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CCD Observations of Gravitational Lenses and Extragalactic Supernovae with the Brorfelde Schmidt Telescope

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Abstract. The Brorfelde Schmidt telescope has been modified to use a 1024 × 1024 12 micron pixels CCD camera. The field is 27 × 27 arcmin. When required, the spatial sampling is improved by co-adding multiple exposures with small offsets. The telescope is operated in service mode, with one observer carrying out several different observing programmes in parallel. The telescope is particularly well suited for long term monitoring programmes, most notably photometric monitoring of gravitationally lensed QSOs and searches for extragalactic supernovae.

1. Introduction

Copenhagen University Observatory operates a 50/77 cm Schmidt telescope at Brorfelde in Denmark. The focal plane scale of 137 arcsec/mm was chosen to match an atmospheric seeing in Brorfelde of 2 arcsec. Over the last decade the priority of observational programmes has gradually moved away from research requiring a wide field (the last one being a search for new minor planets and improving the ephemerides for known ones). New research fields call for photometry of objects with small separations and covering a field which is only a fraction of a degree. As an example, the telescope has played an active role in monitoring the double quasar, DQSO 0957+561 A,B based on photographic photometry of the two QSO images separated by 6 arcsec in the sky.

The photometry of the overlapping QSO images has to be performed as point spread function (PSF) fitting photometry. The non-linear response of the photographic emulsion causes the FWHM of the PSF to vary with the flux of the objects, and therefore limits the accuracy of such photometry to values ranginq fram 0.06 to 0.10 mag, dependent on the seeing during exposure.

2. The CCD Camera

The photographic plateholder has now been replaced by a CCD camera based on a JPL CRAF/Cassini 1024 × 1024 pixels CCD. The pixel size is 12 x 12 micron, corresponding to 1.65 arcsec/pixel. The field size is 27 x 27 arcmin, which is quite sufficient for programmes that are presently undertaken at the telescope. However, although we are using the smallest pixels available to us, the spatial sampling is inadequate on nights with good seeing. With the CCD

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camera which offers quick determination of the telescope focus, we now find seeing values during the winter period down to 1.5 arcsec FWHM. The low spatial sampling is improved by co-adding multiple exposures with small offsets between exposures. Also a new reduction software, named "Rotate-and-Stare" has been developed in order to obtain effective subpixel resolution (Teuber et al. 1994). The method is based on the assumption that the PSF is either circularly or elliptically symmetric.

The CCD detector is housed in an evacuated cold-box and is permanently cooled by a three stage Peltier element. As the CCD camera is located inside the telescope tube, it is considered essential that excess heat dissipated from the camera to the surroundings is kept at an absolute minimum. This is achieved by circulating cold water with an anti-freeze agent through a heat exchanger to remove the heat from the camera electronics as well as from the warm end of the Peltier cooler. Next, the cooling water removes excess heat from the CCD on the guide telescope and finally is taken through a radiator in the basement of the building. Besides the cryostat with the CCD, the camera contains a filter wheel and shutter and all associated electronics. Even then the camera is compact enough that it does not cause any optical vignetting other than that of the original plateholder and spiders. The filter wheel is equipped with Johnson B and V and Gunn R, I and Z filters approximating the standard systems. A remaining sixth filter position is allocated for a Red focal extender to be used when better spatial sampling is required at the sacrifice of field size.

The CCD controller is a prototype of a design, "BroCam" which is currently being developed for large format CCDs at telescopes at ESO, La Silla and at the Nordic Optical Telescope, La Palma. The BroCam is described by Florentin-Nielsen (1993). All control signals and data are transmitted on two optical fibres providing complete galvanic isolation and noise free communication between the telescope and control room. Data acquisition is performed on a 486 type PC AT equipped with an additional high speed image buffer. This PC is connected on Ethernet to a HP735 workstation running IRAF v2.10 software. Sections of the CCD images in a compressed form may even be transmitted via a modem connection to the observer's home computer for evaluation immediately after exposure thus enabling him to "look over the shoulder" of the observing assistant who is doing most of the observing tasks at the telescope.

The telescope is equipped with a computerized telescope control system and an autoguider, based on a Sanyo LC9913 CCD mounted on an x,y carriage on the guide telescope. However, for direct imaging with the science CCD, the noise in exposures of more than 1 minute duration is dominated by photon shot noise of the sky background. Hence, long integrations can most efficiently be obtained as a number of 5 to 10 minute exposures. Near the meridian and at moderate zenith distances the tracking of the telescope is so good that autoguiding is not needed for such short exposures.

The Schmidt telescope can be used with an objective prism yielding a dispersion of 290 Å/mm at 6000 Å. Used in conjunction with the standard filters to limit the spectral range and hence the sky background level a limiting magnitude of 14.8 is obtained in 10 minutes R exposures. The telescope is generally being used in a "service mode", i.e. one observing assistant takes the observations for all the projects, which are run concurrently during the night. At present five

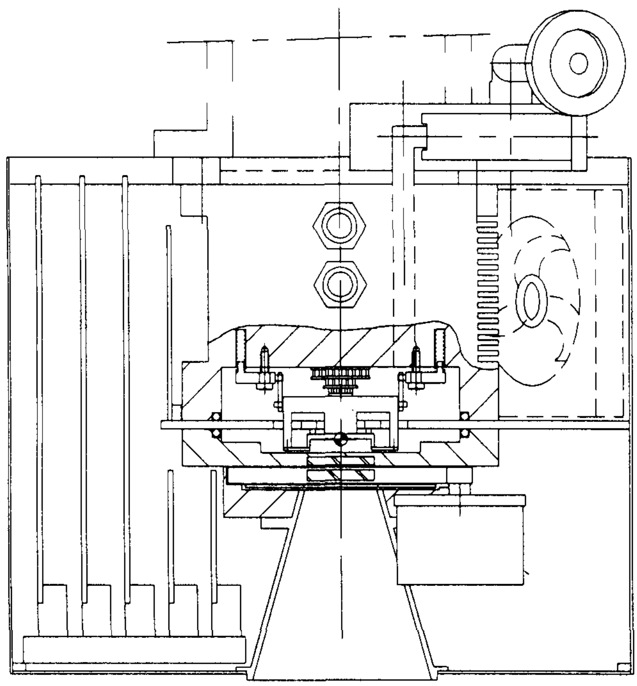

Figure 1. The CCD camera with its shutter and filterwheel and associated electronics is located in a compact housing at the position of the previous plate holder. The camera is thermally neutral as the heat from the electronics and the warm end of the Peltier elements is removed by circulating water.

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observing projects are run. Some of the research projects are in the nature of long term photometric monitoring of selected objects. Frequent time slices of telescope time is an ideal mode of operation for such projects. The two most important examples of this observing mode are now described.

3. CCD Photometry of Gravitationally Lensed QSOs

The project aims at detecting variations in the flux from multiply imaged QSOs and to perform cross correlation of the data from the individual images in a search for a difference in the light propagation time, dt. This work was initiated photographically in 1981. Florentin-Nielsen (1984) published the first dt value for the double quasar, DQSO 0957+561 A,B. dt was found to be 1.55 yr, meaning that variations in the flux from the QSO was seen in the A-image 1.55 years before a corresponding variation was seen in the B-image. This measurement was used to conclude that the QSO is indeed at its cosmological distance and to estimate a value of the Hubble parameter, $H_0 = 77$ km/s/Mpc.

Although the determination of dt has now been confirmed by several observers, most recently by VLA observations (Hewitt 1992), the conclusion with respect to H_0 is still quite uncertain, mainly because the deflecting mass consists of a cluster of galaxies at $z = 0.39$, and the distribution of mass within the cluster is only poorly known.

With the CCD camera it is now possible to monitor several additional gravitational lenses. One of them, QSO 0142−100, is particularly well suited for deriving H_0 as the deflector plane is apparently quite clean, i.e. only one galaxy is responsible for the lensing. Also this lens system and QSO 0957+561 are well suited for measuring the total mass of the deflector inside the so called Einstein radius, including dark matter, whether or not this is baryonic. Finally, in one case, QSO 2237+030, four images of the same QSO are seen through the central part of a relatively nearby galaxy, ($z = 0.03$) and therefore the chance of detecting microlensing high amplification events is particularly high. Light curves of such events may eventually reveal the geometric structure of the QSO itself with an angular resolution of 1–10 μarcsec.

RFN takes part in similar gravitational lens monitoring programmes using the Nordic Optical Telescope at La Palma and the Danish 1.54 m telscope at ESO, La Silla. However, the Schmidt telescope has yielded very useful data, and it will remain a main source for these observational data in the near future, as the light curves are sampled much more closely in time all year round than with any of the other telescopes due to the continued access to time on that telescope.

In several of the gravitationally lensed quasars the images are separated by as little as 1–2 arcsec. It is therefore not possible to obtain photometry of the individual images, but measuring the total flux of all images in a gravitational lens does provide the extremely useful information that one of the components is varying. Also, it is generally true that variations will occur in the brighter image first. Thereby the Schmidt telescope acts as an early warning for the larger instruments at La Palma and La Silla where telescope time is much more scarce.

4. The Copenhagen University Supernova Program - CUSP

Although the number of detected supernovae is around 1000 the rate is poorly determined since most detections are made by chance. The samples of galaxies are usually badly defined and never described, the limiting magnitudes are uncertain, supernovae are not detected in the central parts of the galaxies due to saturation of the photographic plates whilst large and very uncertain correction factors for inclination are often used. Control times are poorly known.

Since the supernova phenomenon is rare the number of detections per year in any reasonably well defined sample of galaxies is always small. Distributing the detections of different types of supernovae on different types of galaxies requires a long term program to determine the individual rates. A long term program in this case is no less than 10 years.

The luminosity function of supernovae is basically unknown, and we do not even know if intrinsically faint supernovae (like SN1987A) are very rare or frequent. Furthermore, it is still unclear to what extent type Ia supernovae can be used as standard candles, e.g. for cosmological studies, to mention a few of the astrophysical problems that may motivate the efforts to carry out a long term survey program.

Our sample of galaxies is defined as the Revised Shapley Ames catalogue galaxies north of declination $-10°$ and out to the distance of the Virgo cluster ($v_0 \leq 1200$ km/s) and including the Virgo cluster of galaxies itself. The number of galaxies is then 334. The method we use to search for supernovae is a difference technique. A "new" frame is rotated to a "standard" frame, and the frame with the sharpest PSF is smoothed to give identical PSFs. After scaling to the counts in the standard frame, the two frames are supposed to be identical except for variable and moving objects. The galaxies disappear completely in the difference frame and changes in the luminosity of 0.05 mag of individual objects are easily seen. In practice we divide a difference frame into $10 \times 10 = 100$ subframes and scan each frame by eye. A full comparison of the two frames takes approximately 20 minutes.

The detection limit for supernovae in our survey is fainter than $R = 17.5$ for exposures of 300 s, which is more than 5.5 magnitudes below the peak brightness for type Ia supernovae in our most distant galaxies. One observation of each galaxy per year is sufficient to detect 75 per cent of even the most distant type Ia supernovae.

The search is performed in a red passband since in this case we gain from the low atmospheric and interstellar extinction, relatively red colours of the supernovae in late evolutionary stages and the high sensitivity of the CCD.

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Discussion

Cannon: How easy will it be to distinguish between microlensing events and intrinsic variations of a background quasar?

Florentin-Nielsen: It is generally difficult. One way to discriminate between the two effects is that microlensing works differently in the continuum where the radiation is believed to originate from the very compact accretion disk of the black hole and in the emission lines that are predominantly from clouds covering a large space around the black hole.

Hawkins: It is worth pointing out that once you have removed the time delay variation, any residual variation will be due to microlensing. This can then be used to probe dark matter along the line of sight. It is worth continuing the monitoring for as long as possible (5–10 years minimum) to measure this. It seems to me a very important programme.

Florentin-Nielsen: Thank you, I agree.