Since the advent of digital imaging in the 1990s, many professional Schmidt cameras have been converted to use digital technology. In August 1998, I visited my first digital Schmidt at the Cote d'Azur Observatory in Calern, a city in Southern France. The telescope, with a 90 cm front correcting plate and 1.5 m mirror, was instrumented with a Loral 2048x2048 sensor. Unfortunately, this facility has been closed due to budget restraints, but many other professional Schmidt cameras are still operating digitally.

A Schmidt telescope is composed of an easy-to-make spherical mirror, an aspherical correcting plate, and a curved focal plane exactly in the middle between mirror and plate. Because of the focus position, this telescope cannot be used for observation; this is solely a photographic telescope to be used with film or digital sensors. But, while placing a flexible and light film inside the tube is a relatively easy task, using a CCD camera is much more complex. In the following, some solutions for the main technical problems will be shown with particular attention to the author's solution.

The power of a Schmidt telescope is undoubtedly the wide corrected field; for example, for the Calern telescope, the full field is more that 5°x5°, imaged with 300 mm square film plate! While professional astronomers consider this a fundamental characteristic for surveying, amateur astronomers would appreciate it for astrophotography of large objects, such as emission nebulas.

In the 1990s, the amateurs who owned a Schmidt camera could not afford the huge prices of large, professional CCD sensors. Only in the first years of the new millennium, in particular in the last three years, big CCD arrays have become available at reasonable prices ($5000 to $10,000). So, many amateurs thought that it was the right time to materialize a dream: the digital Schmidt camera (in short DSC). In every continent, often independently, many implementations have been fashioned, each with slightly different technical solutions. Some of the amateur DSCs I am aware of include those of Fabrizio Marchi, Italy; David Levy, USA; Mike Harlow, UK; Tanaka Kazuyuki, Japan.

My Schmidt camera

I too was among the number who dreamed of a DSC. This turned out to be feasible thanks to my friend Aldo Radrizzani, who is one of the best Italian astrophotographers; in the '90s, he shot hundreds of high-quality Technical Pan frames with his 300/400/615 mm Schmidt (the numbers refer respectively to the diameter of the correcting plate, the mirror, and the focal length). In 1998, after visiting Calern with Aldo, we had long discussions about such a project, but the time was premature. Unfortunately, Aldo passed away in 2005 before seeing the DSC becoming a reality. He left his telescope to me, and in late 2006, I succeeded in modifying it to become digital.

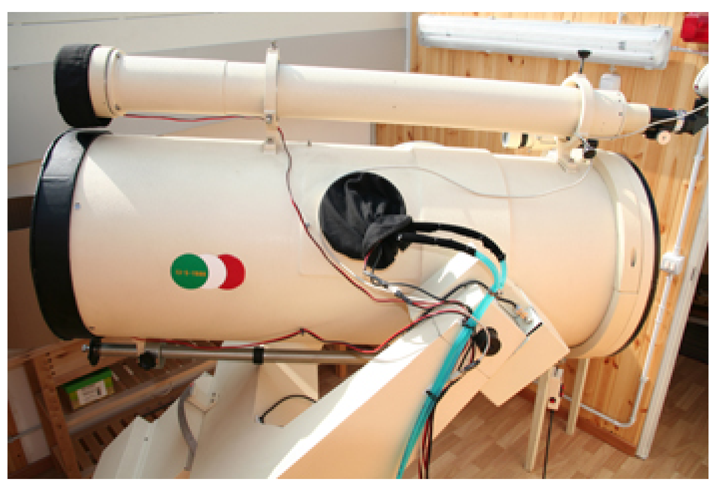

Figure 1– The author's 600 kg Schmidt telescope

Figure 2: Internal support for the camera

The conversion was definitely not an easy task. Many competences had to be put together to realize such a project, and I was lucky to have found very helpful friends and professionals who made this possible. The result is a great instrument that is able to image the sky from my light-polluted backyard in Tradate, Northern Italy. And, thanks to the comfort of the observatory that I built around the DSC, I have started to play with other disciplines, such as variable stars and minor planet astrometry.

The Curved Focal Plane Problem

The main problem for the conversion of a traditional Schmidt telescope to digital is that the focal plane is curved. This is not an issue with film, because the minimal required bending is easily obtainable. Unfortunately, silicon CCD chips cannot be bent in any way.

The simpler solution is to take advantage only of the central corrected field of view, which is only a few millimeters in diameter. Therefore, a big CCD sensor is not required; typically a 6x4 mm detector with small pixels is used. This solution, not useful for wide-field astrophotography, is suited for studies such as variable stars, thanks to the huge gathering of light.

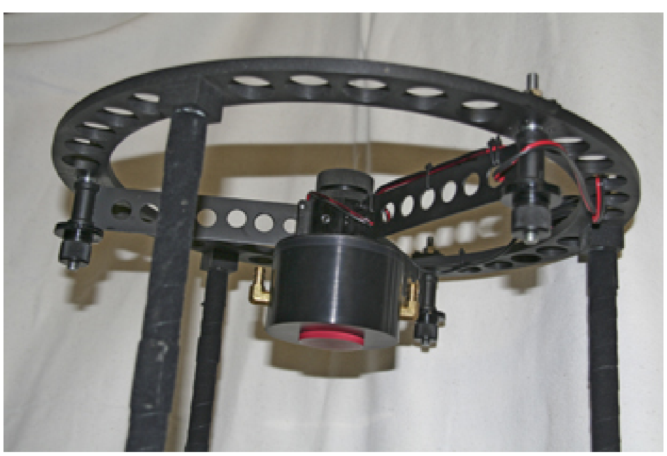

Figure 3: A detail of the CCD camera spider. The focusing is obtained with the three hand knobs.

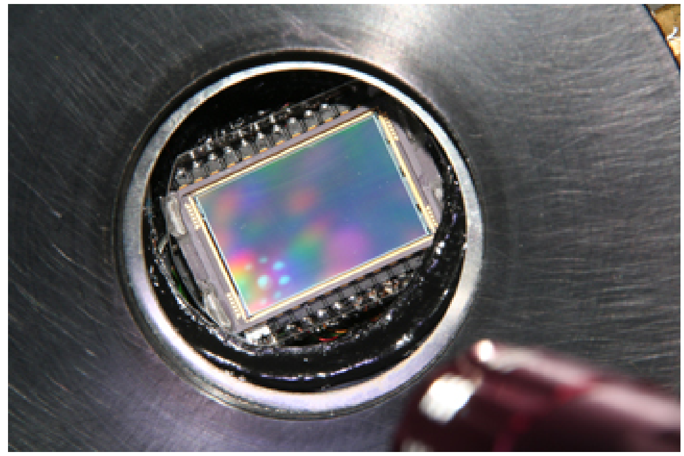

Figure 4: The CCD chip with the correcting lens glued on the ceramic frame. To have a more convenient shape, the circular lens was cut on the upper and lower sides.

The best solution is to correct the lens (or group) to get a usable full field. A single plano convex lens is the simplest solution as well as the one I have adopted. This solution is not new and was previously used in the film plate epoch, because the glass plates could not be bent to the necessary curvature. But, this works only if the focal plane is nearly in contact with the plane surface of the lens (with film this was not a problem). In the CCD cameras, the focus is usually precluded by an optical window placed typically from 5 to 20 mm from the focal plane. One mm is usually the maximum distance for a plano convex lens to work acceptably. Fortunately, this is also the height of the ceramic frame around the CCD, where the chip manufacturer usually glues a protective optical window that is removed by nearly all manufacturers of cameras for astronomy. My correcting lens was placed exactly there.

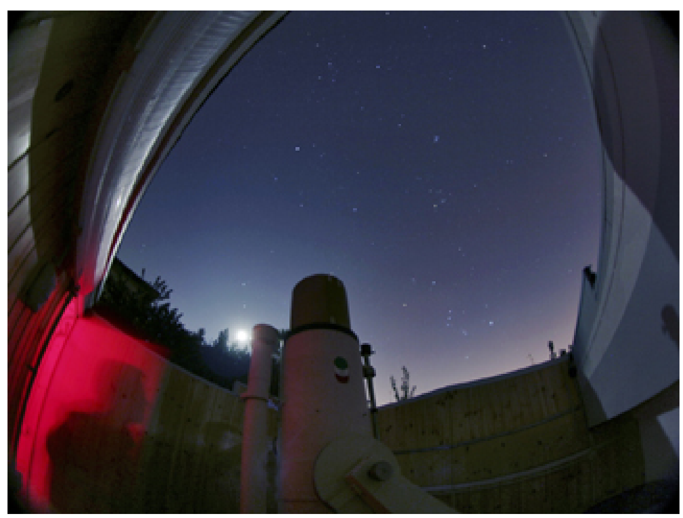

Figure 5: The light pollution and the Moon glare illuminate the DSC while imaging comet 17P/Holmes on 1 November 2007. Imaged with a Canon EOS 350D with 60 s exposure and 8 mm f/3.5 fisheye lens.

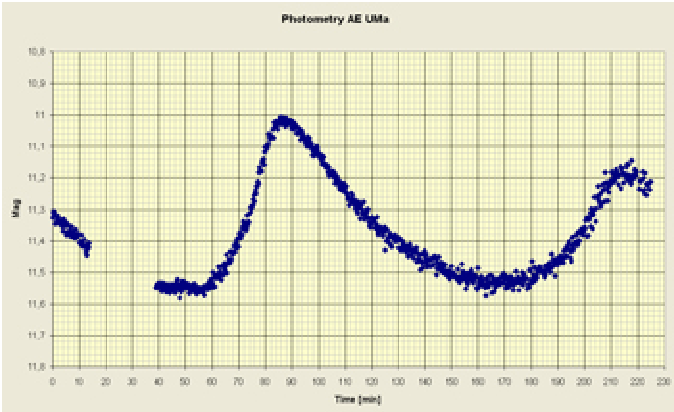

Figure 6: A light curve of the short period variable star AE UMa captured in the night of 29 April 2007 with a green filter, starting at 20.14.46 UT.

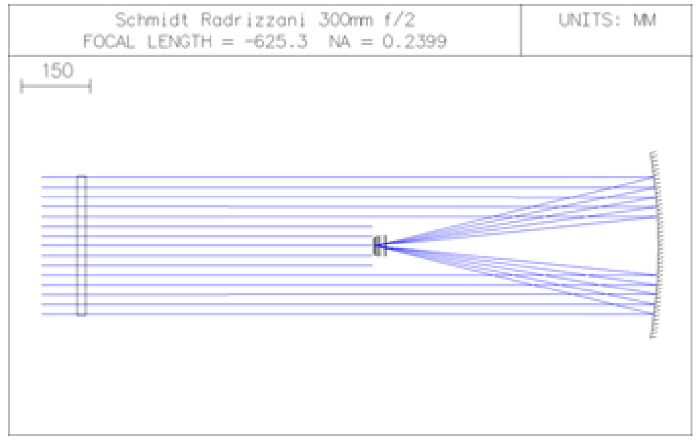

Figure 7: Ray tracing of the author's 300/400/615 Schmidt

Then, I computed the necessary lens curvature with a ray tracing software, and I evaluated the expected optical performances. Due to the very fast focal ratio, plane optical windows and filters can also modify the optical correction. A smaller thickness is better, so I selected a 1 mm thick sapphire optical window and 1 mm thick Astronomik LRGB-Ha filters. By absolute terms, the optical quality is not perfect, because a lot of rays are outside the airy disk; but, from a practical point of view, the quality is good because the spot diameters are, at the worst, 15 µm over the entire field of view and in the whole visible spectrum. The lens was manufactured by the Italian optician Romano Zen, the same person who figured the optics of my Schmidt twenty years ago. The gluing on the CCD frame is critical because of cooling, and to avoid thermal stress cracking, a silicone-based glue for low temperatures must be used.

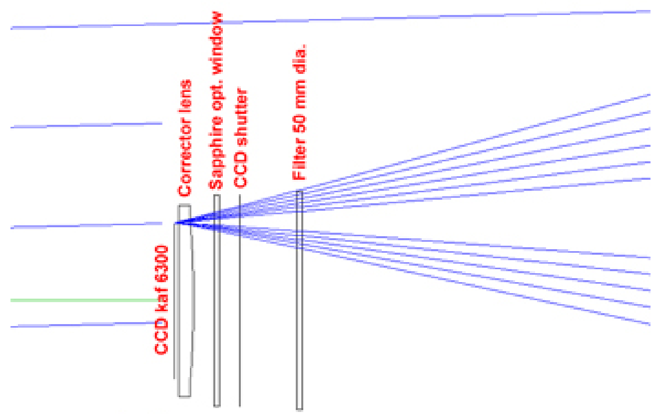

Figure 8: Detail of ray tracing in the focal region, with the correcting lens, the optical window and a filter.

Another solution is to use a multiple-lens corrector outside the CCD camera. The manufacturing of such lenses is a very expensive task and therefore is usually avoided. But, the Japanese amateur Tanaka Kazuyuki had the idea to use a commercial apochromatic doublet from a Borg 50ED refractor. Kazuyuki modified a Meade Schmidt Newton by shifting the correcting plate. The exact positioning of the available optical parts was determined by means of a ray tracing software. And, thanks to the Newtonian mirror, he was able to get a very convenient external focus, where he placed a SBIG STL 11000 camera. However, when compared to a standard DSC, this elegant solution has the drawback of needing a longer focal length to acceptably maintain the secondary mirror obstruction.

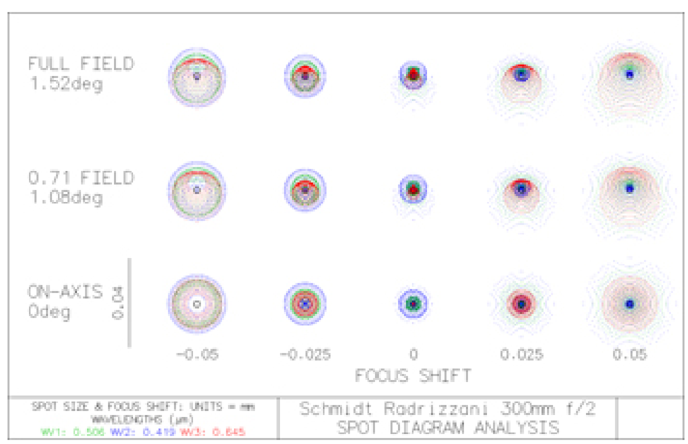

Figure 9: Spot diagram analysis of the adopted solution show that the optical quality is sufficient for the selected CCD all over the field up to the extreme corners (1.52° radius).

Figure 10: The IC 1848 and 1805 nebulas in Cassiopeia with a total exposure of 26h40m captured in this 4 panels mosaic during 5 whole nights. October 2007

Additional problems

The digitalization of a Schmidt camera has many other small problems. The first is that the CCD camera external dimensions must be small to avoid excessive obstruction. Unfortunately, modern cameras with big chips typically have very big external cases with a 20 cm2 cross-section. In early 2006, the only camera on the market that I found with a small case and a big chip was the Yankee Robotics Trifid2 6303e. Nowadays, many more alternatives are available, such as Starlight Xpress SXVF-H35 and 36.

A problem connected to the CCD camera is the heat produced by the Peltier cooling system. Letting the heat inside the optical tube is not a good idea, especially if the tube is closed. Fortunately, the camera I had selected was provided with liquid cooling, so I have built a pipeline passing through two of the three camera holders. The heat was extracted from the tube by means of a mixture of water and glycol ethylene, a liquid usually used for car radiators. The approximate freezing temperature of 40°C prevented a very dangerous freezing inside of the camera during the winter. On the pump side of the pipeline, a small radiator for PC modification was used to maintain the liquid at a constant temperature.

Filters are another issue; for the same reason that a big CCD camera case is not allowed, the big cross-section of a filter wheel is not admissible inside the optical tube. So, I have designed a zero-vignetting magnetic filter holder, which was manufactured by my friend Franco Martegani. Unfortunately, this solution has the drawback that the filters must be changed manually. This is usually not a problem for me, because I typically expose for a whole night with the same filter.

The filters are connected to another problem: the focusing of the Schmidt camera is really hard to achieve. Hence, parafocality is a must, and the filters must all have the identical thickness, with a peak-to-peak maximum deviation of 0.01 mm. The selected Astronomik filters were carefully measured and were found to respect this hard requirement. In my telescope, the focusing mechanism consists of three hand knobs connected to the three camera spiders. That is a focus and planarity contemporaneous regulation. Without any aid, the focusing procedure is a really painful task, taking multiple nights. But, I've found that by using CCD Inspector software, this procedure becomes a more affordable, half-night task. Fortunately for me, this operation had to be executed only once, because my telescope is provided with focus-to-mirror bars made of Duran 50, the same glass used for the mirror, with a small thermal expansion coefficient. After a year of imaging, I can say that I have never needed to retouch the focus.

Another side problem is that my 20-year-old Schmidt was mounted on a fork mount provided only with slow motion motors. To get the maximum from the DSC, I have added an AstroElectronic FS2 GOTO system; encoders were a necessity due to the many flexures of the mount, which were not designed for high precision pointing. Moreover, I have had to substitute the tangent arm declination motion with a gear wheel, furnished by my friend, Ivan Mariotti. As a result, now I get a 6 arcmin pointing error (computed as standard deviation) all over the sky, which is good considering the wide field of view. Tracking is quite an easy task considering the short imaging focal length. I use a 120 mm f/13 refractor, a black-and-white webcam, and a 0.4x focal reducer.

Conclusions

After more than a year of usage, I can testify that a DSC is really great gear for imaging wide field emission nebulas with narrowband filters, even from a light-polluted backyard. In fact, I have always imaged from a city with an average limiting magnitude of 4.5 and sky brightness of 19 mag/arcsec2 at zenith. I have found that resulting images are worth the big efforts that were necessary for the modifications: the images have an impressive dynamic range and depth. The extremely fast focal ratio allows me to get a very high signal-to-noise ratio, even in the faintest parts of the nebulas. As an example, my

Figure 11: This image of M31 galaxy was captured with the DSC without filters, while the colors were captured separately with a Canon EOS 350D and Pentax 75 refractor on a different night. The 35 min (35x1 min) luminance image was captured when the cooling piping was not yet present, and so without cooling.

Figure 12: Comet 17P/Holmes a week after the explosion shows a yellow dust coma, a green gas coma and a small blue gas tail. This image was captured on 31 October 2007 using RGB filters and a total exposure of 90 min.

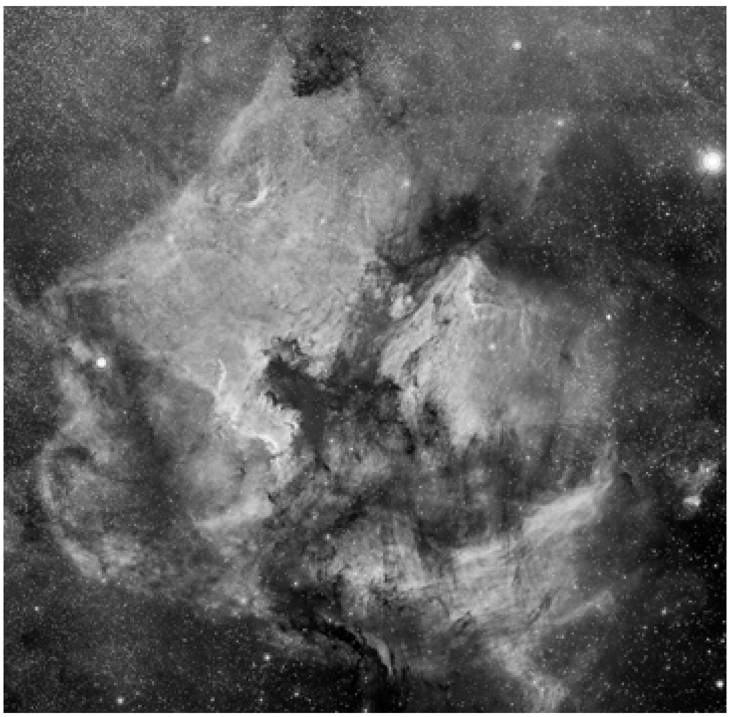

Figure 13: The North America nebular complex is really intricate if observed with a total exposure of 29 h. This was the time necessary to capture the 6 panels mosaic, in 9 whole nights. June and July 2007.

multi-hour, H-alpha exposures never required noise reduction algorithms (such as Neat Image or Noise Ninja), even after applying heavy image processing techniques.

Demonstrating the interest that amateurs have in DSC, I am aware that some European telescope manufacturer (see links) started to sell complete telescope-plus-CCD systems that do not require the purchaser to solve all the problems that I have described.

Advancements in DSC are still possible: the usable field of view of Schmidt telescopes is even bigger with today's affordable CCD chips. If, in the future, 80 mm square chips will be available at reasonable prices, the amateur-size DSCs would be able to image even more impressive shots of the deep sky. ♦

Acknowledgments: I would like to thank all the friends and professionals that made it possible for me to realize my DSC dream. Beyond those whom I have cited, some other strong guys helped me in dismounting and re-mounting the really heavy 600 kg telescope: Alberto Brunati, Alessandro Gambaro, Alberto Gianni, Antonio Paganoni, Stefano Simonelli.

About the author: Warning: a DSC can cause dependence! As an example, Lorenzo Comolli is "wasting" nearly all clear nights imaging the sky from his backyard, while in the clouded nights he elaborates the gigabytes of files.