-correlation analysis of the extragalactic γ -ray background and cosmic shear, PhRvD 94 063522

Debono I., Smoot G. F. 2016 General Relativity and Cosmology: Unsolved Questions and Future Directions, Univ 2 23

Di Porto C., et al. 2016 The VIMOS Public Extragalactic Redshift Survey (VIPERS). Measuring non-linear galaxy bias at z ~ 0.8, A&A 594 A62

Heintz K. E., et al. 2016 Determining the fraction of reddened quasars in COSMOS with multiple selection techniques from X-ray to radio wavelengths, A&A 595 A13

Man A. W. S., Zirm A. W., Toft S. 2016 Resolving the Discrepancy of Galaxy Merger Fraction Measurements at z ~ 0-3, ApJ 830 89

Favole G., et al. 2016 Clustering properties of g-selected galaxies at z ~ 0.8, MNRAS 461 3421

Scottez V., et al. 2016 Clustering-based redshift estimation: application to VIPERS/CFHTLS, MNRAS 462 1683

van Uitert E., Schneider P. 2016 Systematic tests for position-dependent additive shear bias, A&A 595 A93

Fagioli M., et al. 2016 Minor Mergers or Progenitor Bias? The Stellar Ages of Small and Large Quenched Galaxies, ApJ 831 173

Pacifici C., et al. 2016 The Evolution of Star Formation Histories of Quiescent Galaxies, ApJ 832 79

Belardi C., et al. 2016 The DECam minute cadence survey - I, MNRAS 462 2506

Lavoie S., et al. 2016 The XXL survey XV: evidence for dry merger driven BCG growth in XXL-100-GC X-ray clusters, MNRAS 462 4141

Blake C., et al. 2016 The 2-degree Field Lensing Survey: design and clustering measurements, MNRAS 462 4240

Liu T., et al. 2016 A Systematic Search for Periodically Varying Quasars in Pan-STARRS1: An Extended Baseline Test in Medium Deep Survey Field MD09, ApJ 833 6

Calistro Rivera G., et al. 2016 AGNfitter: A Bayesian MCMC Approach to Fitting Spectral Energy Distributions of AGNs, ApJ 833 98

Hung T., et al. 2016 The GALEX Time Domain Survey. II. Wavelength-Dependent Variability of Active Galactic Nuclei in the Pan-STARRS1 Medium Deep Survey, ApJ 833 226

Möller A., et al. 2016 Photometric classification of type Ia supernovae in the SuperNova Legacy Survey with supervised learning, JCAP 12 008

Schirmer M., et al. 2016 About AGN ionization echoes, thermal echoes and ionization deficits in low-redshift Lyα blobs, MNRAS 463 1554

Khostovan A. A., et al. 2016 The nature of Hβ+[O III] and [O II] emitters to z ˜ 5 with HiZELS: stellar mass functions and the evolution of EWs, MNRAS 463 2363

Ziparo F., et al. 2016 LoCuSS: exploring the selection of faint blue background galaxies for cluster weak-lensing, MNRAS 463 4004