Draft version February 10, 2010
Preprint typeset using LaTeX style emulateapj v. 08/13/06

LRP WHITE PAPER ON CFHT

Harvey B. Richer
Department of Physics & Astronomy, University of British Columbia
Draft version February 10, 2010

ABSTRACT

CFHT is Canada's premier 4m class telescope and one that is strongly supported by the community. It has a history of 30 years superb service to Canadian astronomers. But what is its future? CFHT is moving forward with improving the local seeing through dome-venting and is examining several possible new instruments which could potentially carry it forward as a first-ranked telescope for the next several decades.
Subject headings:

1. A SHORT HISTORY

CFHT, Canada's premier 4m class telescope, is located at one of the best sites in the world for ground-based astronomy. The telescope began routine operations in 1980 and during the ensuing three decades it has exhibited remarkable innovation in both instrumentation development and queue scheduling. Among the new concept instruments which have played a major role in the science done at CFHT were MOS/SIS, the HF cell, HRCam, MegaCam and ESPaDOns. MOS/SIS put CFHT on the map as a first-ranked facility by carrying out such projects as the CFRS (Lilly et al. 1996) and the CNOC galaxy redshift surveys (Yee et al. 2000). These surveys helped establish that the matter density for the Universe was ~ 0.25, clearly demonstrating that there was not enough mass to close the Universe and setting the stage for the discovery of dark energy. The Hydrogen-Fluoride (HF) cell was a device used at CFHT to provide an extremely stable wavelength calibration providing a velocity accuracy of about 13 m/sec (unprecedented at the time), just about the same velocity as the Sun around the Sun-Jupiter centre of mass. The cell and CFHT were then used for some of the first attempts to detect extrasolar planets (Walker et al. 1995) and pioneered the technique that became so successful about a decade later. HRCam was one of the first instruments world-wide to use adaptive optics (AO), achieving unprecedented angular resolution imaging in the optical when it was first introduced. Subsequent developments at CFHT and elsewhere have continued to build on its legacy. Among other science (Racine and McClure 1993) it provided superb gravitational lens imaging in the early 1990's and this work led to similar studies eventually with the Hubble Space Telescope.

2. RECENTLY COMPLETED LEGACY SURVEYS: A GLIMPSE OF THE FUTURE

CFHT's MegaCam is the largest imaging camera in the world with 370 megapixels that covers 1 square degree of the sky. Recently this camera was used in a legacy program that that consisted of three separate surveys that might be a model for how this telescope will be used in the future. The CFHT DEEP Legacy Survey (LS) was a large survey that discovered more than 300 distant supernovae which were used to show that the expansion of the Universe was accelerating making it necessary to introduce the concept of dark energy. This was among the first studies to determine the equation of state of dark energy. An archival study of these data later yielded a supernova at a redshift $z = 2.4$ (Cooke et al. 2009), currently the highest redshift supernova known. This survey led to some of the highest cited papers ever from CFHT data (e.g. Astier et al 2006).

CFHTLS WIDE has been and still is the best (and most ambitious) deep optical weak-lensing survey in existence. The only next generation surveys that will surpass it will be done a few years from now (e.g. PanSTARRS, DES, KIDS). A few of the key results that have been obtained are the largest angular scale measurement of dark matter clustering from weak lensing (Fu et al. 2008) and the masses and shapes of dark matter haloes (Parker et al. 2007). However, some challenges were encountered during the the survey that diminished its overall effectiveness and should be carefully thought through if a similar survey structure is put in place in the future.

• funding: it was unfortunate that the NSERC SRO program vanished when it was most needed for the WIDE analysis. Funding considerations should be part of any future planning for such large surveys.

• survey management: there existed some differences in opinion as to how best to adjust the surveys in face of higher observing overheads and poorer weather than anticipated in the planning stages. This ended up compromising the execution of the WIDE survey. This might have been mitigated by a neutral oversight body that acted as an arbitrator for adjusting time allocated to the surveys.

• consequences: no Canadian-French science team was ever put in place, instead there were scattered small teams, which is quite inefficient particularly for science which requires a very serious effort in the early stages of the survey such as calibration and systematics control. Only two years ago, when the data became public and when it became obvious that international competition would become a serious threat, was a large team put in place to work on weak lensing.

The third component of the Legacy Survey was the Very Wide (VW) component. As with the other components, it was driven by a central science goal with secondary science topics addressable by the data set. The main science driver for the VW was the orbital structure of the outer Solar System beyond Neptune (known as the Kuiper Belt), with the data also being usable by astronomers interested in the structure and stellar properties of our Galaxy. The goal was to image 1000 square degrees near the ecliptic plane in three filters. After several semesters of data-taking it was clear that the amount of data per night that the telescope was generating for the Legacy Survey as a whole was insufficient. As a result, the decision was made in mid-2005 to halt the VW, allowing only some tracking time to prevent total loss of the set of objects discovered until that date. This decision resulted in the VW-component's science being seriously compromised. Little Galactic science has been published from data that were acquired and the number of outer Solar System dectections were only a small fraction of that anticipated at the outset, resulting in this component of the LS not having a dramatic impact.

3. CURRENT LARGE PROGRAMS

Aside from a vigorous PI program, CFHT currently also has a number of large programs exploiting the large area capabilities of both MegaCam and the high spectral resolution and polarimetry mode of ESPaDOns.

The Pan-Andromeda Archaeological Survey (PAndAS) is a Large Program that was awarded 226 hours and will be acquiring data until the end of 2010. PAndAS is obtaining imagery of over 300 square degrees of the M31/M33 sub-group, to provide the deepest and most complete panorama of galaxy haloes available, over a volume of $\sim$15 million cubic kiloparsecs, identifying galactic structures and substructures down to $\sim$33 magnitudes per square arcsec. To reach this faint limit, it is essential to resolve the individual stars in these galaxies, so that stellar density can be used as a proxy for integrated light. As such, PAndAS is unrivaled by any other extragalactic wide field survey and it is only possible in the Local Group using the unique capabilities of CFHT and MegaCam. The primary science driver is to provide an observational dataset to constrain cosmological models of galaxy formation over an order of magnitude in halo mass. As cosmology turns its attention to the details of galaxy formation, datasets such as PAndAS will become increasingly valuable as tests of and constraints on the models that are being developed. The existing images of M31 and M33 obtained by PAndAS show a spectacular panorama of the complex outer regions of galaxies, with a plethora of dwarf galaxies, stellar streams and diffuse structures (McConnachie et al. 2009). Stellar population studies have a long history of success in Canada, and PAndAS is the first to exploit the detailed information these provide – stellar ages, metallicities and global structures – homogeneously over an entire galactic subsystem. This project is an excellent complement to other near field cosmology science conducted for the Milky Way such as SDSS, Segue, Pan-STARRS and GAIA that have similar science motivations to PAndAS. Pushing to more distant galaxies in the local volume – where there is a statistically larger sample of galaxies over a full range of morphological type – requires wide field capabilities with high spatial resolution to overcome crowding issues, and demonstrates the need for wide-field AO capabilities on large telescopes that approach the diffraction limit, or space based facilities with a wide field. CFHT is exploring the possibility of such an instrument with a feasibility study for a wide field AO system called 'IMAKA.

The Next Generation Virgo Cluster Survey (NGVS, 771 hours over four years) is a prime example of a program that is not just uniquely suited to CFHT, but that could not be carried out more efficiently with any other existing facility. The program capitalizes on the wide-field imaging capabilities of CFHT/MegaPrime to survey the Virgo cluster – the dominant mass concentration in the local universe and the largest collection of galaxies within 35 Mpc – from its core to virial radius, for a total areal coverage of 104 square degrees. Compared to the Virgo Cluster Survey (VCS) of Binggeli et al. (1987), which currently serves as the optical standard for Virgo, the NGVS represents dramatic improvements in depth ($\sim$100 times fainter in luminosity for point sources), surface brightness (40 times fainter), angular resolution (factor 6 better in encircled energy), completeness, and wavelength coverage (five bands versus one for the VCS). In addition, the NGVS employs a dedicated observing sequence that allows the detection of faint, diffuse structures and filaments (the "intra-cluster light") that permeates the space between galaxies – never before mapped over the entire extent of the cluster. The science goals enabled by the survey range from a study of the faint-end of the galaxy luminosity function, the characterization of galaxy scaling relations over a factor 10^7 in mass, the cluster/intracluster medium/galaxy connection, and the fossil record of star formation and chemical enrichment in dense environments. At its completion in 2012, the NGVS will also represent the widest contiguous field ever observed at these depths, thus enabling numerous ancillary projects – from a survey of the Galactic halo to a cosmic shear measurement of the matter power spectrum on large scales.

Several large spectroscopic programs using ESPaDOns are also currently being executed at CFHT. One of these is being led by a Canadian and involves observations of high mass stars. Massive stars are rapidly-evolving astrophysical systems with intense radiation fields and powerful stellar winds that drive the chemistry, structure and evolution of galaxies. The evolution of a massive star is intimately tied to the mass it loses by its stellar wind and to its rapid rotation, both of which can be strongly influenced by magnetic fields. The Magnetism in Massive Stars (MiMeS) Project is a collaboration among more than 50 of the foremost international researchers of the physics of hot, massive stars, with the basic aim of understanding the origin, evolution and impact of magnetic fields in these objects. The cornerstone of the project is an allocation of 640 hours of telescope time on CFHT from 2008-2012 (9 semesters). The MiMeS Large Program exploits the currently-unique high-resolution spectropolarimetric capabilities of CFHT+ESPaDOnS to obtain critical missing information about the poorly-studied magnetic properties of these important stars, to confront current models and to guide theory. At the time of writing this report, MiMeS had been in operation for nearly 3 semesters. Because of queued service observing the observational work has been surprisingly successful. To date MiMeS has acquired 170 hours of validated observations, corresponding to approximately 470 individual reduced spectra of about 80 stars. The rate of discovery of new magnetic stars has been far better than expected - in fact, the program has already completely consumed the 50 hours of observing time reserved for follow-up of newly-detected targets. MiMeS is therefore poised to be a significant success for the CFHT, and a model for future large programs. MiMeS, and its sister project, MaPP (Magnetic Protostars and Planets), represent an efficient, high-impact exploitation of CFHT and its capabilities.

4. THE CFHT SITE

Notwithstanding the absolutely first-rate science that has come from CFHT, the facility has still not taken full advantage of its superior site with perhaps the best ambient image quality of any ground-based location. If it were able to fully exploit the superb location, CFHT, properly instrumented, could remain at the forefront of astronomical research for the next two decades. CFHT is currently moving in this direction and there is every expectation that this goal can be realized with an appropriate commitment from its various communities. It is known from studies at CFHT (Salmon et al. 2009, Racine et al. 1991) that the delivered image quality is largely limited by sources within the facility itself. Dome seeing, mirror seeing, and the optical figure of the telescope optics each degrades the image quality. While the adverse effects of CFHT's enclosure on its delivered image quality are well established (Racine 1991), the emergence of improved technologies and an improved understanding of the turbulence at and above the site has led to a renewed effort to recapture the best possible seeing for the facility. The CFHT Board has taken the first steps towards this goal by authorizing the Corporation to spend monies necessary to place vents in its dome. This will have the effect of constantly flushing the dome with fresh outside air and avoid turbulence caused by heat within its structure. The next important step on the road to a wide field imager capable of carrying out near diffraction limited science is also being pursued at CFHT with its 'IMAKA initiative which will provide near HST-like imaging over a field of view 400 times that of ACS. In addition, CFHT is also exploring several multi-object spectroscopic initiatives (which would also benefit from improved image quality) that will be capable of metallicity and radial velocity determination of stars as a follow up to GAIA. On the high resolution spectroscopic front, SPIRou (near infrared spectrometer and polarimeter) has been granted phase A funding from CFHT. The main science goal of this instrument is to locate Earth-type planets in the habitable zone around low mass M-stars.

5. THE PRESSURES ON CFHT

The position of CFHT within the astronomical community can be assessed by a number of factors: pressure for time on the telescope, number of papers published based on CFHT data and the citation history of these publications, general satisfaction in the various communities on the operations and governance of the telescope. The Canadian oversubscription rate on CFHT has generally varied between 2 and 3 in the past decade. In the most recent semester it has exceeded 3. This is similar to the pressure that Canadians exert on Gemini. From 1998 through 2005 there were about 50 papers per year credited to CFHT data. From 2005 to 2008 (reflecting the Legacy Programs to some extent) these numbers rose steadily and reached more than 110. For 2009 the expected number will be about 100. By contrast Gemini produced 150 papers in 2009 from two 8m class telescopes. Gemini, however, has not as yet reached full maturity - this typically taking a decade or more for a major observatory.

Of particular interest is the impact of the scientific publications from various observatories. Here CFHT has an extremely strong record, in fact, amongst the strongest of all the observatories in the world. This is shown in Figure 1 below where the impact of CFHT papers compared to that of other major observatories is illustrated.

Leaving aside new instruments and an improvement in the seeing at the telescope, what are the other influences on CFHT? On the Canadian side, NRC has linked a possible decrease in its support to the operations of CFHT to the beginning of operations of TMT. This possibility was already mentioned in the previous Long Range Plan. TMT currently remains unfunded by Canada even though operations are currently scheduled to start in 2018; a more realistic date is 2020. However, CFHT remains strongly supported by the Canadian community and its future may depend less on TMT and more on its value to Canadian science. Evidence for this value comes from the recent "Report of the Gemini Assessment Point Panel" which stated that "CFHT has enormous support within the community, is consistently over-subscribed and has continued to produce cutting-edge science results. As a package, Gemini and CFHT both provide complementary, yet equally critical resources to the community." Support for CFHT from the French community seems robust enough to envision a well-supported future up to at least 2018 or 2020. The French seem particularly interested in SPIRou, 'IMAKA and a potential follow up of GAIA with a wide-field high resolution (R=20-30,000) multi-object spectrograph.

Funding is always an issue with any scientific establishment. CFHT has made special efforts to control expenditures by: 1) attracting other partners to share the expense of operations and cost of new instruments 2) controlling the number of staff (CFHT once had 50+ employees and now is down to 32 full-time staff) and 3) pursuing a full automation plan (ready by 2011) which will allow for remote observing; making observations from Waimea with no one in the dome.

6. SUMMARY AND FUTURE

CFHT is arguably situated on the best-developed optical telescope site in the world. This makes it a national treasure that should be nurtured to produce the best science possible. The CFHT Corporation is making serious efforts in this direction. With dome venting, an increased effort to control local seeing, a new potential instrument or two that can focus on cutting-edge science by exploiting the improved conditions at the telescope, and strong community support, CFHT can remain scientifically competitive for the foreseeable future.

In this summary we have not discussed the possibility of replacing CFHT with a larger more modern telescope. With TMT potentially on the horizon and Canada's commitment to Gemini renewed, a funding scenario with Canada as a key player to replace CFHT seems unlikely.

Contributors: Mark Chun, Dennis Crabtree, Michael De Robertis, Laura Ferrarese, Brett Gladman, Alan McConnachie, Ludovic van Waerbeke, Christian Veillet, Greg Wade

REFERENCES

Astier, P., et al. 2006, A&A, 447, 31
Binggeli, B., Tammann, G.A., & Sandage, A. 1987, AJ 94, 251
Cooke, J., Sullivan, M., Barton, E. J., Bullock, J. S., Carlberg, R. G., Gal-Yam, A., & Tollerud, E. 2009, Nature, 460, 237
Fu, L., et al. 2008, A&A, 479, 9
Lilly, S. J., Le Fevre, O., Hammer, F., & Crampton, D. 1996, ApJ, 460, L1
McConnachie, A. W., et al. 2009, Nature, 461, 66
Parker, L. C., Hoekstra, H., Hudson, M. J., van Waerbeke, L., & Mellier, Y. 2007, ApJ, 669, 21
Racine, R., & McClure, R. D. 1993, Optics in Astronomy: 32nd Herstmonceux Conference, 247
Racine, R., Salmon, D., Cowley, D., & Sovka, J. 1991, PASP 103, 1020
Salmon, D., Cuillandre, J-C., Barrick, G., Thomas, J., Ho, K., Matsushige, G., Benedict, T., & Racine, R. 2009, PASP 121, 905
Walker, G. A. H., Walker, A. R., Irwin, A. W., Larson, A. M., Yang, S. L. S., & Richardson, D. C. 1995, Icarus, 116, 359
Yee, H. K. C., et al. 2000, ApJS, 129, 475

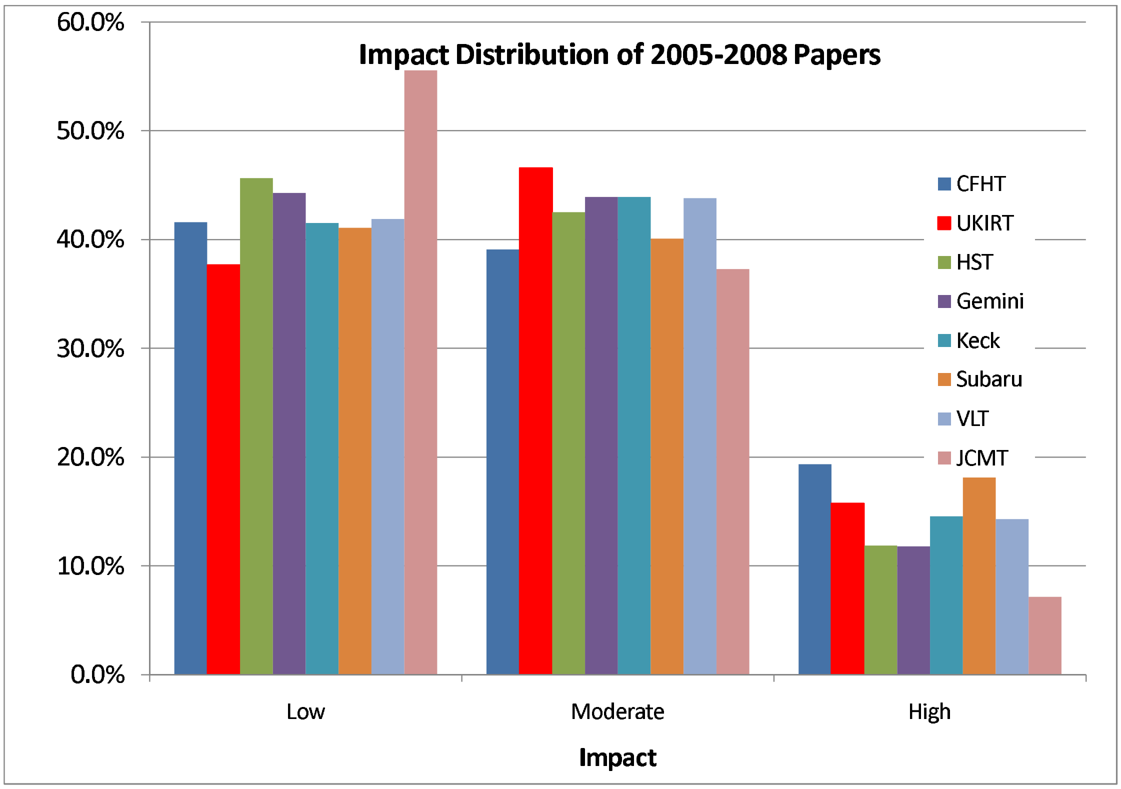

Fig. 1.— This plot indicates the impact of papers published by some of the most prominent observatories. The impact of a paper is the number of citations for that paper divided by the number of citations to the median Astronomical Journal paper of the same year. The impact of a paper is age normalized allowing a comparison of papers of different ages. Generally a better performing telescope will have a lower percentage of low impact papers and a larger percentage of high impact papers. On this plot the impact of CFHT publications is clearly amongst the best of all the telescopes. Statistics for other 4m general purpose optical telescopes were generally not available. That is why they are not included in this plot. This diagram was prepared by Dennis Crabtree.