Application of Image Dissector Photomultipliers

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ABSTRACT

We describe an image dissector photoelectric system that is used for acquisition, guiding, focussing, and photometric monitoring in telescope control. A similar system is used for area scanning and spectrophotometry.

I. *TELESCOPE CONTROL*

Photoelectric devices for controlling astronomical telescope tracking have been developed in one form or another for more than a quarter of a century (Whitford and Kron, 1937; Babcock, 1948; Uttley, Jones and Manns, 1948). They have not been universally used, possibly because of the expense and development effort required, even though improved performance of photoelectrically guided instruments has been demonstrated. Among the presently available devices that can be used for guiding directly on images without recourse to mechanical moving parts are quadrant photomultipliers (Rome, Fleck and Hines, 1964), image dissector tubes (Reed, 1967; Adam, 1970), and a number of imaging devices (Wampler, 1969; Hunten, 1970). In preparing for the 150 inch telescopes, we have selected the image dissector because of factors including spatial resolution, ease of control, and cost. We have been acquiring experience through prototype models used at the telescope since 1967. Our guider development was concurrent with those of Reed (1967) and Hunten (1968), but we used digital rather than analogue methods because of the nature of the digital control used in driving the 84 inch telescope and planned for the 150 inch telescope. These uses of the image dissector differ from the principle of the Edinburgh image dissector guider (Adam, 1970) in that we depend on the directional stability of the undeflected on-axis beam as maintained by good magnetic shielding.

(*a*) *Guiding*

The image dissector photoelectric guider now in use with the stellar telescopes at Kitt Peak (Ball and Hoag, 1968) uses digital data processing as we wished to employ photon-event counting techniques for error detection. Also, we are required to have a digital output signal when closing the guiding servo loop by means of the digitally controlled telescope drive motors we use.

The image dissector selected is an ITT FW-130 (S-20) having an effective aperture of about 6 arcsec for the scale used. This aperture admits most of the photoelectrons from a centered star image yet discriminates well against sky and background noise. The dark background is about 6 counts s^{-1} under normal operating conditions. Error detection is accomplished by incrementing the position of the electron image of the star in a step scan back and forth across the aperture and, by appropriate gating, accumulating in an up/down counter the difference count between photon events on either side of the undeflected position. Scans are made in both the right ascension and declination directions. A schematic diagram of the system is presented in Figure 1.

The response of the guider is adjusted by preselecting the number of 122 Hz scans according to the brightness of the guide star. We generally use a sufficient number of scans to obtain 6400 or more photon counts in the sampling period. This provides an rms error within about 0.03 arcsec at the 84-inch telescope. Varying the length of the sampling period changes the bandwidth. In making this adjustment, when the telescope is driven to make guiding corrections, care must be exercised to avoid exciting fundamental modes of vibration in the mounting. The fundamental mode, in the case of the 84-inch telescope polar axle, occurs at about 3 Hz.

At the completion of the last scan in a sampling period, the residual binary count remaining in the up/down counter is transfer-gated to a shift register. It is then shifted towards decreasing bit significance according to the number of scans employed in the sampling period, thus providing gain control. The content of the shift register is then processed as the desired output data for the digitally controlled

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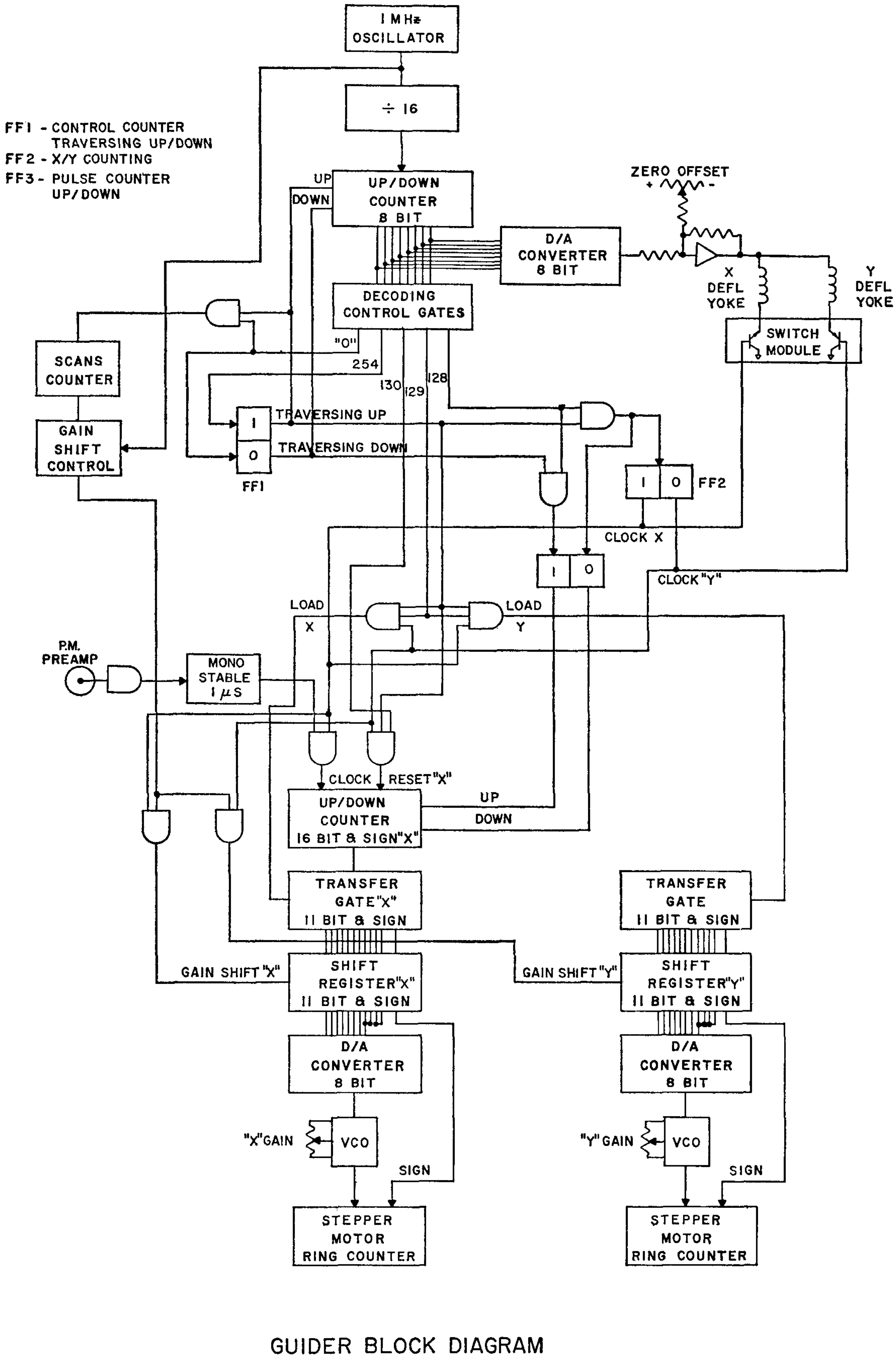

Fig. 1
Schematic diagram of the image dissector guider control unit.

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torque drive motors on the 84-inch telescope. All data transfer and processing occurs during the on-axis step of the aperture scan. Thus scanning, error detection, and data processing are completed for one axis before the scanning signals are switched to the other axis. The result of one guider test is shown in Figure 2.

The prototype guider camera is equipped with double slides of the Weitbrecht (1962) design so that it can be used with any telescope. When this system is used, the digital error signals are converted to a d.c. control voltage for operating the appropriate cross-slide motor control unit.

The guider performs well at the 36-inch reflector to a magnitude of about V = 12.5 with a band width of about 0.2 Hz. Because of incoherence in some seeing motions over angular distances used in

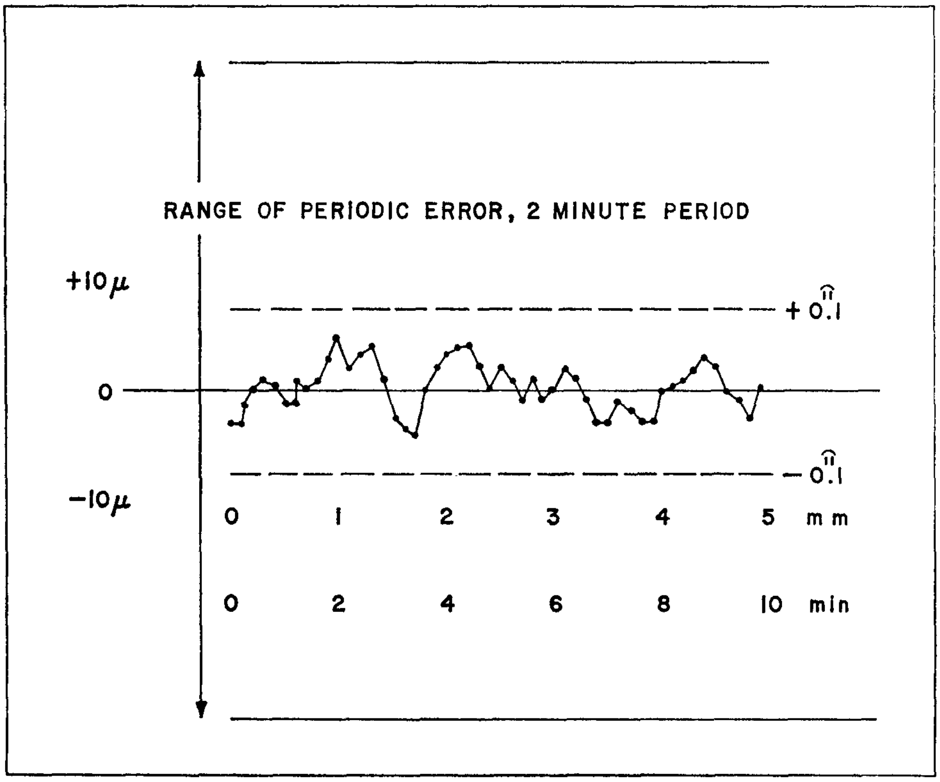


Fig. 2

Guider test using the digital drive controls of the 84-inch telescope right ascension drive. The telescope was uniformly trailed in declination during a 10-min exposure while the image dissector guider was controlling tracking in right ascension. The trails were measured in the right ascension direction with a comparator at intervals of 100 μ = 6 sec of time in the trail direction.

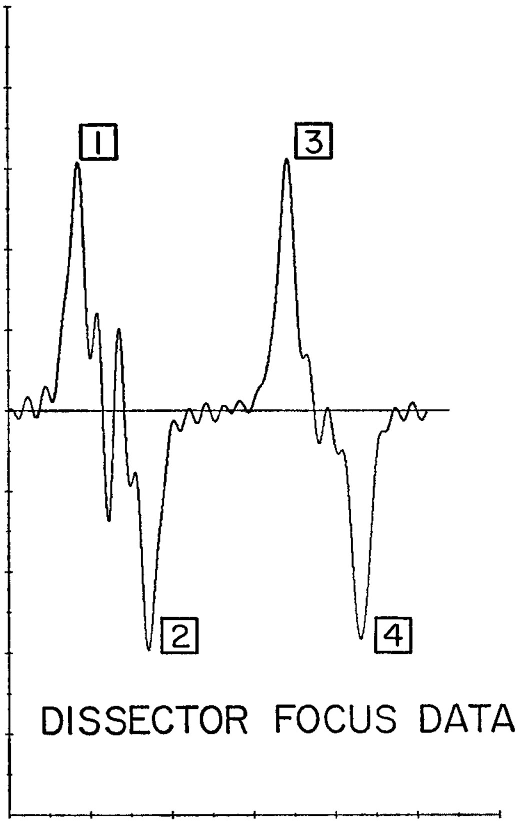
off-axis guiding, fast response times are unnecessary in widefield photography with telescopes having smooth drives.

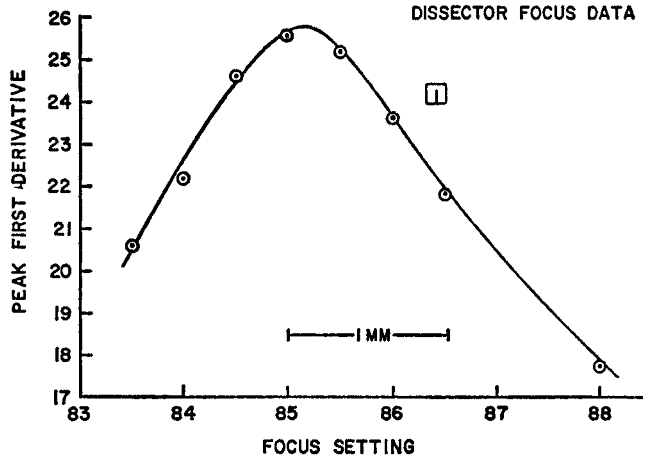
(*b*) *Acquisition*

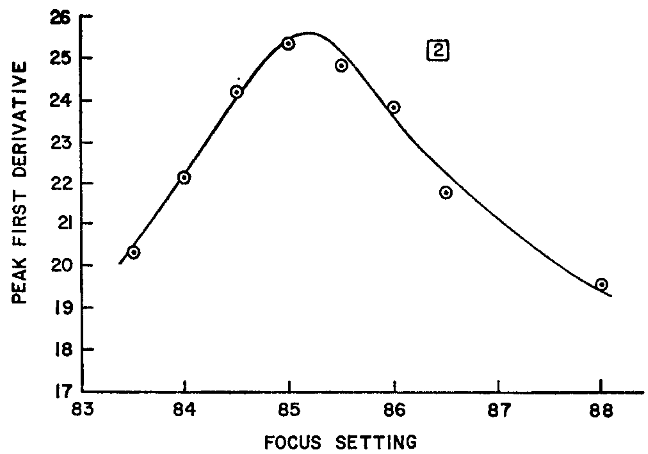
In using our prototype camera, guide stars are normally located either by inspection at the telescope (sometimes a slow process) or by guider probe offsets previously determined by an appropriate grid used with photographic charts. Because of telescope pointing errors and inaccuracies in reading the grid, guide stars do not generally fall within the small range of automatic acquisition of the scanning pattern previously described. We have, therefore, developed a "TV" scan mode for the image dissector that can be used to display the guider probe field on a cathode ray tube. When the pulses from photon events are broadened to 1 μ sec at a raster scan frequency of 15 Hz, guide stars to a brightness limit suitable for guiding can be seen and moved into automatic acquisition range. With experience, this display also serves as an aid in judging and setting the appropriate sample time for the guider.

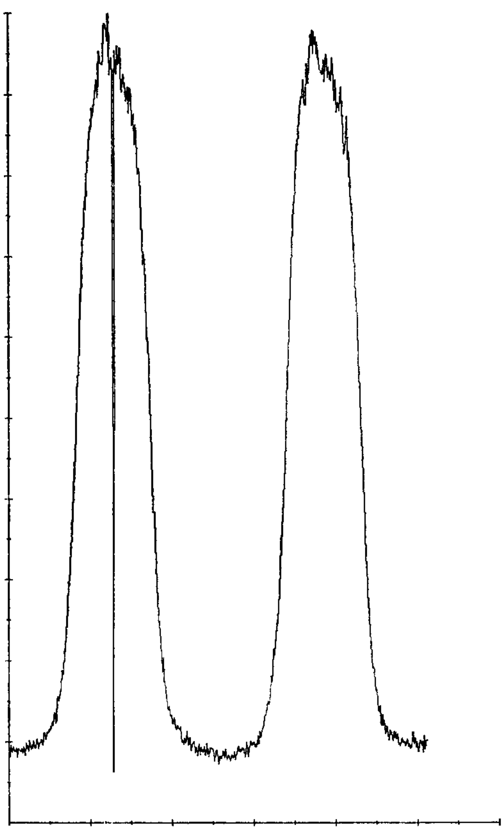
(*c*) *Focussing*

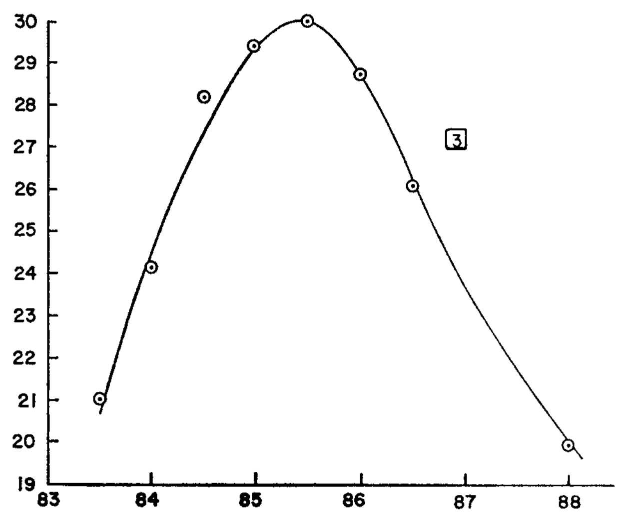
The image dissector photomultiplier used as described also provides information concerning the distribution of light in the guide star image. If photon events are counted and stored for each incremental

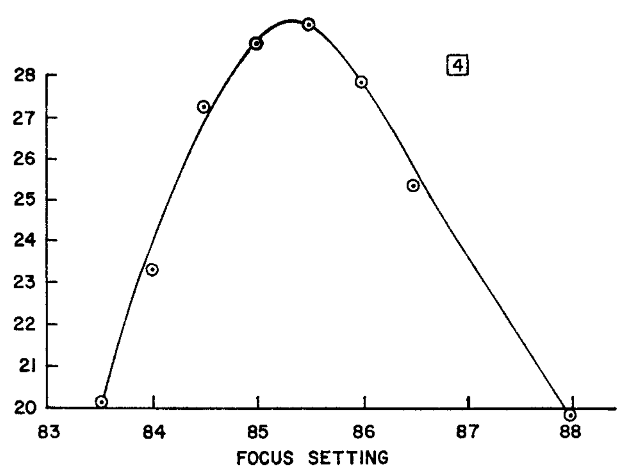












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position of the scan, information related to the size or intensity gradients in the guide star image can be recovered. When this information is available for two or more appropriate focal positions, the best focus can be determined. This kind of experiment has been done using a computer at the 84-inch telescope and the results are illustrated in Figure 3. The two curves in the lower left part of the Figure represent the raw data for both the east-west and north-south scans at one focal position. These data were smoothed and differentiated and are shown again in the upper left part of the Figure. Maxima represent peak slopes derived from the original data. Finally, maxima for a number of focal settings are shown in the right hand part of Figure 3. One then estimates the focus at which the peak of the first derivative is a maximum. Though the results of the two sides of the scans agree in both the EW and NS cases, the best focus indicated by the data for the right ascension direction differs from that determined for the declination direction by about 0.13 mm. This result indicates that there was apparent astigmatism in the optical system at the time of the experiment, a conclusion verified by conventional knife-edge measures made at the same time.

The method of focussing described has yet to be put on a practical basis. However, we feel that focus monitoring can be achieved, while guiding, on time scales appropriate to the stability of large telescopes and to the brightness limit set by satisfactory guiding.

(*d*) *Photometric Monitoring*

The features of the system described for focus monitoring can also be used for monitoring brightness and hence variations in transparency. Furthermore, the scan and data collection program can be modified to permit sky brightness monitoring to be accomplished at an appropriate distance from the guide star image. Thus, for some observational applications, the guider can function as an exposure meter. As in the case of focus monitoring, the photometric monitoring can most easily be done with partial use of a computer. These applications, then, can be readily accomplished only in cases of inherently expensive telescope systems.

(*e*) *The Proposed* 150-*inch Telescope Guider*

The guider we propose is schematically shown in Figure 4 as drawn by L. A. Cowell who is working out details of the final design. A right angle mirror or prism moving on orthogonal ways diverts light to an image dissector tube or to a backup visual system all carried on the same fixture. The image dissector tube can be driven along the diverted telescope optical axis independently of the probe for focussing. Because the F/7.9 Ritchey-Chrétien field is concave toward the secondary with a radius of approximately 3 m the photocathode of the image dissector tube must be positioned at an appropriate axial position (z-value) for each probe position in X and Y to preserve the relation between the instrumentation focus and the guider focus.

The guider will be mounted on an instrument rotator. This requires that the deflection coil signals be resolved so as to produce scans that are always in the right ascension and declination directions regardless of the position angle of the instrument.

Two identical probe and guider systems will be provided; one on each side of the guider section case. This will not only allow for a spare system but will also provide an empirical means of correcting for first order field rotation that may result from imperfect mounting alignment, flexure, or refraction in some telescope positions.

II. *AREA AND SPECTRUM SCANNING*

After demonstrating the spatial stability of the image dissector photomultiplier used in the guider, we applied a related tube to photometric and spectrophotometric instrumentation (Hoag and Ball, 1969). The image dissector selected for scanning was an ITT FW-4011 S-11 having a photocathode diameter of 1 inch and an aperture of 2×0.2 mm in the electron image plane in front of the dynodes.

Fig. 3

(a) Focus data obtained with the image dissector guider. The lower curves are the raw data showing count vs. spatial position for an east-west scan of the image at the left and the north-south scan at the right. The missing central channel in the east-west scan is a programming artifact. The upper curves are the first derivatives of the smoothed scan data.

(b) Maximum slopes of image light distribution observations made with the guider at eight focus positions. Curves 1 and 2 are from east-west scans. Curves 3 and 4 are from north-south scans. The interpolated peak of the first derivative gives the focus of "sharpest" image. Note the residual astigmatism shown by the differing values of focus determined in the two directions.

The background noise level of this tube is unfortunately high (thought to be caused by outgassing of internal resistors), but it has been useful for a number of purposes.

(a) Scanning Control and Multiscaler System

Our first scanner consisted of the ITT F-4011 S-11 tube operating in the photon counting mode interfaced to an RIDL 400 channel multiscaler. A schematic diagram of the control system is shown in Figure 5. Horizontal deflection currents were obtained by converting either the output of a three-place digital switch or the RIDL counting channel address to an analogue current using a 10-bit D/A converter and a low drift current feedback type amplifier. Vertical deflection signals were similarly obtained from a three place digital switch only. As the amplifiers we used had a settling time of

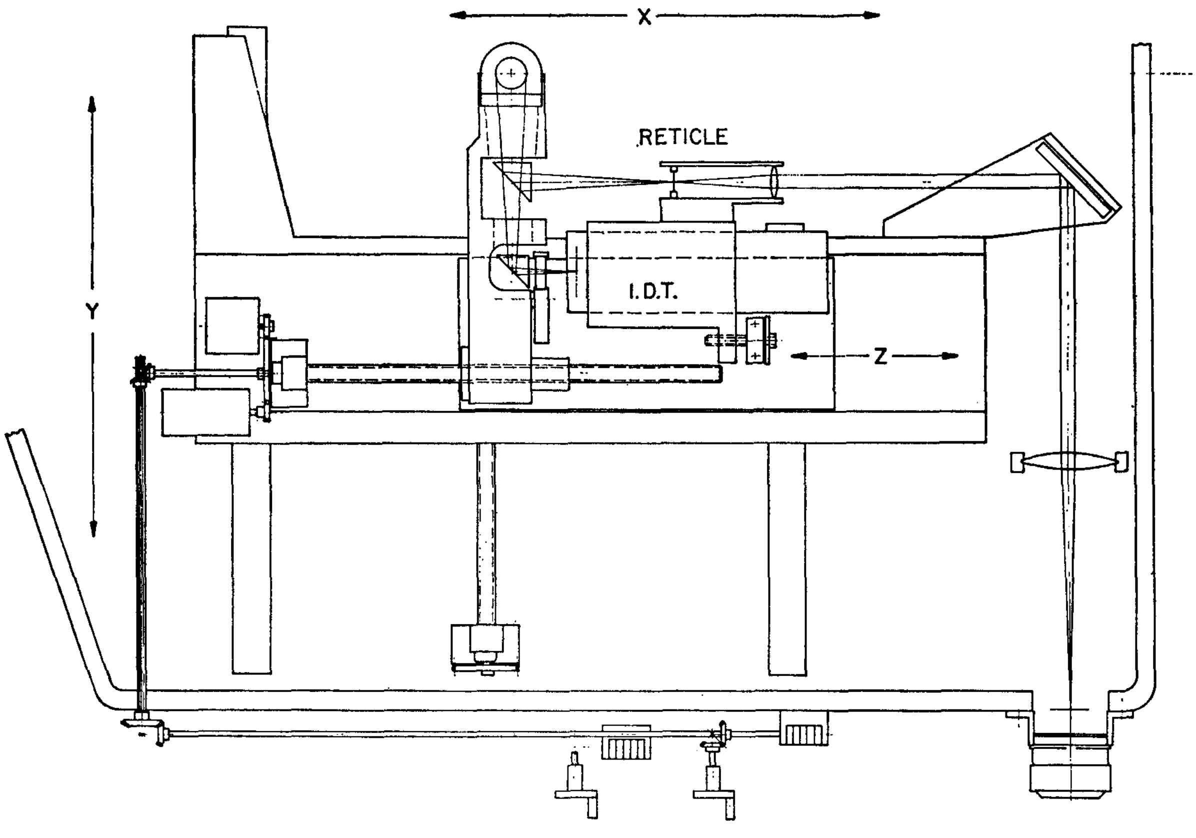
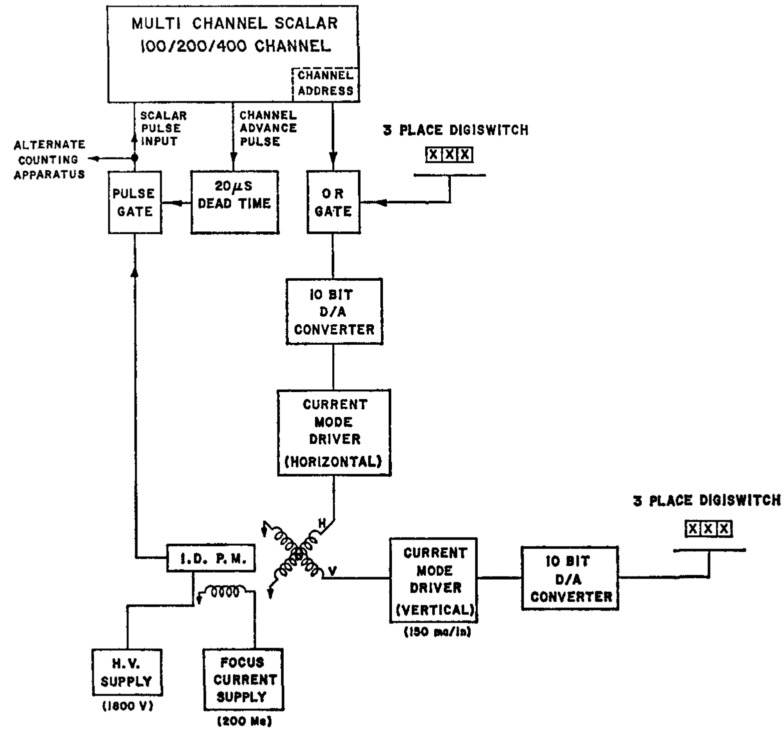


Fig. 4
Schematic drawing of part of the proposed 150-inch telescope Ritchey-Chrétien focus guider.

approximately 15 μs, we used the RIDL channel advance pulse to generate a 20 μs deadtime signal to ensure accuracy.

The RIDL allowed selection of 100, 200, or 400 channels which were advanced in a sequential mode at selectable channel duration times. We normally used a channel time of 400 μs which permitted scanning 400 spatial channels at a scan rate of 6.25 Hz. The scale of the incremental deflections was such that the electron image moved one quarter of the slot width or 0.05 mm from one channel to the next. Another feature of the control permitted alternate scans at two selectable positions at right angles to the scanning direction in an add-subtract mode. Thus sky noise compensation could be accomplished for some kinds of observation.

Three examples of the use of this scanner are shown in Figure 6. Two are examples of area scans made with the image dissector tube mounted on the prototype guider camera. The third is a spectrum scan made with the tube attached to a camera mounted on the 36-inch telescope Cassegrain spectrograph. The photocathode response and collection efficiency of this tube are surprisingly uniform. For



FIRST SPECTRUM SCANNER

Fig. 5

Block diagram of an image dissector photomultiplier scanner control and multiscaler timer and data system.

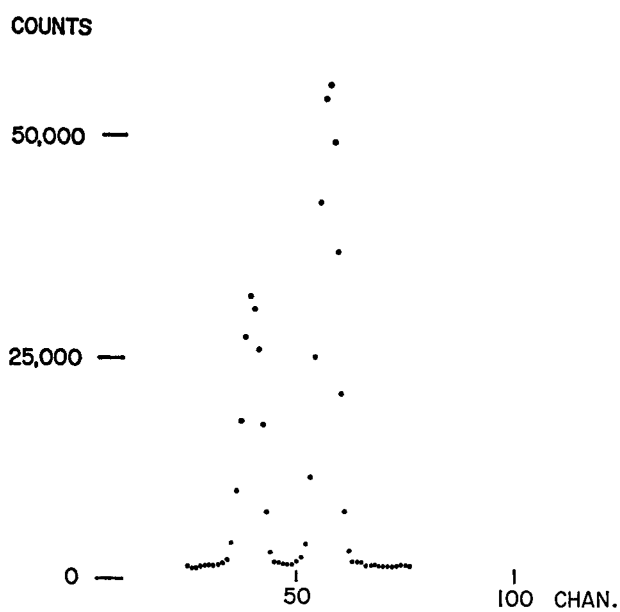


Fig. 6

Area and spectrum scanner results.

(a) Direct scan of components of the double star ADS 16095. Separation 22.3 arcsec; telescope scale 30 arcsec mm^{-1}; image dissector slot 0.2 mm incremented in steps of 0.045 mm; 900 scans of 100 channels (all channel points are not shown); pulse count integration time is 0.16 sec $channel^{-1}$.

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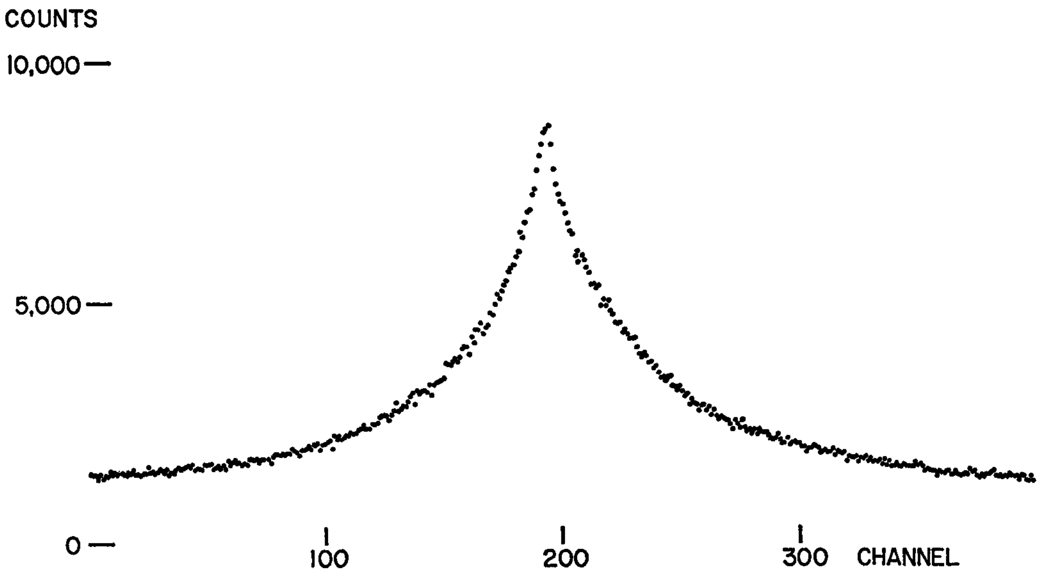

Fig. 6

(b) Direct scan of the minor axis of M31. The pulse count integration time is 0.5 sec channel^{-1}; No. 1 36-inch F/7.5 reflector; 0.2 × 2 mm dissector slot; telescope scale 30 sec mm^{-1}; 0.045 mm step^{-1}; scan range 9 arcmin.

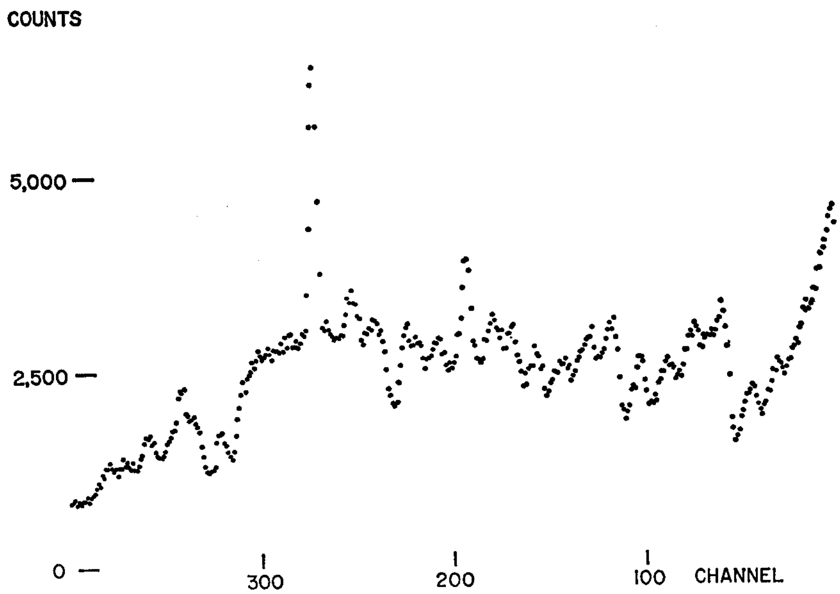

Fig. 6

(c) Scan of the spectrum of o Cet, gM6e. 13.3Å slot width; range λλ3700–4940Å. The prominent lines in the blue region are CaII K and H, Hδe, CN and Hγe.

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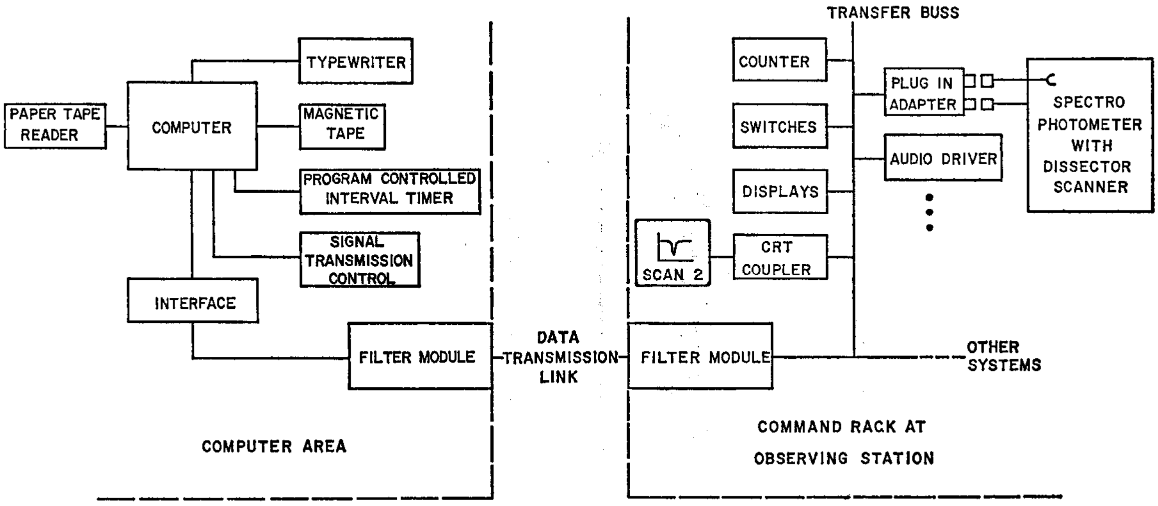
uniform photocathode illumination, the overall response of the tube is constant to within deviations of only 2 per cent over the central 20 mm.

(*b*) *Computer Control*

The TELCOM 1 computer system (developed by D. E. Trumbo) illustrated in Figure 7, has more recently been used for image dissector scanner control. A unique feature of this system is a data transmission and information switching arrangement requiring a minimum of cabling between the observers' Command rack interface and the computer and its peripheral equipment. Except for loading programs and retrieving data tapes, the observer never sees the computer which is located in an office room well away from the telescope. The communications system greatly reduces wiring problems, nearly eliminates complex switching, and makes possible very good protection against electrical interference. This is done by providing a buffer register at each source or destination of information. When information is to be exchanged between two points, the computer designates one a source and the other a destination. Another computer command then causes a unit to generate a number of transfer pulses (1 to 64) which are distributed throughout the system, and the buffer register transmits or receives the information serially by bit. The transmission rate is 1 MHz but could easily be increased



TELCOM I COMPUTER SYSTEM

Fig. 7

Block diagram of a computer system used to control the image dissector photomultiplier in scanning and data collection.

by a factor of 3 or 4 if desired. The length of the transmission link is not critical. We use 250 feet of cable now. It could just as well be 1000 feet.

Because serial information transfer is utilized, only a single gate is needed to switch from one source of data to another. By allowing a variable number of transfer pulses, long information strings are easily handled. The computer is only involved in getting the transmission started and is not tied up for any appreciable period of time. As only a few address lines and one information line are needed, the connecting lines can be individually noise isolated rather cheaply. This is done by shielded pulse transformers for the fast signals and differential twisted pairs for the level address lines. The net result is a system gratifyingly immune to the usual transients generated when telescope control relays operate.

The compact Command rack at the observing station is readily adaptable to a variety of observing instruments, a large variety of generalized controls and readouts have been provided. A special plug-in adaptor is used in interfacing an instrument to the computer system. Changing observing programs involves only putting the new instrument on the telescope, inserting its plug-in adaptor in the Command rack, and loading the computer program appropriate to this instrument.

The Command rack contains a Tektronix 611 storage oscilloscope that is used to display alphanumeric and graphic information. Data is normally displayed as it is being collected.

The computer system has been interfaced and programmed to run the image dissector photomultiplier as a scanner. The standard scan again consists of 400 equally incremented spatial positions

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of the electron image on the tube aperture. The program cycle for one position is 1 millisec including a 20 μs interval for change in position and data transfer, thus photon events at a particular location are being counted 98 per cent of the time. The scan program can be quickly changed to any format by means of a keyboard on the Command rack. A typical storage oscilloscope display of data for a spectrum scan is shown in Figure 8.

(*c*) *The Schroeder Spectrometer*

In order to take advantage of the TELCOM 1 computer and the image dissector as a scanner, Dr. D. J. Schroeder, Optical Design Consultant at Kitt Peak National Observatory, designed for us a small spectrometer matched to the characteristics of our F/13.5 36 inch telescope and a new image

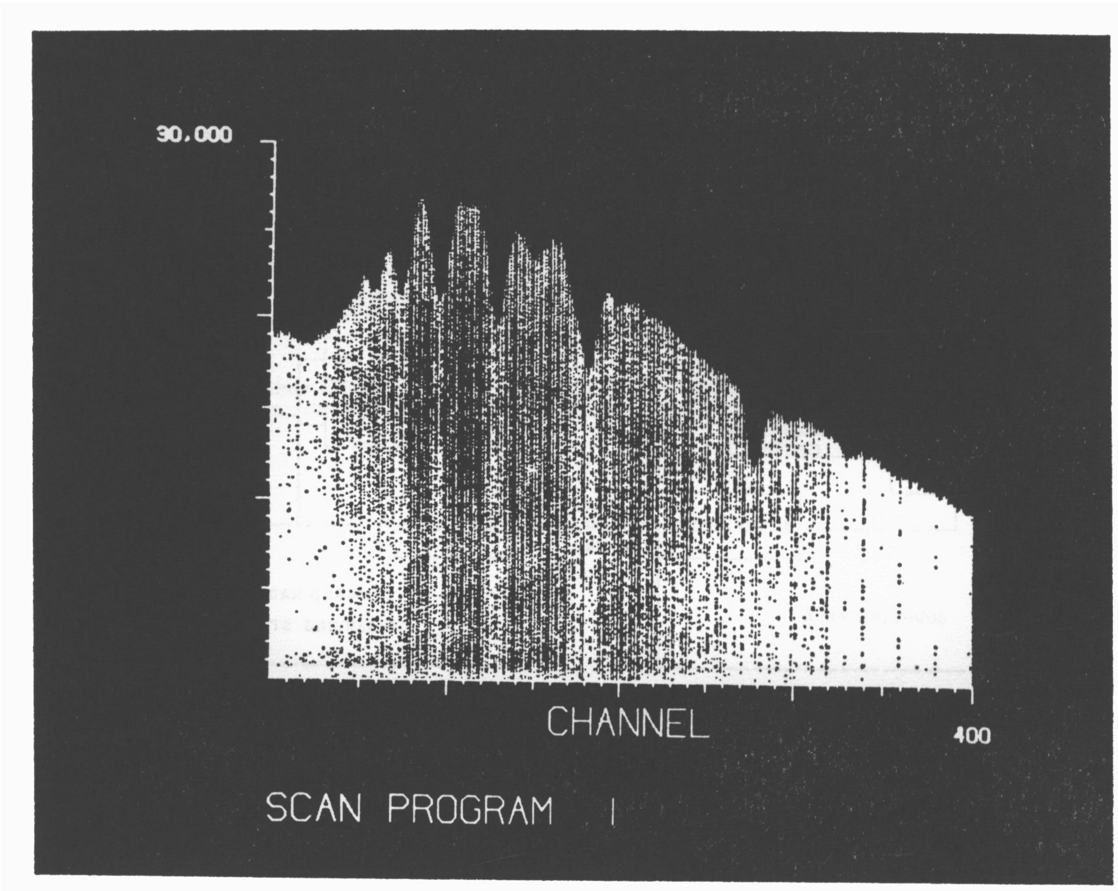

Fig. 8
Storage oscilloscope display of image dissector spectrum scanner data (HD 120315, B3V).

dissector photomultiplier. This instrument, now in use, is an asymmetric Czerny-Turner spectrometer which is diagrammed in Figure 9. The projected width of the monochromatic image of a 6 arcsec entrance aperture is 0.3 mm. Because the collimated beam diameter is only 24 mm, inexpensive gratings can be used and five have been purchased that have the properties described in Table I.

The spectrometer is constructed so that it can be used with the Kron electronographic tube (Kron, 1969) and other image tubes, as well as with image dissectors.

Because the image dissector photomultiplier is a single channel device, it is best suited to rapid intercomparison of flux at a limited number of spatial positions. The computer scanner control system makes it easy to restrict the image positions measured in any manner required for a particular program. An example of programming is shown in Figure 10. In this example, 40 channels were programmed, thus the data collection rate for those channels was 10 times as fast as the rate for the same channels when the full scan program was used.

Additional examples of use of the image dissector scanning system are presented in Figure 11.

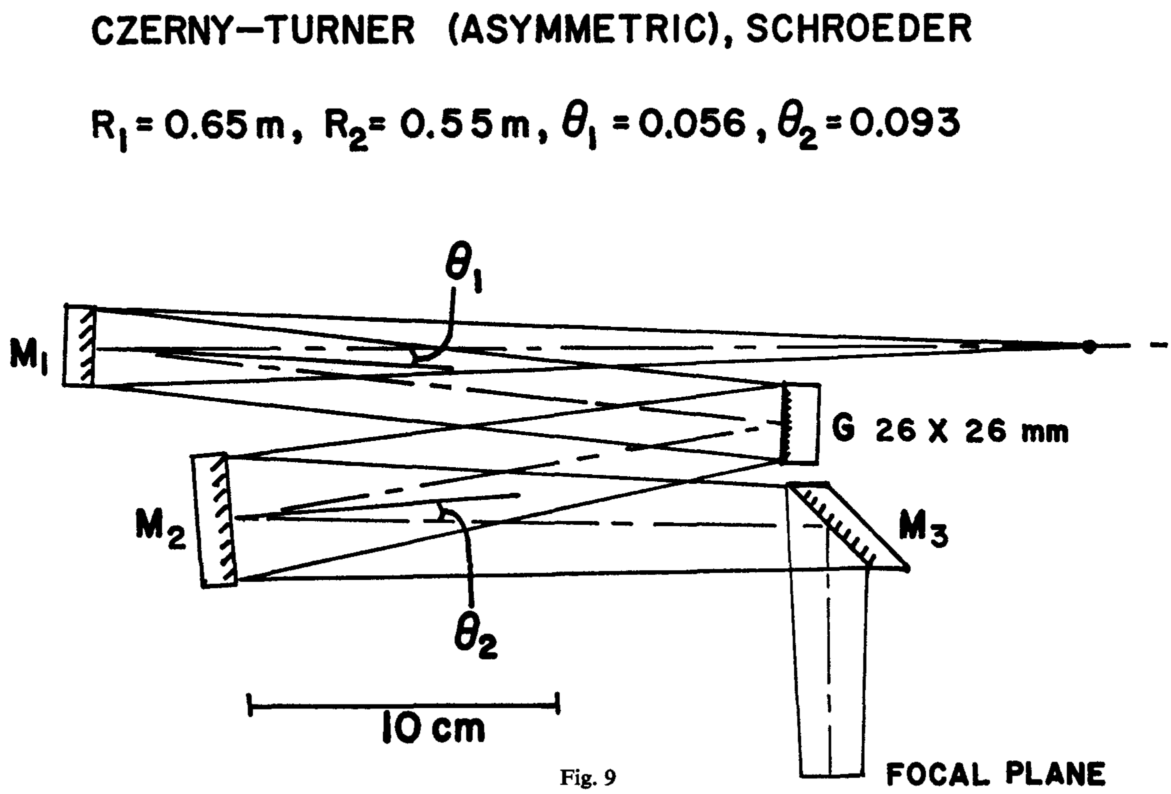

Fig. 9

Optical diagram of the spectrometer used with the image dissector photomultiplier.

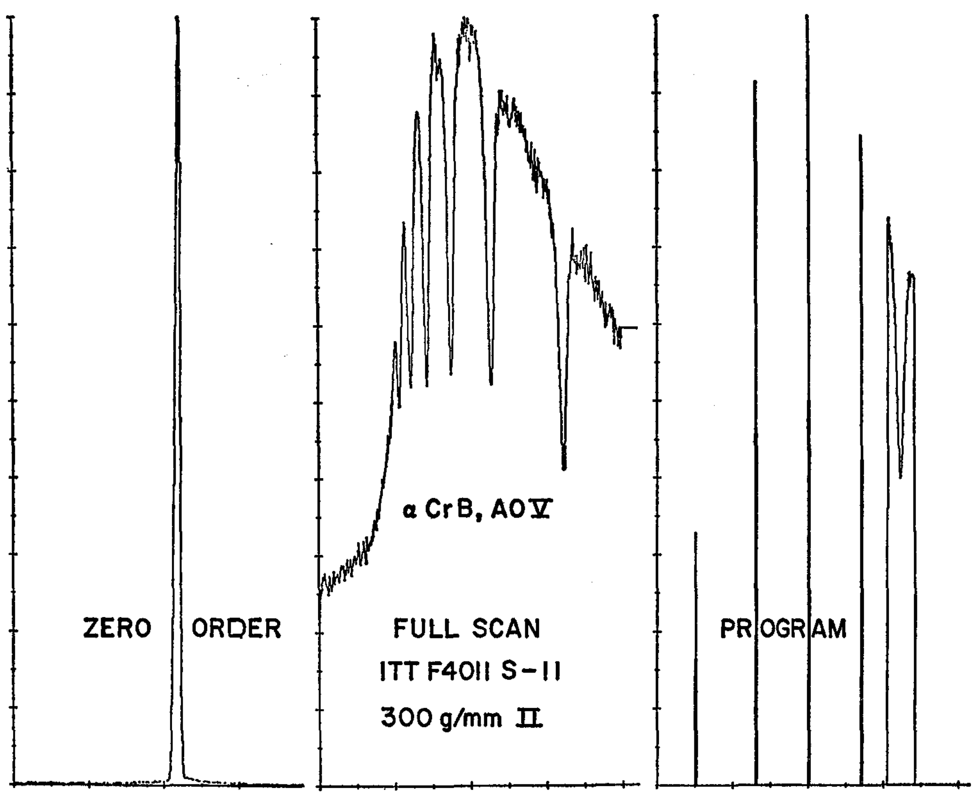

Fig. 10

Dissector scans of HD 139006, A0V. At the left, a scan of the zero-order image; in the center, the region λλ3500–4700Å scanned through all 400 spatial channels; and on the right, a scan of a limited program. In all cases, the count is normalized to 10 000 counts at the peak channel count.

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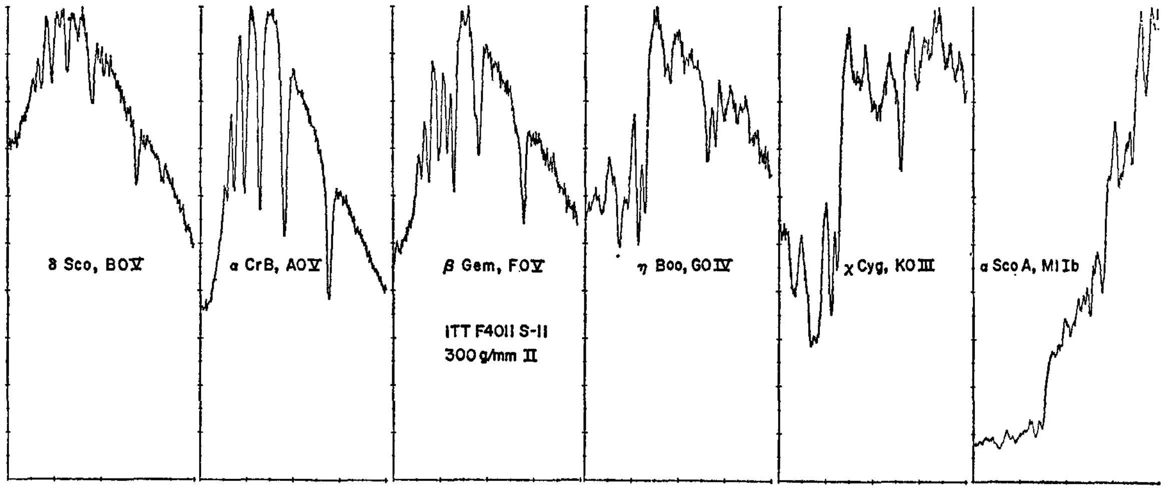

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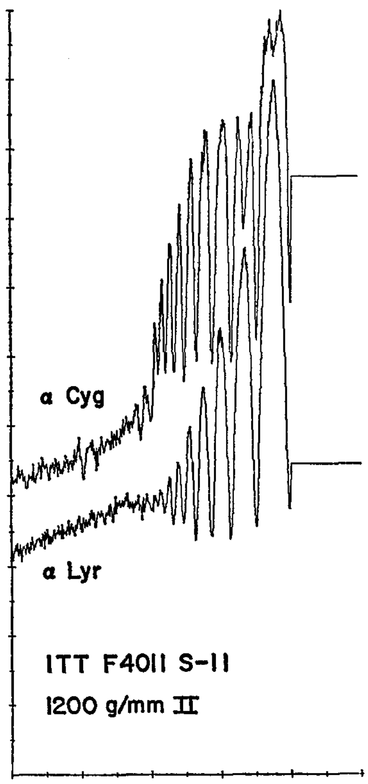

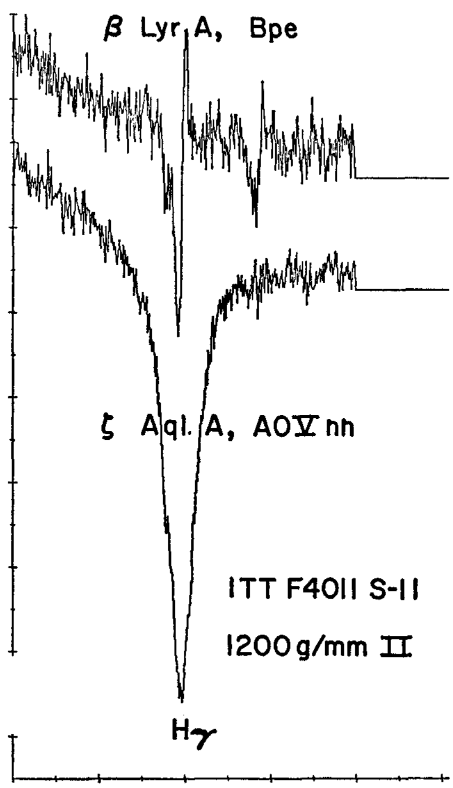

b c

Fig. 11

Further examples of dissector scanner data.

(a) For a variety of spectral types.
(b) Resolution of about 3.3Å per slot width. The spatial advance per channel is thus about 0.08Å.
(c) Hγ features for two stars.

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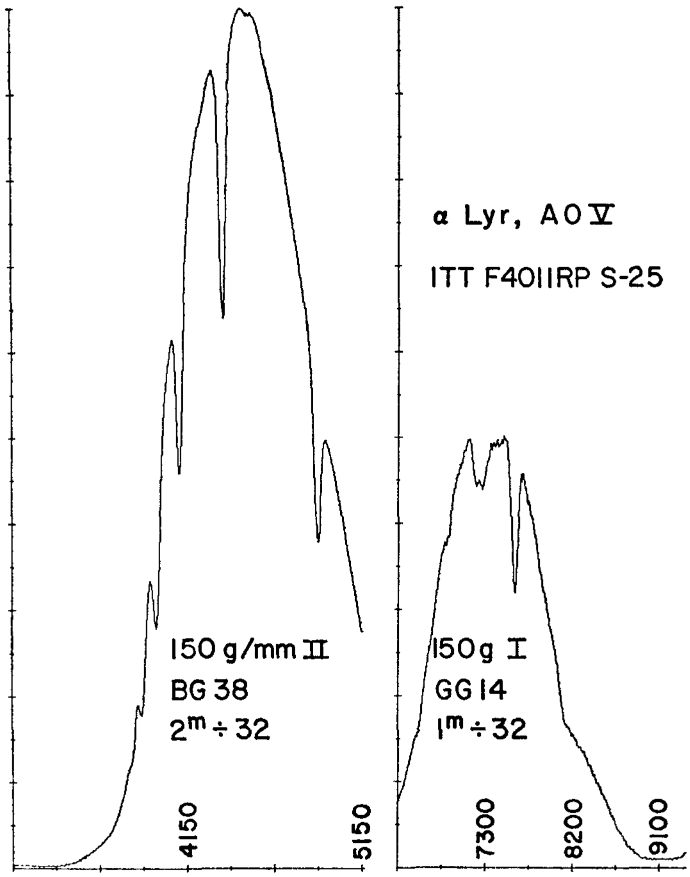

Fig. 12

First trial of the FW 4011 S-25 image dissector photomultiplier tube. The grating remains fixed and order separation filters were used to isolate the second order blue and the first order red. The slot width resolutions are approximately 40Å in the blue and 80Å in the red. The features near the maximum in the first order red trace are telluric. Paschen continuous absorption can be seen near λ7900Å.

TABLE 1

GRATING AND SPECTROMETER PARAMETERS

Grating	g/mm	λ Blaze	Blaze eff.	$\Delta\lambda/\Delta l$ (Å/mm)	F4011RP S-25 Slot (Å)	F4011 S-11 Slot (Å)	Scan (Å) Coverage
150 (I)		8000 (I)	86%	242	80	53	4800
200 (I)		7265 (I)	81%	181	60	40	3600
300 (I)	150 (II)	7500 (I)	82%	121	40	27	2400
	200 (II)	3633 (II)		91	30	20	1800
600 (I)	300 (II)	7500 (I)	80%	60.5	20	13.3	1200
1200 (I)	600 (II)	7500 (I)	80%	30.3	10	6.7	600
	1200 (II)	3750 (II)		15.1	5	3.3	300

Tests of a newly acquired ITT F4011RP S-25 image dissector tube are now in progress. The results shown in Figure 12 illustrate the spectral coverage of this tube at low resolution for one grating in one position.

III. *OTHER DISSECTOR APPLICATIONS*

We are incompetent to acknowledge the very large amount of work that has been done with image dissector tubes in aerospace applications. As mentioned before, at least two other guiders using image dissectors have been used with conventional telescopes (Reed, 1967; Adam, 1970). Other work with these tubes is in progress in astronomy and is known to us primarily through hearsay. Dr. W. G. Tifft, University of Arizona, has been developing image dissector photomultiplier systems for direct area scanning of galaxy images and for direct scanning of photographic plates.

Several astronomers are experimenting with dissectors as a means of "reading out" photoelectron events occurring in phosphors in high gain image intensifiers. E. J. Wampler, Lick Observatory, W. K. Ford, Jr., Carnegie Institution, J. G. M. Duthie, University of Rochester, and E. H. Eberhardt, ITT, are among those who are exploring this possibility of a "digital image tube" system.

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DISCUSSION

P. GILLINGHAM: (*a*) Have you measured the effective quantum efficiency of the image dissectors you use; in particular, do you find a serious loss in electron collection at the first dynode? (*b*) In the TV scan mode for acquisition, what are the scan field, scan rate, and threshold sensitivity?

A. A. HOAG: (*a*) We have only the manufacturer's information on this quantity, it has not been independently measured. In regard to uniformity of response across the photocathode, it's good to 2 per cent over a 20 mm range, which indicates that not only is the photocathode reasonably uniform, but its collection efficiency has worked out rather well across this 20 mm of the photocathode. The first image dissector we used for spectrum scanning unfortunately was extremely noisy; they put voltage dividing resistors in the tube, and we suspect that it's leakage from those resistors that made the tube noisy. The new S-25 dissector we have is very good. With an aperture of 0.3×0.6 mm we have a background count of about 6 events per sec. (*b*) We're using 15 raster scans per sec and we're broadening the pulses by 1 μs so that we can see them easily on a cathode ray tube, and we can rather easily see stars down to the guiding limit, which is something else that I didn't mention. Pardon me for giving a paper in answer to questions! With a 36-inch telescope we guide down to magnitude 12.5, with a bandwidth of 0.2 Hz.

Q: Did I understand that you do count photons with these dissector tubes, you can detect a single photoelectron as a pulse?

A. A. HOAG: That is correct.

A. P. LINNELL: Was the spectrum scan display corrected for the phototube sensitivity function?

A. A. HOAG: No, you saw the response.

R. F. NIELSEN: When using the image dissector for automatic guiding, do you have to use a computer in order to generate control X- and Y- signals? The differences in pulse count of the scans have to be divided by a measure of the total brightness of the guide star.

A. A. HOAG: Actually at the present time we're using a hard-wired control system that is contained within one 19-inch panel rack, and it's our intention in the case of the 150-inch telescope to have a hard-wired control system for guiding, as a standby unit, but to use the computer as well because we wish to determine information concerning focus, transparency, and sky brightness at the same time, and here we think it makes sense to use the small computer for this process; but it's not necessary to have a computer to use this as a guider.

J. RÖSCH: You had a slide showing errors of less than 0.1 arcsec, but is this integrated over a certain time?

A. A. HOAG: That's correct. On the present controller we scan at a uniform rate but we can vary the number of scans that are used in getting an error signal, and we change the bandwidth in this way. When using the telescope drive as a means of correcting the position of our telescope, we have to avoid those frequencies that represent natural harmonics in the mounting. In the case of the 84-inch this is at about 3 cycles. We don't believe that it's meaningful to guide at very fast response times because the coherence across the field at high frequencies is not good.

J. RÖSCH: Yes, the field of coherence is quite small, so if we use a guider there's no point in using such a system with a fast response.