Adaptation of CCD Cameras to Schmidt Telescopes

ABSTRACT. An optical design concept for the adaptation of a CCD system to a Schmidt telescope is studied. Considerations on the use of filters and the wish to achieve a modular design led to the principle of a focal reducing optics as an optical standard interface. A cheap realization at the 35 cm Schmidt telescope of Hoher List will be introduced.

1. Introduction

The study of very extended H-II regions demands observations of wide fields at very low surface brightnesses. This is a task suitable for smaller telescopes on account of the availability of observing time. The theoretical limiting magnitude for extended deep-sky objects depends only on the relative aperture of the telescope optics

$$N = \frac{D}{f}, \qquad (1)$$

where N is the relative aperture, D the aperture diameter, and f the focal length of the optics. Thus the Schmidt telescope is ideal for such purposes. Schmidt telescopes originally were developed for wide-field imaging using photographic plates. Their disadvantage is the field curvature, which plays an important role at large fields.

Today the CCD detector is the preferred imaging system with a very linear response and a high quantum efficiency. It also produces images in digital form. The easiest way to adapt a CCD system to a Schmidt telescope could be the exchange of the photographic plate holder by the CCD detector. But this would result in some disadvantages.

2. An Optical Standard Interface

Actually there exist two different principles of CCD devices: liquid gas cooled and Peltier cooled devices. Although the Peltier cooled devices can be minimized in their size, they still need additional cooling like ventilators. It is not very useful to install such a CCD device inside the tube of a small Schmidt telescope. We decided to use an available Newtonian secondary mirror for the adaptation of a CCD outside the tube of the Schmidt telescope. In this case, however, polarization observations are not possible.

Astrophysical investigations usually need wavelength separation for the physical study of the celestial objects. For the further design we have to think about the use of filters, prisms, and other additional optics with the Schmidt telescope. Filter plates or prisms in a convergent beam of an optical system always cause errors like spherical aberration or shift of the focal plane. However, the use of filters or prisms in the entrance pupil of an optical system avoids these problems. The principle of a focal reducing system enables the use of small filters. It projects the entrance pupil to a smaller real image — the exit pupil. This can be used as well as the entrance pupil (Geyer & Hoffmann 1993). Generally the effective focal length can be scaled by any factor. Thus we will call this the principle of an *optical standard interface* (OSI).

The first optical component of the OSI is the field lens collimator, which corresponds to the eyepiece in visual observations. The second component is the camera lens with the detector, according to the human eye. The advantage of the OSI is its modular design. As in visual observations the 'eye' can be exchanged. So it is very easy to use different camera lenses for various observation techniques.

CCD detectors are flat detectors. But the design of additional optics like the OSI permits the correction of the field curvature of the Schmidt system.

3. The 35 cm Schmidt at Hoher List

Today it seems to be old-fashioned to use a small Schmidt telescope for wide-field imaging. But, as we have seen, a telescope with a low relative aperture can be very powerful for investigations on very faint and extended objects.

The Schmidt telescope at Hoher List has an effective aperture of 350 mm, 500 mm mirror diameter, and a focal length of 1370 mm (relative aperture of about 1:4). As mentioned above, a secondary plane mirror is used to bring the prime focus outside the tube. The field collimator of the OSI consists of an achromatic lens with focal length of 80 mm having the same relative aperture as the telescope. A plano-convex field lens of 200 mm focal length close to the prime focus defines the exit pupil of the collimator at a distance of 50 mm behind the achromatic collimator lens. A simple achromatic lens identical to the collimator lens acts as camera lens (see Fig. 1). This yields a scale of 1:1. A filter box between the collimator and the camera lens allows the selection of different spectral bands.

We use a CCD detector with the new low dark current technology from Kodak. The detector size is about 7 x 5 mm^2 divided into 768 x 512 pixel. The squared pixels are 9µm in size. The total field of view gives 17.6′ x 11.7′ at a resolution of 1.3″/pix. As a number cruncher for the image processing an ATARI TT030 computer with 12MB RAM and 240MB harddisk storage capacity is used.

The current optical design is not yet perfect. We have an additional field curvature, coma and also astigmatism. The field curvature (defocus) and coma can be recognized because it spreads beyond the unusual small pixel size of the new CCD detector. The astigmatism can be found only in the calculated spot diagrams of the optics. But it is possible to operate on imaging and also photometry with pixel binning. Optical calculations showed that a meniscus lens immediately behind the prime focus (instead of the plano-convex field lens) will be able to correct the additional field curvature and also residual coma and astigmatism. These and further improvements would enable the use of the larger Kodak CCDs with 1536 x 1024 pixel with this equipment.

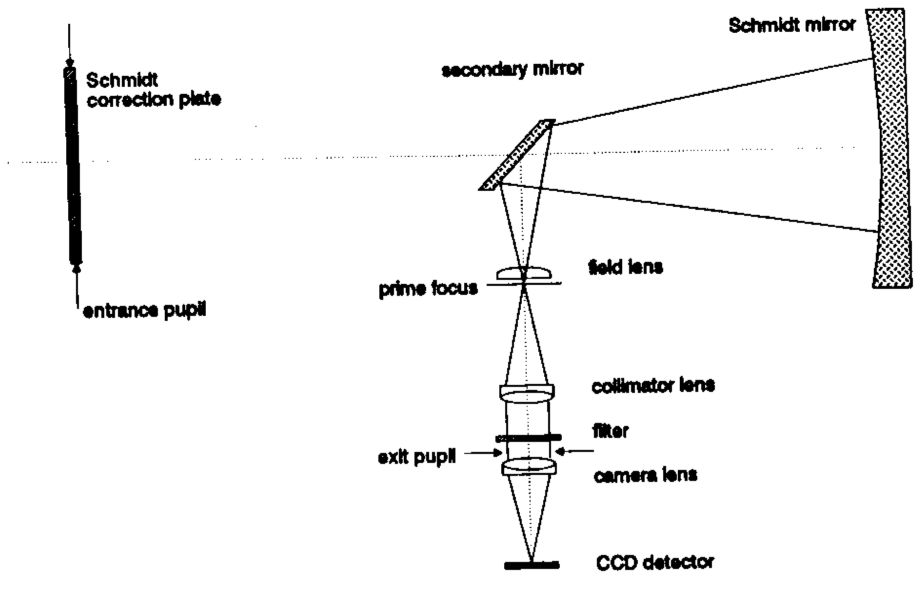

Figure 1. The principle of the Schmidt telescope with the optical standard interface.

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The Hoher List CCD Focal Reducer System: a Versatile Instrument for Fieldspectroscopy and Direct Imaging

With the introduction of CCD detectors in the astronomical observing technique about 10 years ago, dioptric focal reducer systems (FRS) became essential equipment for direct imaging, polarimetry, Fabry-Perot-interferometry and field spectroscopy (also named 'multi-object spectroscopy' [MOS]) at the larger telescopes of many observatories. The reason is that the 'field efficiency'

$$2\theta = d/(N_{ef} \cdot A) = d/F_t \text{ [rad]}$$

(d = linear diameter of the detector, N_{ef}, A, F_t are the F-number, the aperture and focal length of the telescope, respectively) is very small for present day CCD sizes used in the direct focus of the telescope.

An 'afocal FRS' consists of a field lens collimator, similar to a Kellner ocular, and a camera lens, the entrance pupil of which has to be matched with the real exit pupil of the afocal telescope-collimator combination. The diameter of the exit pupil δ is given by

$$\delta = f_{coll}/N_{ef}$$

In an optically well designed FRS the collimator and camera should be de-coupled, so that camera optics of different f-ratio can be used. If the focal length of the camera lens is smaller than that of the collimator, a reduction of the telescope focal length by the factor

$$m = f_{coll}/f_{cam}$$

takes place. Therefore the field efficiency of the telescope is increased now by the factor m:

$$2\theta = d\ m/F_t$$

The advantages, principal techniques and possibilities of FRS have been shown and developed by us, about which we reported at several occasions already in the pre-CCD-times (Geyer 1979; Geyer 1981; Geyer, Hoffmann & Nelles 1979; Geyer & Nelles 1984).

The Hoher List Observatory Zeiss-FRS at the 1.06 m f/14.5 Cassegrain telescope has a field lens collimator of 720 mm focal length. The free distance between the telescope focus and the fieldlens system is 253 to 257 mm (longitudinal chromatic aberration!) and a relevant one of 150 mm between