A CCD SPECTROGRAPH FOR THE UNIVERSITY OF TORONTO SOUTHERN OBSERVATORY IN CHILE

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ABSTRACT

A low-noise, glycol-cooled CCD has been installed on one of the Garrison classification spectrographs and tested using the 61-cm Helen Sawyer Hogg telescope[1] of the University of Toronto Southern Observatory (UTSO) on Las Campanas in Chile. The spectrograph is small and would not be able to support the large, liquid-nitrogen dewar used for the UTSO direct-imaging system. Operated in the MPP mode, the PM512 CCD has such low dark current that it can function successfully at −46°C, thus avoiding the need for a large dewar on the end of the spectrograph.

RÉSUMÉ

Un DTC a faible bruit et refroidi au glycol a été installé sur un des spectrographes de classification Garrison et testé avec le télescope Helen Sawyer Hogg de 61 cm à l'observatoire sud de l'université de Toronto (UTSO) sur Las Campanas au Chili. Le spectrographe est petit et ne pourrait pas supporter le grand thermos d'azote liquide utilisé par le système d'imagerie directe de l'UTSO. Lorsqu'opéré dans le mode MPP, le CCD PM512 a un courant de fuite si bas qu'il peut fonctionner à −46°C, évitant ainsi l'utilisation d'un grand thermos.

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1. Introduction. The advantages of having a CCD (charge coupled device) detector with a classification-resolution spectrograph on a small (61 cm) telescope at a clear, dark site are considerable. While spectrographs with digital detectors are available on most large telescopes, there are very few on small telescopes. This deficiency is primarily a result of the high cost of spectrographs, good-quality detectors, and associated image reduction facilities relative to the capital cost and annual budget of a small telescope. However, large telescopes are oversubscribed and are not available for certain kinds of long-term or bright-star projects. The 61-cm Helen Sawyer Hogg telescope at the University of Toronto Southern Observatory (UTSO) is thus in a unique niche and we are taking advantage of the opportunity to do unique kinds of research in the field of moderate-resolution (0.2–0.4 nm), digital spectroscopy.

Located at a height of 2282 m in the foothills of the Chilean Andes, 180 km north of La Serena, the UTSO has been in operation since August of 1971.

[1]The 61-cm telescope of the University of Toronto Southern Observatory was dedicated 19 June 1992 to Helen Sawyer Hogg in appreciation of her major contributions to the study of globular clusters and of her long and distinguished service to the University of Toronto (Seaquist 1992).

It has been the site of many surveys and several important discoveries, such as a pure helium star (Garrison and Hiltner 1973), the brightest cataclysmic variable (Garrison *et al.* 1983), and new double-mode RR Lyrae stars (Clement *et al.* 1986), among many others. Supernova 1987A was discovered by UTSO Resident Observer Ian Shelton six years ago using the nearby Carnegie 10-inch astrograph, but the first photoelectric observations of the event were taken with the UTSO 61-cm telescope (Shelton 1989, 1993).

Telescope time is available to all astronomers solely on the basis of the scientific merit of proposals, regardless of nationality or institution of origin. Service observing is available for a fee and the popularity of this option is increasing.

The UTSO facility is described by MacRae and Hogg (1976) and by Garrison and Beattie (1990). The original liquid-nitrogen-cooled CCD for direct imaging is described by McCall, English and Shelton (1989). The new system uses the same controller and image processing hardware, but a different CCD, a different cooling system, and updated control software. It will be described elsewhere.

In this paper, we include a description of the instrument and the results of initial testing, as well as brief descriptions of three research directions to indicate the kind of work that can be done with this new equipment.

2. The instrument. This particular version of Garrison's original 1969 classification spectrograph was built in 1976 in the David Dunlap Observatory (DDO) shops by David Blyth and Bruce Campbell, and was used with a Reticon detector by Campbell for his 1978 thesis (Campbell 1978).

The spectrograph beam size is 2.54 cm, the collimator focal length is 39.37 cm, and the camera focal length is 15.24 cm, so the diminution is a factor of 2.58. The slit is usually set at 2 arcseconds, or 100 micrometres, which gives a projected slit of two 20-micrometre pixels.

The collimator and camera lenses are coated for maximum blue (380–500 nm) response, but the system can be used over a larger range (380–900 nm).

The Photometrics PM512 CCD from Ford (now LORAL) Aerospace is coated with META-CHROME II for enhanced blue and ultraviolet sensitivity. It has extremely low dark current when used in the inverted (MPP) mode, and can be operated without a heavy liquid-nitrogen dewar.

The detector package (figure 1) is relatively compact and lightweight (1 kg), suitable for a small spectrograph (figure 2), which would not be able to support a heavy dewar without serious flexure problems.

To prevent pump vibrations from ruining the seeing, the cooling pump and reservoir are located near the telescope pier on a trolley rather than on the telescope. The tubing is long enough that the trolley rarely has to be moved. For example, during three recent observing runs totaling six weeks, the trolley was moved only once.

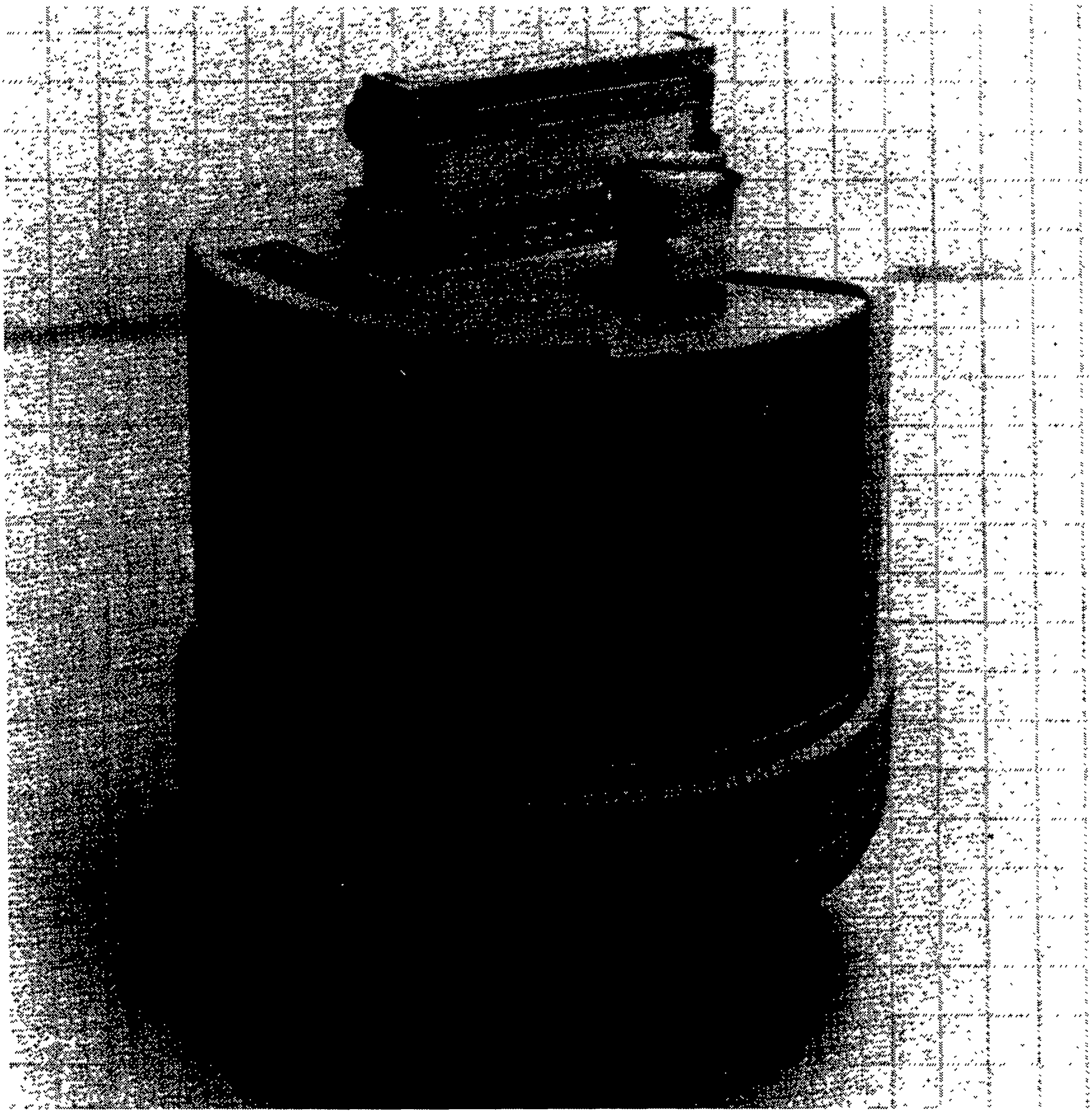

FIG. 1—The Photometrics PM512 liquid-cooled CCD.

Because the UTSO telescope already has, for direct imaging, a Photometrics PM512 (with a liquid-nitrogen dewar), the Heurikon computer hardware and software previously installed for CCD control and image processing are available for the new detector. See McCall, English and Shelton (1989) for details, though the system described in that article used an older chip, which has since been replaced by the PM512. A new, improved version of the software was installed with the new CCD.

The dark current for the glycol-cooled (–46°C) PM512 in the MPP* mode is approximately 7 electrons per pixel per minute at the normal gain setting of 90,

*MPP = Multi-Phesic-Pinned

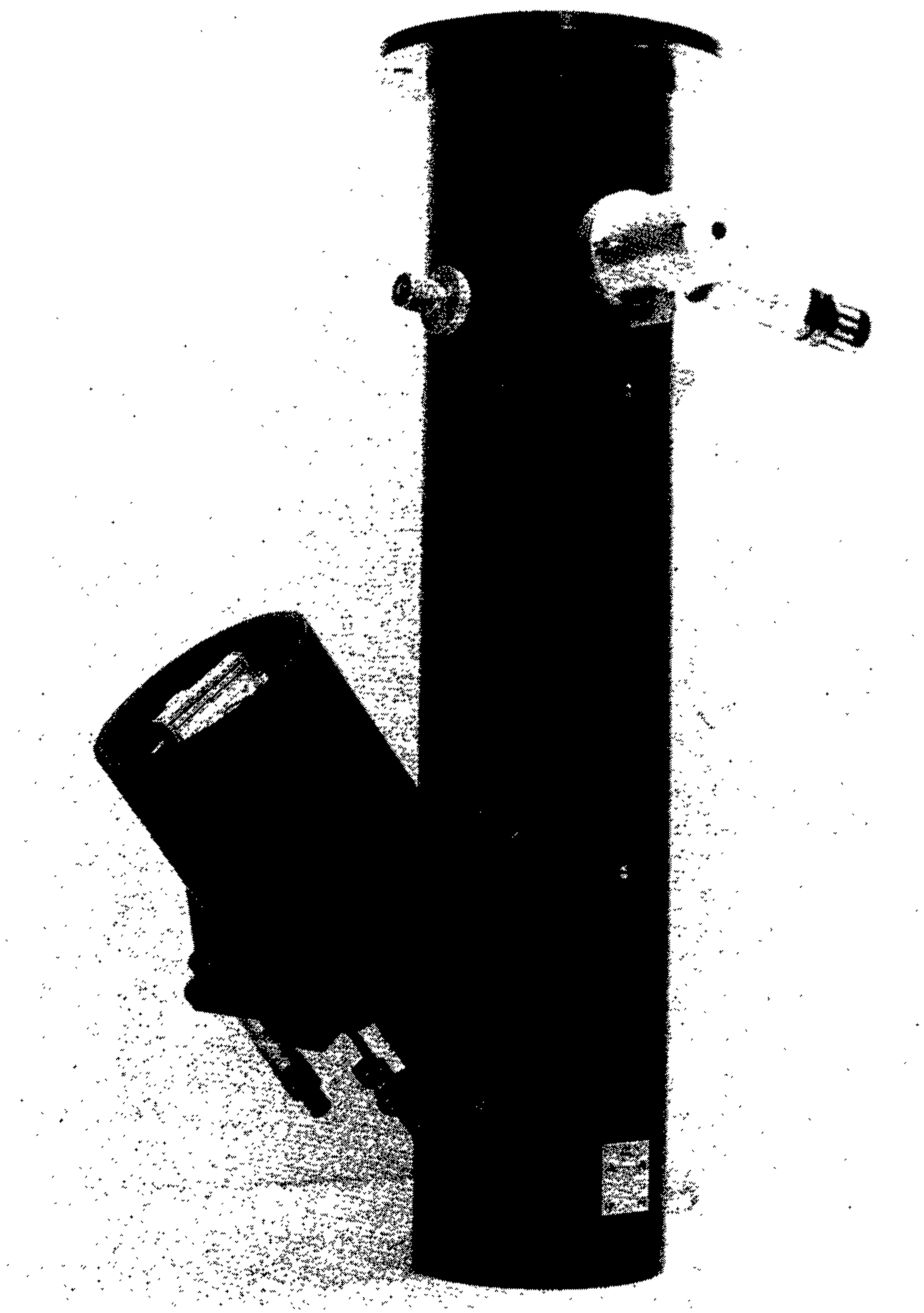

FIG. 2—The Garrison classification spectrograph with Photometrics PM512 CCD.

TABLE I
AVAILABLE GRATINGS

Pitch (lines/mm)	Blaze	Blaze Angle (degrees)	Dispersion (order)	Resolution	Range
360	10,000Å	17.45	75Å/mm (2nd)	1.5 Å/pix	768Å
600	10,000Å	10.35	45Å/mm (2nd)	0.9 Å/pix	461Å
600	4,700Å	8.63	109Å/mm (1st)	2.2 Å/pix	1100Å
1800	4,700Å	26.75	39Å/mm (1st)	0.8 Å/pix	400Å

and less with lower gain, so reasonably long exposures are possible. The read noise is less than six electrons per pixel. Thus the dark count noise dominates the read noise for exposures exceeding one minute.

There are 5 electrons per ADU* at the normal gain setting of 90, and 15.5 at zero gain setting. When operated in the MPP (inverted) mode, the well size is reduced to 16,383 ADU, so, in order to achieve a very high signal-to-noise ratio (200–500), the spectra are widened along the slit. An unanticipated, but interesting, result is that an image of the widened spectrum appears on the screen at the end of the exposure and the quality is high enough that preliminary classification can be carried out immediately, using the image on the screen!

With the 600 lines per mm grating (second order blue blaze), the resolution is 0.09 nm per pixel, so the CCD covers about 46.1 nm. Other gratings, listed in Table I, are also available. Using this grating, the exposure time for a B = 12 star at a signal-to-noise ratio of 100 and resolution of 0.18 nm (2 pixels) at 520 nm is roughly 30 minutes. Some examples of the first spectra are shown in figures 3 and 4.

3. Archiving. The problem of the archiving of digital data has been discussed recently at some length (*e.g.* Viotti 1991). Most observatories are using tape, either Exabyte or 9-track, and are not bothering with renewal of tapes for long-term archiving. This is clearly short-sighted and is a waste of valuable telescope time.

Two years ago, we decided to archive fully all digital data from UTSO, using the best technology available. For this purpose, optical disk technology seemed the most reliable. Two Write-Once, Read-Many (WORM) drives were obtained from Corel, an Ottawa-based company listed as "best" in the computer magazines (*e.g.* Byte) at that time. One drive was sent to Chile and the other retained at the DDO in Toronto. Unfortunately, the Photometrics-Heurikon computer in

*ADU = Analogue-to-Digital Unit

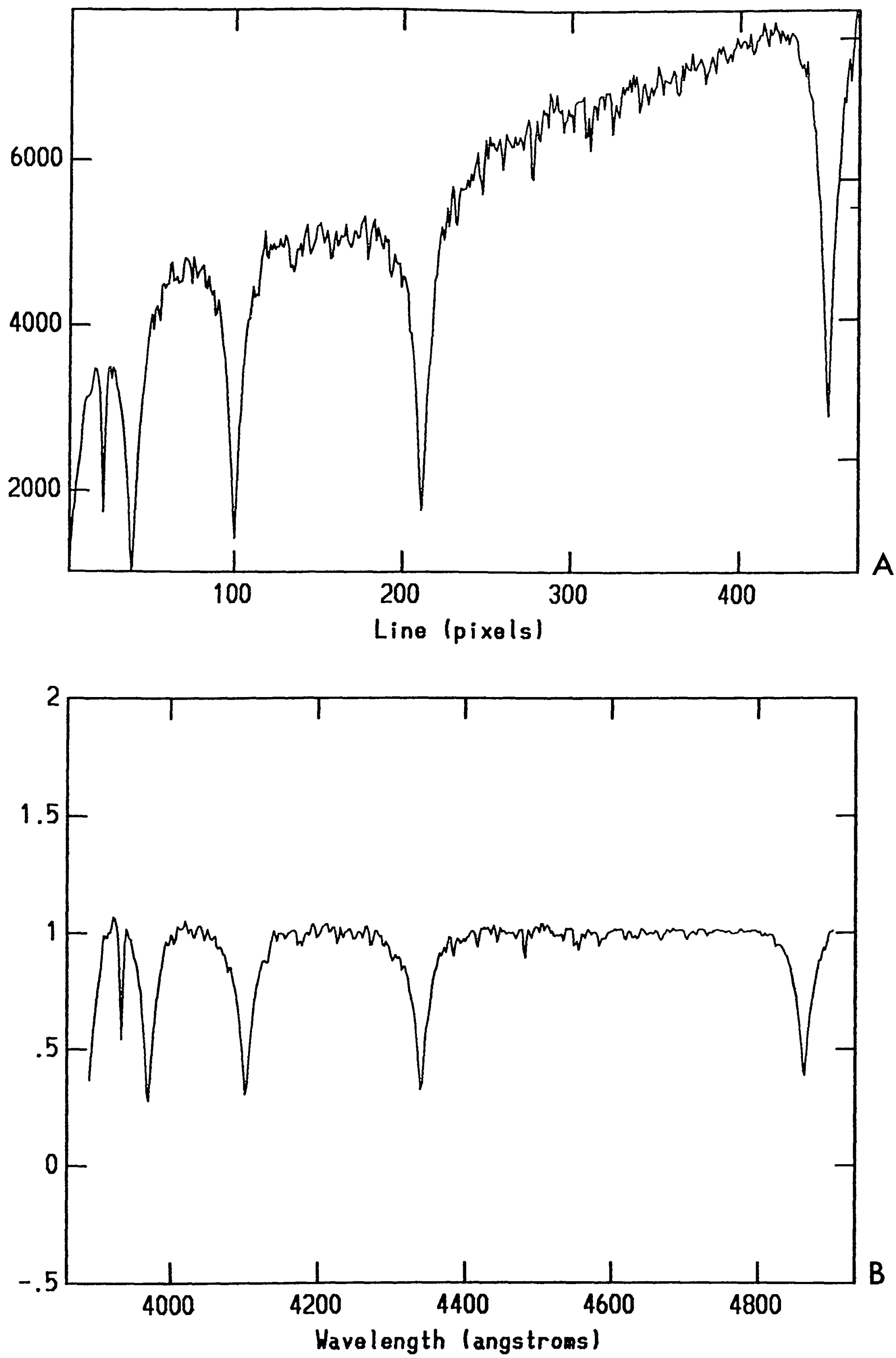

FIG. 3—Test samples of spectra taken in Chile with the new CCD and the first-order, 600 lines/mm grating. Alpha Piscis Austrini: A3 V: a) raw CCD spectrum, and b) reduced by Beattie using the IRAF package. The vertical scales are a) ADU and b) relative intensities.

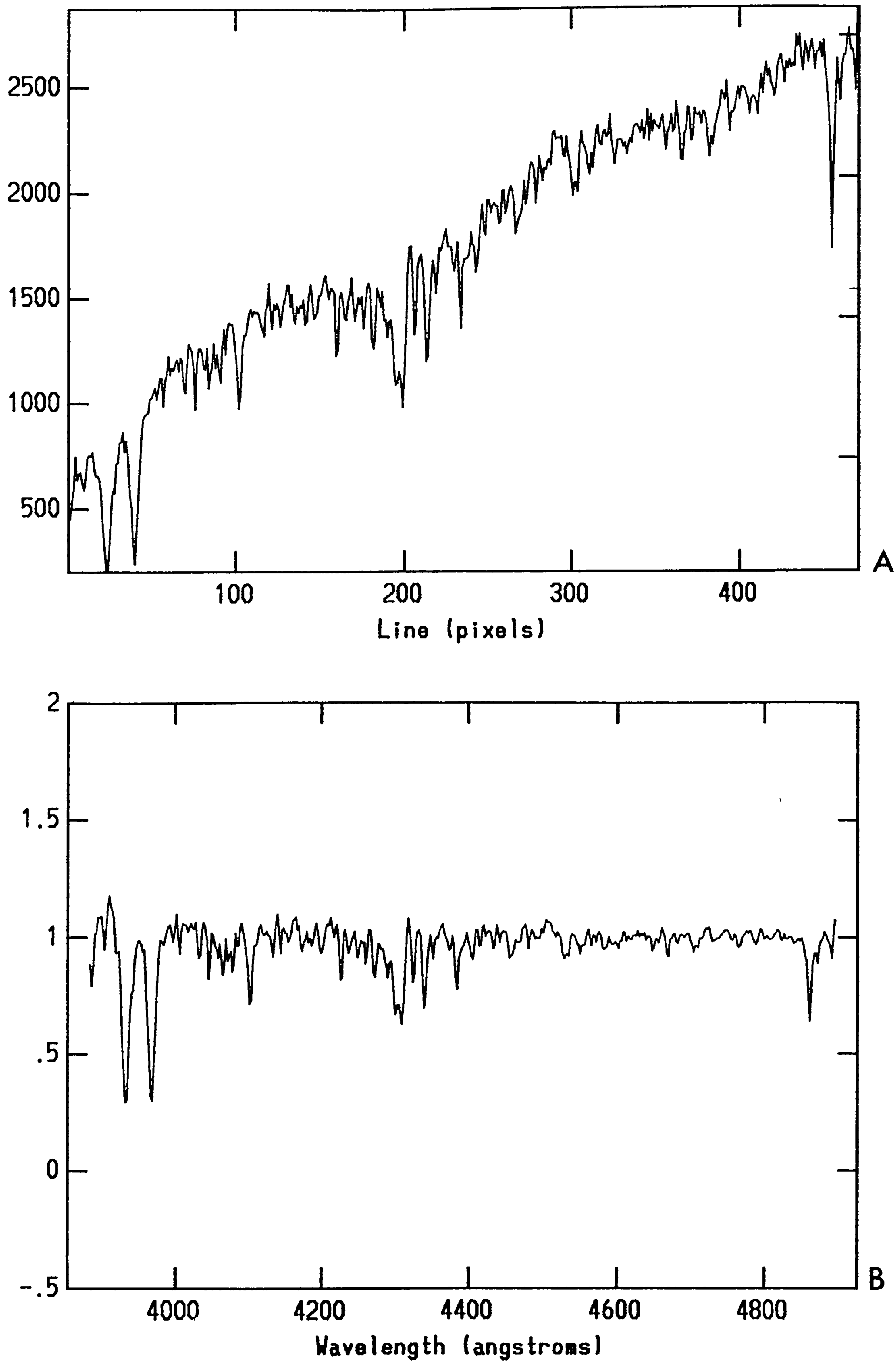

FIG. 4—Test samples of spectra taken in Chile with the new CCD and the first-order, 600 lines/mm grating. Zeta-2 Reticuli: G2 V: a) raw CCD spectrum, and b) reduced by Beattie, using the IRAF package. The vertical axes are a) ADU and b) relative intensities.

Chile has no drivers for network communication or for peripherals other than the 9-track tape drive. Thus, until a new CCD computer and control software can be purchased, the night's images are stored on hard disk and transferred next day to tape, which is read into an IBM PS/2 model 30-286 and then to the WORM drive. The WORM capacity is almost one gigabyte, which under normal conditions holds about two weeks of direct imaging and one month of windowed spectroscopic images. The optical disk is sent to Toronto, where it is transferred to the investigator's medium of choice. The WORM disk is kept in Toronto as an archive. The data are kept on at least two media at all times to prevent accidents from becoming disasters.

The observer is probably the person who is most familiar with the data and the conditions under which it was obtained, so any fully reduced UTSO data sent to Toronto by observers are being kept on a separate WORM, also as an archive. The reduced data take up very little space. Thus, both the raw and fully reduced data are archived.

4. Research Potential. With a high-quality CCD as a detector for a moderate-resolution spectrograph on a small telescope, there are many research projects which can be carried out more easily and efficiently than with similar instruments on a large telescope. Obviously, large telescopes have the edge for faint objects, but literally millions of stars are accessible now, spectroscopically, with the 61-cm telescope.

4.1. Digital Spectral Classification. A major project for a digital spectrograph on a small telescope is the translation of the MK (Morgan-Keenan) System of classification for stellar spectra to the digital dialect. This project, which is being carried out by Garrison and his students, involves the careful intercomparison of digital spectra of MK standard stars, most of which are bright, and the extension of the system to fainter (10th magnitude) secondary standards. A small telescope with a good, clean, stable, digital detector and spectrograph is ideal for the task.

The MK process must be modified to take advantage of the different character of digital data and to avoid the pitfalls as outlined in the 1988 Proceedings of IAU Commission 45 on Stellar Classification (International Astronomical Union 1989, 1991).

The great advantage of this MK project for other users of UTSO is that there will be a database library of all of the MK standard spectra, so users won't have to waste valuable telescope time retaking standards each observing run, as was the case with photographic spectra. A few standards taken to ensure that the resolution and spectral range are the same will be still necessary.

The great advantage to astronomy in general is that the translation process will involve developing techniques and secondary standards which will be useful for classification of digital spectra of extremely faint stars taken with large telescopes. In any case, it is not efficient to use a large telescope for bright stars. At the present time, some large telescopes (*e.g.* the Hubble Space Telescope) have *no* provision for neutral-density filters and thus cannot be used to compare the observed faint stars with bright standards. Thus, the Hubble Space Telescope by itself has no calibrating link to previous data. The link can and should be provided by the less expensive, ground-based telescopes. With a grid of fainter standards, the level of classification discrimination should be improved, and superior to that of photographic spectra.

4.2. Long-Term Variability of Wolf-Rayet Stars: Moffat and St. Louis (University of Montreal) are monitoring WR stars to search for occasional ejection of "super blobs" and evidence for long-period binaries, as well as to study peculiarities and their possible variation. In addition, information can be obtained on how hot winds collide in binary systems containing an O star and a Wolf-Rayet star.

The availability of the Helen Sawyer Hogg 61-cm telescope at UTSO, equipped with a state-of-the-art CCD detector on a good, well-supported spectrograph, allows this kind of uniquely interesting research. The uniqueness is the long-term time element combined with quality CCD spectroscopy, even if the telescope is small.

4.3. MK Calibration of a Zero-Age-Main-Sequence (ZAMS) Fitting Program for Star Clusters. FitzGerald and Harris (University of Waterloo) are developing WATREDAO, an automated cluster ZAMS-fitting program using *UBV* photometry. One of the aims is to recalibrate the ZAMS relationships with MK spectral class. Another is to establish a set of secondary standards in selected clusters. Since most of the clusters have distance moduli between 10 and 13, the proposed CCD spectroscopic system will allow classification of stars to $M_v = 3$, about 2 magnitudes fainter than is practical now.

5. Summary. A small, university-run telescope at a superb southern-hemisphere site now can carry out high-quality, digital, spectroscopic projects. It is especially useful for long-term, large, or bright-object projects. Most projects of this nature would not (and should not) be allowed on a large, expensive, oversubscribed telescope, and would not be possible at a poorer site. In addition, the southern hemisphere offers access to unique objects, unavailable to telescopes in Canada, and the UTSO 61-cm Helen Sawyer Hogg telescope is the only Canadian telescope south of the equator.

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It is a pleasure to acknowledge the help and kindness of the Las Campanas staff of the Carnegie Institution of Washington, which enable us to continue to operate this small, but productive, telescope at such a magnificent site as Las Campanas. Laurent Drissen of Space Telescope Science Institute was very patient and provided considerable help during the shakedown run of the CCD spectrograph.

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References

Campbell, B. 1978, Ph.D. Thesis, University of Toronto
Clement, C.M., Nemec, J.M., Robert N., Wells, T., Dickens, R.J. & Bingham, E.A. 1986, AJ 92, 825
Garrison, R.F. & Beattie, B. 1990, JRASC 84, 246
Garrison, R.F. & Hiltner, W.A. 1973, ApJ 179, L117
Garrison, R.F., Schild, R.E., Hiltner, W.A. & Krzeminski, W. 1984, ApJ 276, L13
International Astronomical Union 1989, Transactions XXB, 327
International Astronomical Union 1991, Transactions XXIB, 328
MacRae, D.A. & Hogg, H. 1976, Physics in Canada 32, 23
McCall, M.L., English, J. & Shelton, I. 1989, JRASC 83, 179
Seaquist, E.R. 1992, JRASC 86, 332
Shelton, I.K. 1989, M.Sc. Thesis, University of Toronto
Shelton, I.K. 1993, AJ (in press)
Viotti, R. 1991, *Archiving and Distribution of Spectroscopic Data* (Instituto di Astrofisica Spaziale CNR, Frascati) p. 31