financing the project and the staff members at La Silla for their assistance during the observations.

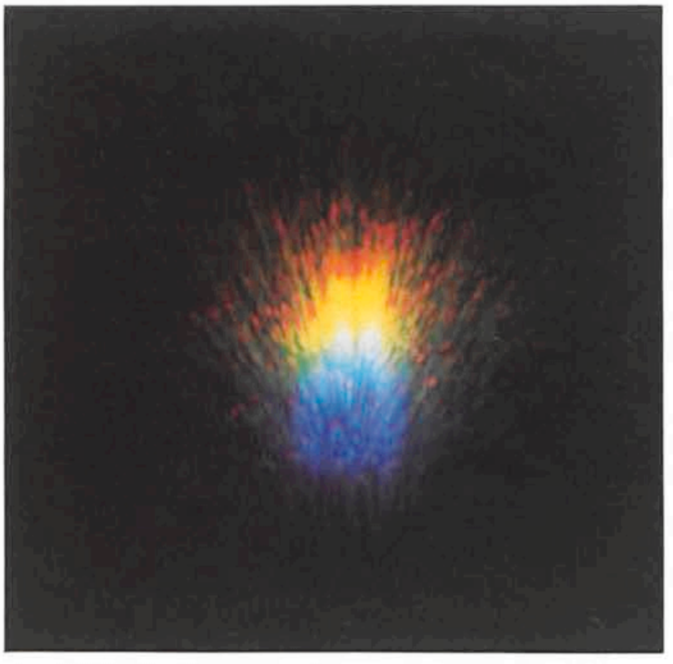

Fig. 4: *Colour photographs of a laboratory spectrum speckle interferogram (see text). The laboratory speckles are produced by special phase distortion plates and the dispersion by a prism.*

The CCD on La Silla

H. Pedersen and M. Cullum, ESO

Introduction

Throughout the history of observational astronomy, there has been a continual demand for detectors of higher sensitivity and lower noise. The ultimate goal, of course, is for an imaging detector that will record every photon reaching it with a noise level limited only by the random fluctuations of the photons themselves. Although we may not yet have the ideal detector, there has been a quiet revolution taking place in astronomy over the last year or so which has caused the world's major observatories to replace many of their older detectors, such as image intensifiers, by Charge-Coupled Devices (or CCDs as they are universally known).

The CCD

About as big as a fingernail, a CCD does not look particularly impressive: a rectangular piece of black silicon somewhat like a small solar cell. But, unlike the power-generating device, the surface of the CCD is divided into a vast number of small, discrete, light-sensitive elements or pixels. The size of these pixels is between 15 and 30 microns across, and the largest CCDs currently made have 640,000 such pixels. Even larger ones are on the drawing board. The CCD chips in use at La Silla at the present time have some 160,000 pixels covering a total field of about 10 × 15 mm^2. CCDs were originally developed by the micro-electronic industry for television applications, but it did not take long for astronomers to discover them and fall in love with them. Their cherished characteristics include a very high sensitivity (responsive quantum efficiency exceeding 80 % has been reported in the 600–700 nm range), linearity, low noise and excellent stability.

The entire surface of the CCD is traversed by rows of transparent electrodes of polycrystalline silicon. By applying a pattern of voltages to these electrodes, a series of potential wells is formed in the underlying silicon. Charge is prevented from spreading laterally along these wells by orthogonal potential barriers diffused into the silicon thus forming a matrix of individual charge-collecting centres. During an integration, electrons liberated by absorbed photons collect at these centres as indicated in Fig. 1a. This shows the potential well structure along the column of a three-phase CCD such as currently used at La Silla. The charge can be moved along the columns by varying the potential of the electrodes cyclically (Figs. 1b and 1c) so that the potential wells, and therefore the packets of accumulated charge, move along like a file of marching soldiers. At the end of an integration, the image is read out, first by shifting the entire charge-image down by one row, so that the bottom row is emptied into a "horizontal" output register, and then reading this register out serially to an output amplifier in the same way. This process is repeated, row by row, until the entire charge-image is cleared from the CCD. The output signals, after being processed and digitized, are transferred to computer mass-storage ready for display, reduction and analysis.

To minimize the accumulation of thermally generated charges during an integration, the CCD is cooled to a temperature of around 150 K. At this temperature, the dark current is negligible for most applications, and integration times of several hours are possible when the sky brightness permits. For reasons of cooling, as well as to avoid the risk of ice forming on the chip and to insulate it thermally from the surroundings, the CCD is mounted inside a vacuum cryostat.

The CCD on the Danish 1.5 m Telescope

The first CCD system to be permanently installed at La Silla was put into operation in June 1981 on the Danish 1.5 m telescope for direct imaging. The initial observations turned out to be so successful that several observers who had originally been scheduled for other instruments had second thoughts

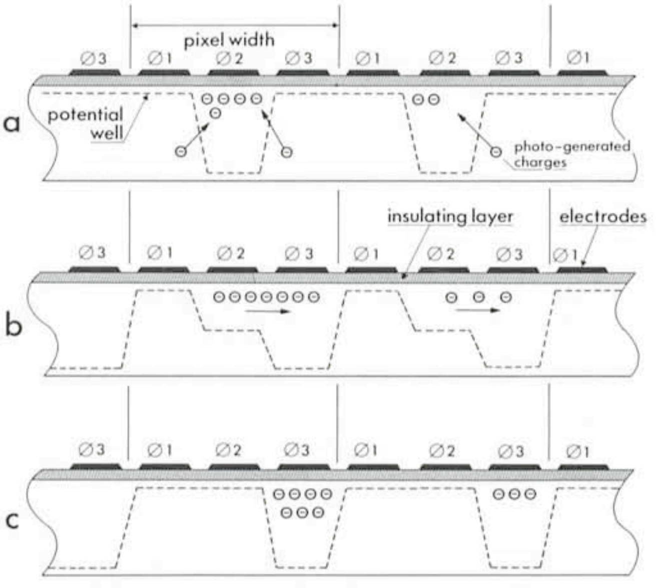

Fig. 1: *Potential well structure generated by the overlaying electrodes along a column of a 3-phase CCD.*
(a) Static potential wells during integration; (b) and (c) charge transfer process during image read-out.

and asked for the CCD instead. It is now the most requested instrument on this telescope. What has the CCD seen in the meantime? Comets, asteroids, lots of stars, identified and unidentified radio, X-ray and gamma-ray sources, nebulae, clusters, galaxies, quasars . . ., in short, any object for which high sensitivity and good photometric accuracy are important and for which a large field is unnecessary.

Apart from scheduled observing, the CCD has also shown great potential in a follow-up mode, for example, for objects discovered with the Schmidt telescope.

An example of a direct CCD image is shown in Fig. 2. This shows the central part of the beautiful barred galaxy NGC 1365. This picture is a 3-colour composite formed from three separate CCD frames taken through B, V and R filters. These were superimposed on a colour TV monitor by using the three frames, appropriately scaled, to modulate the blue, green and red channels of the monitor respectively. This picture can be compared to photographs of the same object taken with the 3.6 m telescope that were published in *Sky & Telescope* **53,** 97 (1977) and *Astronomy & Astrophysics* **87,** 245 (1980).

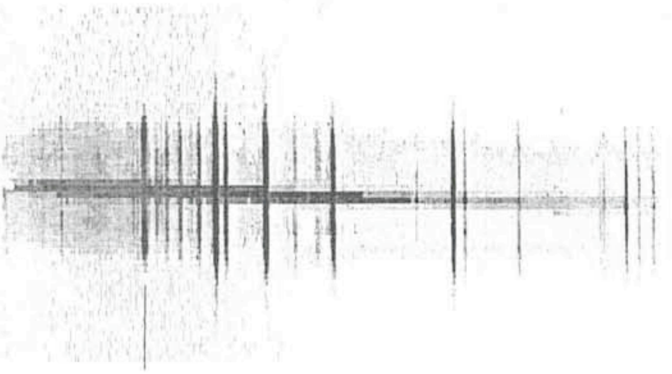

Fig. 3: *Spectrum of NGC 7009 along an E-W line through the central star. The wavelength range is approx. 350 – 475 nm. The night-sky spectrum has been subtracted. The data below 370 nm are contaminated by red light from the 1st-order of the spectrum. (3.6 m telescope, 244 Å/mm, 5 min. integration time, 2" slit.)*

The CCD at the 3.6 m Telescope

The first tests of ESO's CCD camera at the 3.6 m telescope were recently carried out in spectroscopic mode with the low-dispersion spectrograph. This spectrograph is usually used with either an Image Dissector Scanner (IDS) or a Reticon as detector. In both cases the astronomer is limited to the observation of a single point in the sky at a time, together with a small area of neighbouring sky. In many cases, however, it is desired to obtain spectra of extended objects, for example, to observe the rotation patterns of galaxies or the differences in the metal content over the surface of supernova remnants. With the CCD these pose no problem. In one direction one gets the spectral information and the orthogonal direction, from a three-arc-minute line on the sky, the spatial information.

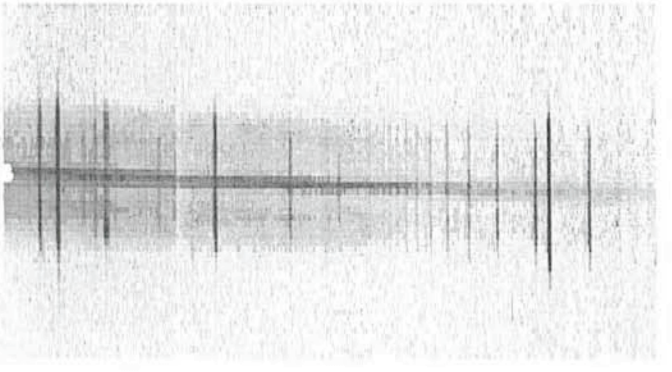

Fig. 4: *Spectrum of NGC 7009. Wavelength range 693–950 nm. 10 min. integration. Other data as Fig. 3.*

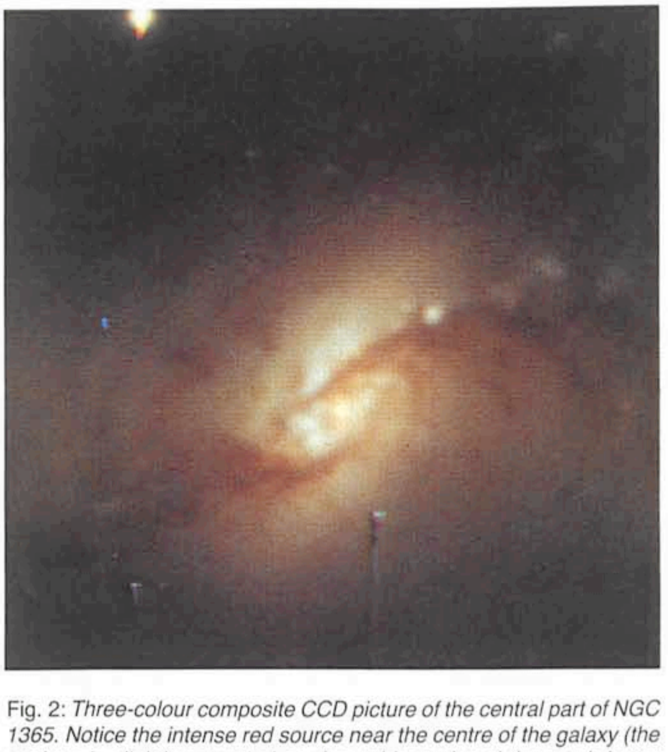

Fig. 2: *Three-colour composite CCD picture of the central part of NGC 1365. Notice the intense red source near the centre of the galaxy (the nucleus is slightly saturated on the red image) and the much hotter patches nearby. The field is 1.25′ × 1.25′; S is up and E to the left.*

Figs. 3 and 4 show two examples of test spectra obtained with the CCD in this way. These spectra, taken during the full moon period, are of the Planetary Nebula NGC 7009, also known as the Saturn Nebula. The grating position for both exposures was the same, the red and blue parts of the spectrum being selected by order separation filters. The vertical line in the middle is the hot central star. To the left and right of it are a number of emission lines originating from elements present in the nebula itself. Close inspection shows that some lines are strongest close to the central star while others (most notably the O II 372.7 blend) are strongest further out. Detailed calculations can tell us about the physical conditions that exist in different parts of the nebula. This task is aided by a pleasant characteristic of the CCD: the narrowness of the instrumental profile. Even very strong emission lines have a shape which is practically only determined by the width of the entrance slit. This can be appreciated in Figs. 5 and 6 which are tracings made from the data contained in Figs. 3 and 4 respectively, and obtained by co-adding the data in the nebula each side of the central star.

As the 3.6 m telescope collects several times more light than the 1.5 m, there are obviously many direct imaging programmes which would benefit from the shorter exposure times possible from the prime focus of the larger telescope. Also, in conditions of exceptional seeing, other programmes could exploit the higher spatial resolution at the Cassegrain focus. All these possibilities should be available to visitors to La Silla during the first half of 1983.

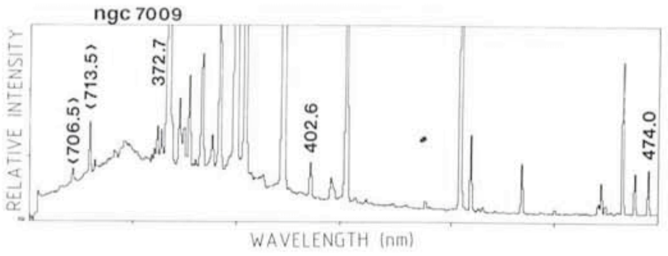

Fig. 5: *Spectrum of the nebulous parts of NGC 7009 in the range 350–475 nm. Other data as Fig. 3.*

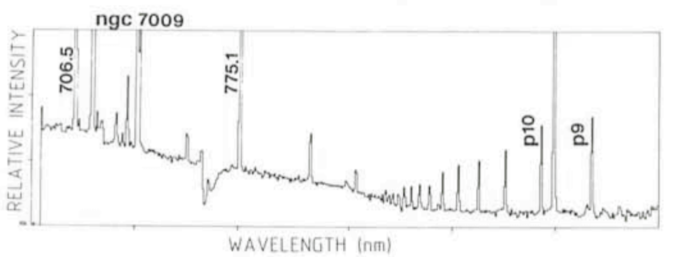

Fig. 6: *Spectrum of the nebulous parts of NGC 7009 in the range 693–950 nm. Other data as Fig. 4.*

Observing with the CCD

Although visiting astronomers are usually shown the telescope and how the CCD is mounted on it, there is no need for the observer ever to enter the dome. All acquisition and operation controls are carried out remotely from the control room. Faced with a couple of computer terminals and a colour monitor, the observer makes the decisions necessary for his or her programme. Almost all parameters are entered interactively on a terminal using a "form-filling" technique in which the observer is presented with a form showing the default parameters which can be left or modified at will. This permits newcommers to familiarize themselves with the equipment very quickly and to minimize mistakes without being too time-consuming or inconvenient for old-hands. The long waiting hours during integrations can be used to examine previous exposures, reduce and make prints of data. It has even been known for observers to sneak down to the midnight kitchen during such periods. This has been made easier of late by the provision of an automatic sequencing system that can be pre-programmed to execute a series of integrations with different exposure times and filters without observer intervention.

Data Reduction

It might appear from the preceding paragraphs that the CCD is completely without problems. This is certainly not so. As with any detector, a lot of care and patience is needed both during the observations, including the many calibration exposures necessary, and afterwards during the data reduction and interpretation. The main problems faced, that are intrinsic to the CCD, include interference effects, dead and "hot" pixels, non-linear columns at very low signal levels, charge transfer problems, and cosmic ray events. Some of these problems can be minimized by correct choice of operational and observational parameters. Others need to be corrected during data reduction. To assist with this there is a large and growing library of software routines available. We hope to return to these problems, and to give some more quantitative performance data in a later issue of the *Messenger*.

The Distance of the Magellanic Clouds

L. Divan, Institut d'Astrophysique, Paris

Introduction

The Magellanic Clouds are very important for many problems of Astrophysics. At a distance of about one tenth of that of the Andromeda Nebula, they are the nearest extragalactic objets, and in many cases the individual stars can be studied in detail. On the other hand, the distance to each Cloud is quite large when compared to the linear dimensions. No distance effect greater than ± 0.15 mag is to be expected on the apparent magnitudes and, practically, all objects can be considered to be at the same distance. A great advantage of the Magellanic Clouds over other groups of stars is that their population, with radial velocities around + 275 km/s for the Large Cloud and + 160 km/s for the Small Cloud, can easily be separated from the Galactic foreground stars. In addition, very little interstellar absorption occurs along the line of sight, either in the Galaxy or in the Clouds. For all these reasons the Magellanic Clouds are a very efficient tool (c.f. the discovery of the period-luminosity relation in the SMC as early as 1904) and considerable efforts have been made to determine their distances.

The Distances to the Clouds During the Last Fifty Years

The distance to the Small Cloud could be estimated for the first time when the "period-luminosity" variables discovered in 1904 by Miss Leavitt were identified as Cepheids by E. Hertzsprung (1913). Cepheid variables are found in the solar vicinity and from their known proper motions and radial velocities, Shapley could determine their absolute magnitudes, the zero point of the "period-luminosity" relation and the distance to the Small Cloud. The first published data, around 1918, placed the Small Cloud definitely outside the Galaxy at a distance d = 19 kpc, changed six years later into 31 kpc after a revision of the apparent magnitude system (Fig. 1). The slow decrease with time of the distance between 1924 and 1951 is mainly due to the fact that interstellar absorption corrections were introduced. It is interesting to note that during the long period extending from 1918 to 1951 the zero point of the "period-luminosity" relation has been revised by several authors who all confirmed the first determinations of Shapley. Much more observational data on proper motions and radial velocities were at hand. The effects of galactic rotation on the motions as well as the effect of interstellar absorption on the magnitudes were included in the discussion. With the exception of an important increase in the absolute luminosity of the Cepheids proposed by H. Mineur in 1945, all the efforts which were made resulted only in insignificant changes of the zero point of the "period-luminosity" relation: the absolute magnitudes of the galactic Cepheids were apparently well established by the converging results obtained by different authors. However, at the same time more and more doubts arose upon