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CFHT's Hawaiian Starlight: Astronomical CCD Wide-Field Imaging for Public Outreach

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Abstract. Canada-France-Hawaii Telescope's Hawaiian Starlight aims at showcasing the technical and scientific excellence of the telescope through the use of stunning astronomical true color images obtained with its wide-field imagers. The image creation process is discussed as well as the paths CFHT has explored with Edizioni Scientifiche Coelum to promote the activities through high quality printing.

1. Introduction

For the longest time, magazine editors and other "cool image" starved media complained about the lack of material images in astronomy. Indeed, after the death of the photographic plates, replaced by the favored use of electronic detectors, low resolution false color images of the deep sky were produced with little concern about aesthetics. However, Space Telescope Science Institute was the first to understand the great potential for producing stunning images of pictures taken through the eyes of the Hubble telescope. On Mauna Kea, the Canada-France-Hawaii Telescope has been the leader in electronic wide-field imaging for the past decade, bringing the largest CCD mosaic cameras in the world at its prime focus. Since 1999, it operates the CFH12K camera (Cuillandre et al. 2001), a 100 million pixels CCD mosaic that produces incredibly detailed images of the sky over a field of view 1.5 times the size of the full moon. Besides allowing key scientific programs, (eg the discovery of the cosmic shear), this instrument, with a depth and resolution never before reached, is also a great tool for producing beautiful images of the sky. This article describes the image creation process, from the basics of target selection, to the more complex task of the final color image creation process, and concludes with the various methods CFHT has adopted for the purpose of showcasing their images.

2. Wide-field CCD imaging at the Canada-France-Hawaii Telescope

The Canada-France-Hawaii Telescope (CFHT) was designed in the mid 1970s as a highly versatile telescope, able to probe the sky through an extended suite of

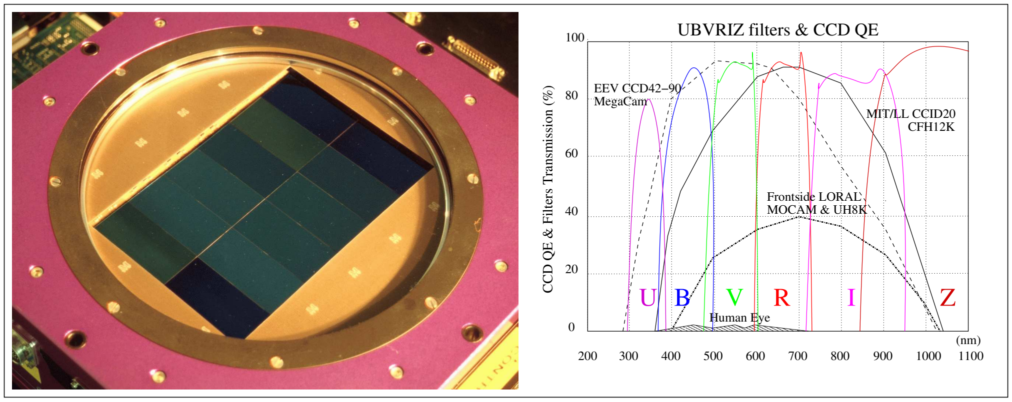

Figure 1. Left: the CFH12K a 100 million pixels CCD mosaic camera mounted at the CFHT prime focus. Right: standard photometric filters used in astronomy and quantum efficiency of the various wide-field imagers used at CFHT since 1994.

foci (prime, cassegrain, coude and infrared) in order to accommodate the needs of various programs to be conducted by the scientific community. The prime detector for astronomical imaging during that decade was the photographic plate, but it was quickly discarded when the first CCDs made their appearance on telescopes in the early 1980s. Though the reduction in field of view was tremendous, the photographic plate could cover only one square degree, whereas CCDs offered many new advantages. As a result, few astronomers hesitated taking that route: a CCD camera is much more sensitive that the photographic film (by a factor of 40), and produces a digital signal which is directly manageable by computers (which were also booming in the 1980s).

While the photographic plate measured ten by ten inches with a fine grain of 10 to 15 microns, an equivalent today of 18,000×18,000 pixels, the first CCDs had only 100×100 pixels! As astronomers adapted their scientific programs to make the best of the small viewing field, there was a strong message sent that great science could be accomplished through the use of CCDs.

As the 1980s and early 1990s saw the development of larger and larger CCDs, up to 2,048×2,048 pixels, their physical size was reaching the limit of the support on which semiconductors were built. A silicon wafer had only a diameter of four inches (it reached six inches in diameter today), a far cry from the required 14 inches that would be needed to create a monolithic detector covering the full prime focus field of view of the CFHT. The only way to achieve larger physical size was to build a mosaic that put several large detectors together. However, the problem with mosaic is the dead space between the detectors; hence, they must be designed in a way so as to minimize these dead spaces. The first CCD mosaic camera to be mounted on CFHT was a prototype built by Gerard Luppino from the Institute for Astronomy (IfA), University of Hawaii (Luppino et al. 1992), a 4,096×4,096 pixels mosaic made of four two-edge buttable 2.048×2,048 pixel CCDs. This immediately triggered the MOCAM project, a duplication of that camera with high quality CCDs (Cuillandre et al. 1996). Meanwhile, the effort on large CCD mosaic was pursued at IfA and in 1995, the UH8k (Luppino et al. 1994) saw first light at the CFHT prime focus, a 8.192×8,192 pixels mosaic

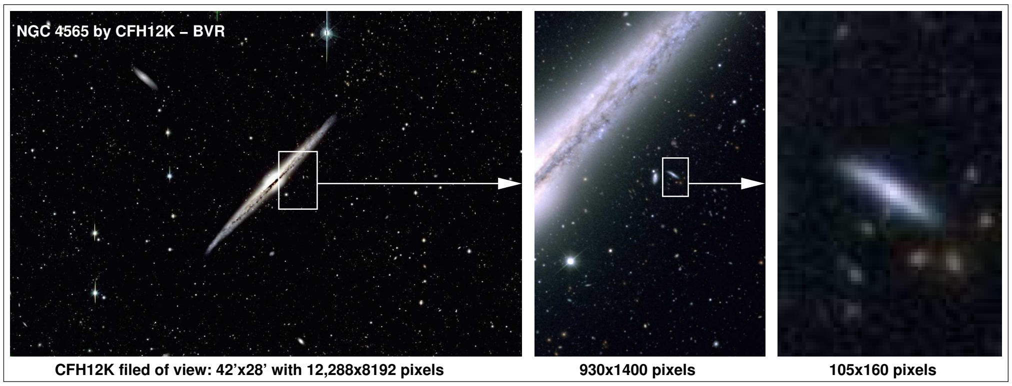

Figure 2. Illustration of wide-field high resolution imaging with the CFH12K: the ratio between the full field of view (left) and the zoom window on the right where the actual pixels are visible is about 6,500.

made of eight 2,048×4,096 pixels CCDs, totalling a staggering 64 million pixels! Unfortunately, the quality of the CCDs was challenging in many ways and science was difficult to conduct. CFHT and IfA then combined their efforts and built a more refined camera with higher quality detectors, and even more pixels. The CFH12K, a 100 million pixels mosaic, saw first light on the telescope in January 1999. The field of view covered by the mosaic was then 34% of the original one square degree available on the telescope.

This new camera kept the CFHT ahead of all the other telescopes worldwide in the domain of high resolution wide-field imaging and allowed its scientific community to conduct new and ground breaking studies of the Universe, like the observational discovery of cosmic astigmatism caused by dark matter in the Universe (Van Waerbeke et al. 2000).

3. What makes a great astronomy picture

The magic of astronomy often lies in the sheer beauty of a nebula or a galaxy. But "magic" and "beauty" are two words remote from the rational scientific jargon; nevertheless, such images are probably responsible for triggering vocations of many renowned scientists and have definitely been, and will always be, the best way to reach the large public in order to convey information on the scale and history of our Universe.

However, making an harmonious image in terms of colors, details and contrasts is not an easy process. For the longest time, due to lack of proper attention to collecting multi-wavelength data, astronomical images were confined to be displayed in false color mode (a color is representative of an intensity, not of its intrinsic color related to some physical process). Also, as previously stressed, the detectors were small, thus providing coarse resolution and not likely to reproduce nice prints even for the half page of a magazine.

Creating a beautiful astronomical image means achieving high resolution, i.e. having a lot of pixels, and CFHT's wide-field imagers deliver such resolution (see figure 2 for an illustration). For the colors, a trichromy approach that matches the simplest way to represent color documents in the media world is mandatory. A decomposition in the R(ed)G(reen)B(lue) domain can cover the whole range of colors, hence obtaining three images in three independent filters is the best approach. Scientific imagers are monochromatic detectors, and to select a given wavelength domain, scientists use a set of standard filters (Johnson et al. 1953, Cousins 1978). This set is represented on Figure 1 (right) with the U,B,V,R,I and Z bands. Now, the RGB channels must be matched to a subset of these filters with the identical wavelength ordering (redder first and bluer last), hence possible combinations are R-V-B, or R-V-U. The redder filters are not as interesting as the bluer ones since the absorption by dust is weaker and creates less contrast in the image. Therefore, the U or B filter for the blue channel is mandatory. Hα emission in the star forming region is at 656 nm for a non-redshifted source, right into the R filter band. Since this is a prominent feature in the Universe, it ought to be represented in the red channel in the final image if one wishes to obtain a "true color" image. This leaves only the V filter for the green channel. The best combination is then the R-V-B to match the RGB channels.

By true colors, one means colors that are close to reality, for example, as aforementioned, Hα will be reddish on the image, just as our eyes see it. The plot on Figure 1 also shows the sensitivity of the human eye, and one can notice that the best match is, indeed, the B-V-R set of filters. For an in-depth discussion on true colors rendering, see the article by Wainscoat et al. (1997).

Earlier high resolution imagers such as MOCAM and UH8k were equipped with frontside illuminated CCDs whereas CFH12K provided access to the B-band with its backside illuminated CCDs. It has only been since 1999, with the onset of the instrument CFH12K, that CFHT had the capability to capture data allowing the creation of true color, (i.e. with a set of B, V and R filters) high resolution astronomical images. In 2002, CFHT is commissioning an even larger CCD mosaic: MegaCam (Boulade et al. 1998) with a whooping 350 million pixels and a field of view of one square degree, closing the loop 25 years later by paving the full field of view of the telescope with CCDs.

4. Mosaic image data handling

MOCAM generated 16 million pixels images, UH8k generated 64 million pixels images and CFH12K raised the bar to 100 million pixels! The booming development of computing facilities, especially the PC-based architecture, with huge disk systems were instrumental in permitting the handling of data generated by a camera like the CFH12K. Today, PCs with dual processors cadenced at 2 GHz with one gigabyte of RAM and more than one terabyte of disk space are affordable in the scientific field.

However, when MOCAM was made operational in 1994, the image size made the standard image analysis tool, such as Iraf, totally inadequate for reducing and analyzing the data. FLIPS (FITS Large Image Processing Software, Cuillandre et al. 2002) was developed to address this issue of handling large sets of large images in order to produce optimal frames for scientific analysis, e.g. go from the initial mosaic of detectors to a final monolithic frame with all the various signatures of the instrument removed.

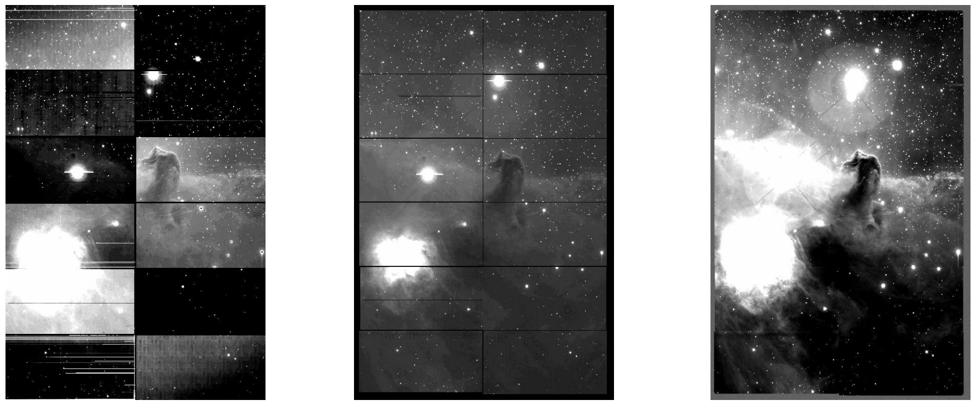

Figure 3. IC 434 region including the Horsehead nebula. Left: raw data coming out from the CFH12K camera. Center: pre-processed frame (bias, dark, flat-field and additive sky correction). Right: final frame resulting from 5 stacked dithered exposures.

Figure 3 illustrates the process to create a suitable scientific frame. First, the data have the basic signature of each of the 12 detectors removed (from left to center): the typical overscan/bias/dark additive correction and the flat-field correction, occasionally followed by some additive sky effects correction. The overall look of the image (center) is one of a unique detector but with many blemishes still present on the images that may include: gaps between the CCDs, cosmetic defects on the surface of the CCDs that are not sensitive to light, cosmic ray spraying the detectors during the exposure and causing white spots and strikes on the image, and passing artificial satellites that trace a continuous line across the image (the CFH12K has a field of view 1.5 times the size of the full Moon, making it very likely to be affected on almost every exposure by such contamination).

To remove these blemishes and build a contiguous image of the sky, one has to recover the areas missed in the first frame with a set of four other images, an optimal number (the pattern is well defined: one center point and four others distributed on a circle around it, none of these five pointing having a similar X-axis or Y-axis coordinate). With 100 million pixels per image, the total quantity of data per color reaches one gigabyte (three gigabytes for the complete set of data to create a true color image). Before stacking together the frames, there is an important characteristic in the camera that needs to be taken into account: when the focal plane was installed the CCDs were not perfectly aligned in the X-axis and Y-axis, nor were they oriented exactly the same way. Instead, small angles are present from one to another (typically a fraction of a degree). Also, the CFHT wide field corrector induces a large scale optical distortion that must be taken into consideration and needs to be corrected before stacking the five exposures. Each image is actually mapped into a larger 13,000×9,000 pixels frame that respect the relative positioning, angle and distortion effect of the

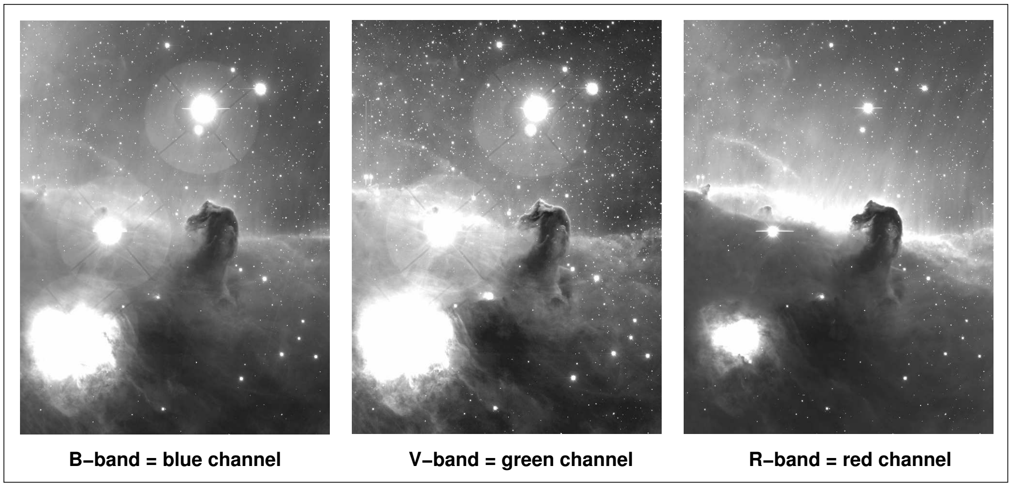

Figure 4. The three individual colors (B,V,R). Notice the prominence of the H-alpha emission in the red filter and the stronger dust absorption in the blue filter.

twelve CCDs versus each other. These five images are then processed with a routine that builds a contiguous image from the information present in the five images (averaging with a sigma clipping algorithm) using some external information such as the physical offset along the X-axis and Y-axis on the sky between each of them. The final result is shown in the right frame of Figure 3. This frame is the one that scientists will use to extract crucial information on shape and intensity of the astronomical objects captured in the image. This will be done for each color independently but one color will suffice for some programs focusing only on morphology analysis.

5. Color image creation process

The final steps to create a nice color image based on three independent color channels requires some reframing of the image because the CFH12K imposes a fixed field of view which does not necessarily match the scale of the astronomical object. In order to get a more visually attractive result, the reframing, as with photography, allows emphasis of some fraction of the image (Figure 4). It should be noted, that with such large field of view, CFHT can cover large objects which have been cataloged for decades, or even centuries, such as the famous Messier catalog, beloved by amateur astronomers.

Combining the three colors together is a subtle interactive process, but a good starting point is to get the stars to be white since the majority of them are similar to the Sun, and therefore should present a white-yellowish color. Usually only minor adjustments are needed once this first color balance is obtained. The left image of Figure 5 shows the result of the combination from the three images of Figure 4.

However, to get the best visual impact, most astronomical images require extra tuning in order to increase contrasts and color saturation. CFHT has

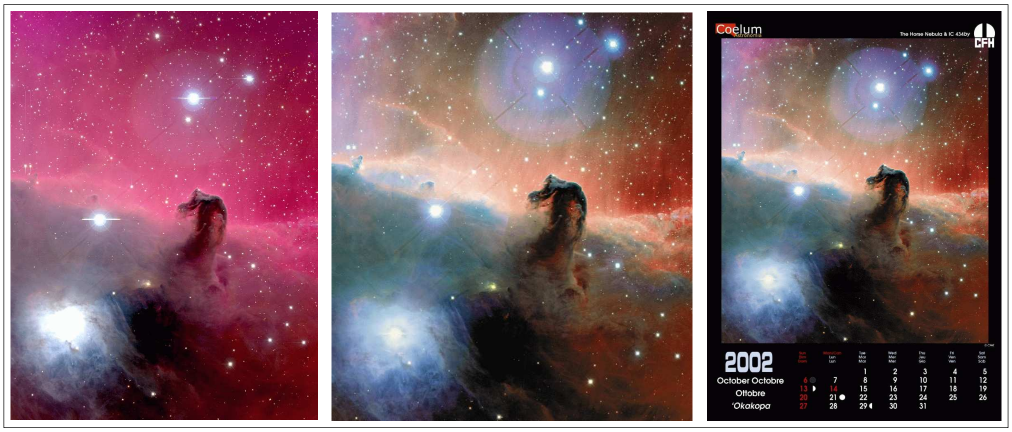

Figure 5. Left: "true color" RGB image. Center: reframed, color and contrast enhanced image by Coelum. Right: final integration in the CFHT/Coelum calendar - A3 page format.

joined forces with the Italian scientific editor Coelum in order to obtain final rendered images that capture the attention of the viewer. While the colors and contrasts start to be a slight departure from the "true colors" paradigm, the end result is always at the service of the image and will ease the embracing by the large public (Figure 5).

6. Public outreach

CFHT opted for not putting the visual material on the web before 2002 since the collection was still reduced, and because other telescopes were already covering that same niche. Instead, in close collaboration with Edizioni Scientifiche Coelum, CFHT developed a strategy based on high quality printing of these large images. It started with an A3 format calendar for the year 2000, with image reproduction as large as 11×13 square inches (Figure 5 right) showcasing the best twelve images produced by CFHT over the last year. After three years, a subset of the images (seven) were selected to be printed for large posters (27×38 square inches) because resolution of the CFH12K images still preserved a crisp impression to the viewer even at close range.

The name of our telescope, CFHT, does not necessarily resonate easily, nor does it stick to memory; hence, a name representing the line of creations by CFHT and Coelum was invented: Hawaiian Starlight. Through the diffusion of the calendars and posters and the creation of the Hawaiian Starlight web site (`http://www.cfht.hawaii.edu/HawaiianStarlight/`) showcasing the images, additional exposure to CFHT has been gained by bringing the images to appear on magazine covers and feature articles (Figure 6), as well as many uses in educational textbooks and multimedia items (TV shows, CD-ROMs, ...).

Figure 6. Left: Science magazine - January 2002. Center: Canadian Geographic magazine - March 2002. Right: CFHT/Coelum calendar - 2002.

7. Conclusion

CFHT's Hawaiian Starlight aims at showcasing the technical and scientific capabilities of the telescope as well as bringing to public a general awareness on science through highlights of astronomical research. The expertise of the scientific editor Coelum has led CFHT to a close collaboration, entrusting them with the editing and production of the tuned-up images and printed material. The result is stunning astronomical pictures reproduced on a high quality medium that are now gaining a reputation on their own.

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