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Image Tubes in Astronomy

William A. Baum

The development of image tubes for astronomy has been a slow and sometime vexing problem. The potential advantage of an image tube over unaided photography was demonstrated more than 20 years ago. Since that time many workers have explored various methods in trying to make image tubes a practical reality for astronomical observation.

Within the past 2 or 3 years efforts to develop image tubes for astronomy have finally begun to bear fruit. Use of an image tube on a telescope is no longer a mere stunt; the technique has become a practical one for making routine astronomical observations. Image-tube papers are beginning to appear regularly in the literature. Thus it may be a good time to review the problem and describe the current state of the art.

The goal is not merely to obtain astronomical pictures in shorter exposure times. A shortening of exposures can be accomplished more easily by ordinary unaided photography at a telescope or spectrograph of shorter focal length than usual, but such a procedure yields a coarser picture containing less information. Similarly, a coarser picture will also result if, instead of a shorter focal length, an image tube of low resolution is used in place of a photographic emulsion; the degradation of the image will partly offset any decrease of exposure time. A comparison of this kind is a good way of judging whether the use of an image tube has really gained something.

The real purpose of using an image tube is to collect more astronomical information per unit time. There are several alternative ways of spending whatever gain is available. Exposure times can be shortened, fainter objects can be reached, or image magnifications can be increased. Suppose, for example, that a particular image tube is found to provide a 10-fold speed gain over unaided photography of equal image quality. Instead of using this factor of 10 to shorten exposure times, we might sometimes choose to raise the signal-to-noise ratio by $10^{1/2}$, or we might choose to increase the resolution by a further magnification of $10^{1/2}$ times. Since the intrinsic resolution of an image-tube system is usually different from that of an unaided photographic emulsion, corresponding images are not ordinarily equal in size when they are equal in image quality.

The concept of information rate has usually been discussed in terms of the amount of picture information per image element. The total number of image elements covered is a separate factor. In this respect, image tubes do not begin to compete with unaided photography. Plates exposed at the 48-inch Schmidt telescope on Mount Palomar, for example, cover about 20,000 by 20,000 resolved image elements, whereas very few image-tube systems exceed 1000 by 1000 elements (2000 by 2000 television lines). Thus, when a very large image of great detail is to be covered, photography wins; but when a gain of threshold is sought, the image tube wins.

The reason that an image tube is potentially able to excel unaided photography is that a photoelectric cathode has a higher quantum efficiency than a photographic emulsion. For a given flux of incident photons, the number of electrons ejected from a good cathode is larger than the number of grains blackened on an unaided emulsion. This ratio of quantum efficiencies is about 30 for blue light and somewhat less for light of longer wavelength. It would directly represent the gain of the image tube if several conditions were fulfilled—namely, if every photoelectron were to produce a grain or grain clump in the final image, if all resulting grains or clumps were of equal size, if spurious background were negligible, and if there were no loss of resolution in comparison with unaided photography at the same focal length. In practice, various image-tube systems do not completely fulfill these conditions; hence the actual gain of the tube over unaided photography tends to be a factor somewhat less than the ratio of quantum efficiencies. We might think in terms of an image degradation factor by which the quantum efficiency ratio must be divided in order to express the true gain of the image tube.

Some types of tubes degrade an image very much more than others. The more times an image is transformed or reproduced, the more the image is likely to be degraded. A television system, for example, tends to introduce a larger degradation factor than a very simple image converter. The preference for simplicity, however, is not in itself a sufficient criterion for the choice of one image-tube system over another. It also turns out that the simplest type of tube from the point of view of physical processes happens to be the most difficult one to operate from the point of view of the observer.

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Camera Electronique

Beginning in the 1930's, the pioneering work on image tubes for astronomy was done by André Lallemand at the Paris Observatory. Television, too, was under active development in various places, but it was not directly aimed at use with telescopes. Simple image converters, like that sketched in Fig. 1, also had an early beginning because of military infrared applications during World War II, and they were followed by cascaded models. The TSE (transmission secondary emission) imaging photomultiplier, the channeled multiplier, and the thin-window tube were born during the 1950's. Within the past decade various developments have branched, so that there are now many different tube designs. Attention in this article is limited to a few particular designs of relatively recent astronomical interest.

Because of their fundamental nature, we should perhaps first discuss electronographic tubes. Lallemand's original *camera électronique* is shown schematically in Fig. 2. It is a glass-walled enclosure that has been very thoroughly cleaned and evacuated. Photoelectrons travel directly from a photocathode in its operating position to an electronographic plate in the cassette. When an accelerating potential of 20 or 30 kilovolts is applied between the photocathode and the plate, the photoelectrons strike the plate with enough energy to produce tiny tracks of several grains each. Thus the initial build-up of image density is approximately linear with exposure. The image is focused from the cathode to the plate by the elements of the electron lens with appropriate potentials on them. Lallemand's camera comes very close to meeting the basic conditions for minimizing image degradation. Nearly every photoelectron is recorded on the electronographic plate, the variation in the number of grains per track is not extreme, and the image resolution is excellent.

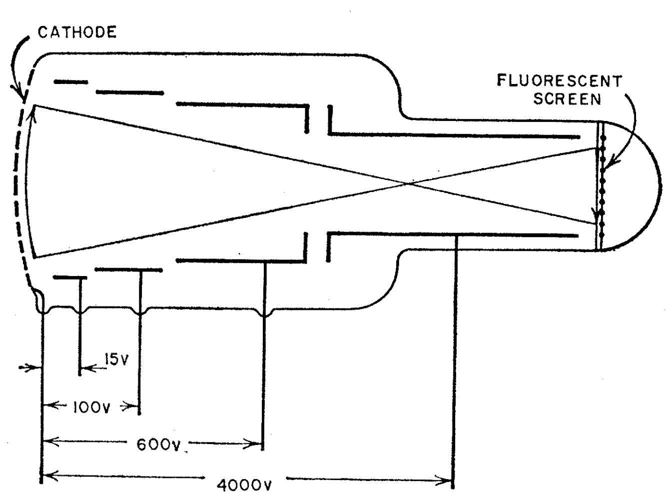
The operation of Lallemand's tube, however, is relatively complicated. Photocathodes are prepared in advance in small evacuated glass capsules. One of these is placed as shown in Fig. 2. This cathode and all other parts of the tube are inserted through the top central opening subsequently covered by the window. The system is then evacuated and baked out as well as can be done without damaging the photocathode and the electronographic emulsions. The procedure must be started more than a day in advance of the intended use of the tube at a telescope.

When observations are to begin, the photocathode capsule is broken by a magnetically actuated hammer, and the naked photocathode is pulled into its operating position by means of the magnetically actuated iron slug. The cassette holds several plates and has a mechanism for changing from one to the next when magnetically actuated. Focusing of the optical image on the photocathode must be accomplished by dead-reckoning, for it is not possible to remove a focus plate from the cassette until after all exposures have been made and the vacuum is broken. Before the tube can be used for another set of observations, it must be completely disassembled, the parts must be cleaned, and it must be put back together again with a new load of plates in the cassette.

Although operation of Lallemand's camera requires trained specialists, it has been used successfully by various collaborators of Lallemand in France and by Walker in California. Figure 3 shows a 4-hour trailed exposure sequence of the spectrum of the spectroscopic binary star AE Aquarii; it was obtained in 1964 by Walker with the Lallemand camera mounted in the coudé spectrograph of the 120-inch reflector at Lick Observatory. The dark features are emission lines that show rapid variations in width and intensity. The curvature of the lines is due to Doppler shift associated with orbital motion. The spectrum is about 1 centimeter long on the original plate.

Two attempts have been made, one by G. E. Kron at Lick Observatory and the other by W. A. Hiltner at Yerkes Observatory, to modify Lallemand's basic system in such a way as to maintain a high vacuum around the photocathode when plates are loaded and unloaded. Both of these workers have placed a vacuum-type valve between one chamber containing the electronographic plates and another chamber containing the photocathode. By this method, the operation of the tube may be somewhat simplified in certain respects, but devices of this kind are all still the tools of thoroughly experienced specialists.

Actually, the valve technique was preceded by two efforts to use a very thin membrane through which the photoelectrons could be shot without permitting gas molecules from a "dirty" vacuum surrounding the plates to con-



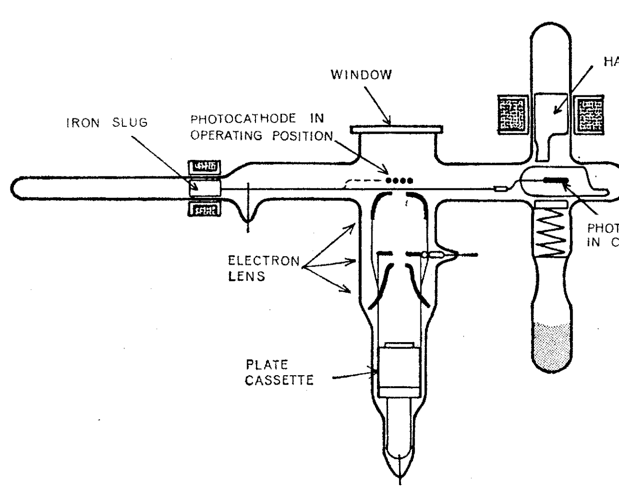


Fig. 1 (left). Early type of electrostatically focused image converter, type 1P25. An optical image focused on the photoemissive cathode is re-imaged by an electron lens onto the phosphor screen. [Adapted from G. A. Morton and L. E. Flory, *Electronics* **19**, 112–114 (1946)] Fig. 2 (right). André Lallemand's *camera électronique*. Operation of this remarkable pioneering apparatus is described in the text. [Adapted from O. Struve, *Sky and Telescope*, **14**, 224–227 (1955)]

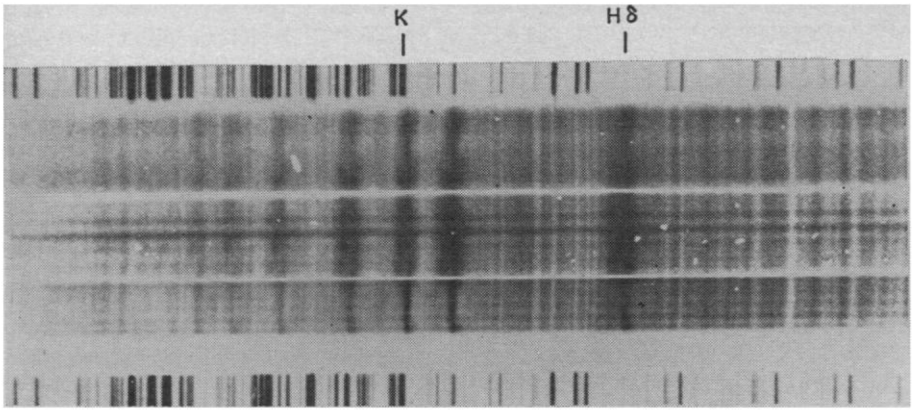


Fig. 3. Trailed spectrum of a variable star obtained by M. F. Walker with a Lallemand camera. The comparison spectra at the top and bottom were produced with an iron arc. The stellar exposure, a juxtaposition of three plates, began at the top and ended 4 hours later at the bottom.

taminate the clean vacuum surrounding the photocathode. Tubes of this kind were operated experimentally by W. A. Hiltner and J. Burns and by J. S. Hall and W. A. Baum, but they were later abandoned in favor of other methods.

Spectracon

A more practical version of the thin-window tube has been developed by J. D. McGee and his collaborators at the Imperial College in London. McGee's tube, known as the spectracon, is now one of the candidates of current interest for astronomical observations. McGee succeeded in designing an electron-permeable membrane strong enough to withstand full atmospheric pressure. It is therefore not necessary to maintain a protective vacuum behind the membrane.

The present version of the spectracon is sketched in Fig. 4. Photocathodes are initially made in separate capsules and are selected in advance before one of them is inserted into a spectracon. The transfer of the photocathode has some similarity to Lallemand's method, but the transfer apparatus is later sealed off and removed, so that the cathode is permanently installed. Annular rings spaced along the tube are connected to an external voltage divided so as to distribute the accelerating potential uniformly. Focusing is provided by a uniform magnetic field parallel to the axis of the tube. The exit window is a sheet of mica, about 5 microns thick, suspended across a 10- by 30-millimeter slot in an end plate whose thermal coefficient is very similar to that of the mica. When an accelerating potential of 40 kilovolts is applied, photoelectrons can be shot through the mica window with a loss of only half their energy. An electronographic emulsion on a thin Mylar base is wrapped around the rubber-coated drum and is pressed gently into contact with the mica output window.

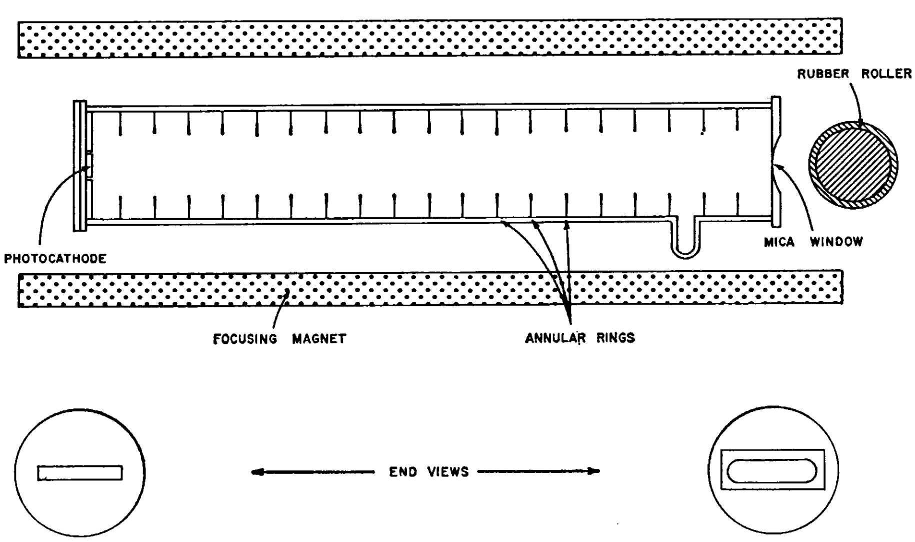


Fig. 4. Spectracon, also known as a Lenard-window tube. When an accelerating potential of about 40 kilovolts is applied across the ends of the tube, photoelectrons from the cathode gain enough energy to penetrate the 5-micron-thick output window and impinge directly on an electronographic emulsion pressed against the window by the rubber roller.

Since the spectracon is a completely sealed-off, permanent tube, no vacuum pumps or liquid-air traps are required, and no elaborate preparation is required before observations can be made. Not only is the operation of the spectracon vastly simpler than that of the Lallemand camera and its relatives, but the performance is almost as good. More than two-thirds of the photoelectrons are recorded, and there is only a slight loss of resolution due to the mica window. Of all the various electronographic tube designs, the spectracon is the most attractive from the nonspecialist's point of view.

Figure 5 shows a sample of a star spectrum obtained in 1963 with a spectracon installed by McGee and Baum in the coudé spectrograph of the 100-inch telescope on Mount Wilson. The region of the spectrum shown is centered at about 3950 angstroms, and the dispersion on the original film was about 3 angstroms per millimeter. The two broad absorption features are the H and K lines of calcium II; details within them indicate that the star has chromospheric emission.

Subsequent spectracon observations in 1965 resulted in improved resolution and higher gains. Tests at that time indicated that the image quality was limited more by the optics of the spectrograph preceding the tube than by the performance of the tube itself. With Ilford XM emulsion behind the tube, the rate of blackening was found to be 34 times faster than the rate for unaided photography on baked Eastman IIa-0 plates. However, some allowance must be made for the greater granularity of XM emulsion as compared with IIa-0. Exposures were also made on Ilford G5 emulsion, which has finer grains than IIa-0, but is one-third as fast as XM. Under favorable conditions the spectracon can resolve about 45 line pairs per millimeter on the XM emulsion and about 70 on G5 emulsion.

In the present version of the spectracon, the electron flight path from the photocathode to the mica window is about 11 inches (280 millimeters). The

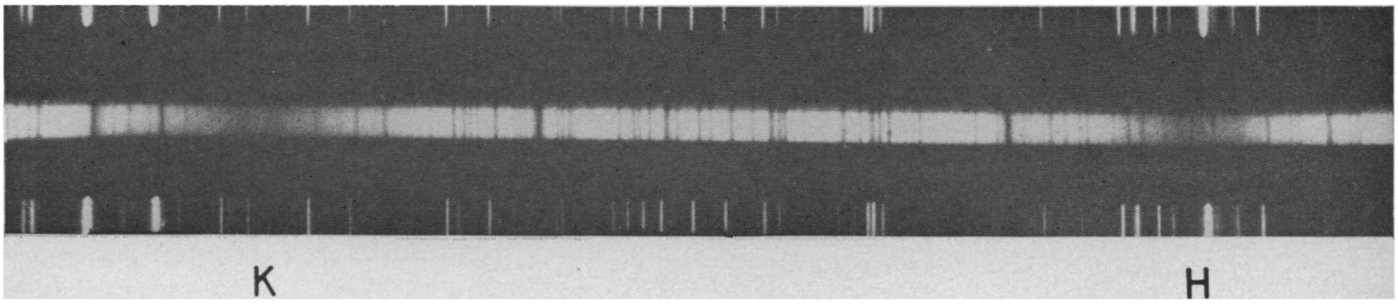


Fig. 5. Portion of a 5-hour exposure obtained by J. D. McGee and W. A. Baum with the spectracon in the coudé spectrograph of the 100-inch reflector at Mount Wilson Observatory. This is a high-dispersion spectrum of a short region in the ultraviolet about 50 angstroms in total length. The spectrum in the center is that due to the star (HD 114710), while the spectra at the top and bottom are due to an iron arc used for identifying wavelengths.

photoelectrons are accelerated from one end of the tube to the other along approximately parallel paths, so the output image is the same size as the input image. Random transverse ejection energies of the photoelectrons cause them to depart slightly from parallel motion, but the uniform axial magnetic field constrains them to slender helical trajectories having nodes at known intervals. For two-node focusing at 40 kilovolts, the present spectracon model requires a parallel magnetic field of about 150 gauss.

If the magnetic field is removed and if the accelerating potential on the annular rings is given an appropriate nonlinear distribution, the spectracon can be focused electrostatically. In such a case the photoelectrons move along paths that cross one another near the middle of the tube, and the output image is inverted with respect to the input image at the cathode. However, this electrostatic method of focusing provides a much smaller area of good image resolution than can be achieved with the uniform electric and magnetic fields for which the spectracon was designed. For the same reason the area of good resolution provided by an electrostatic image converter like that in Fig. 1 is smaller than the image area that can be achieved with a similar converter having a flat cathode, a flat phosphor, a uniform accelerating field, and a uniform axial magnetic focusing field. This is particularly true when a converter tube contains two or more stages in cascade.

Cascaded Image Converter

Among the various types of image tubes available today, the cascaded image converter is the type receiving the greatest amount of attention from astronomers. The essential features of a cascaded converter are sketched in Fig. 6. The tube is cylindrical, with flat windows at the ends. Figure 6 shows a single intensifying membrane at the center of the tube, but similar tubes have been built with two or more such membranes. The membrane is an extremely thin transparent sheet coated with a phosphor layer on one side and a photocathode on the other. Photoelectrons from the primary cathode at the end of the tube are accelerated to the intensifying membrane, where they excite the phosphor screen. Photons emitted by this phosphor cause photoelectrons to be ejected from the photocathode on the other side of the membrane, and these secondary photoelectrons are accelerated to the phosphor screen on the output window. Owing to the uniform axial field of the focusing magnet, the cathode image is reproduced at the intensifying membrane, and the membrane image is reproduced again at the output phosphor screen. Following the tube, an optical system must be used either for viewing or photographing the output phosphor image.

By a suitable choice of photocathodes and phosphors, the performance of a cascaded converter like that in Fig. 6 can be made good enough to assure the ultimate photographic recording of most of the image information from the primary photocathode. For an efficient S-20 cathode with its peak response in the blue region of the spectrum, one photoelectron is ejected, on the average, for every seven incident blue photons. If the accelerating potential across the first stage is 10 kilovolts, each photoelectron striking the phosphor side of the intensifying membrane will cause about 350 photons to be emitted. These, in turn, will eject about 50 photoelectrons from the photocathode on the other side of the intensifying membrane. If the accelerating potential of the second stage is also 10 kilovolts, the 50 secondary photoelectrons will result in emission of about 17,500 photons from the output phosphor screen. Thus the overall light gain of the tube for blue light is 17,500 divided by 7, or about 2500.

Very thin aluminum films overlaid on the backs of the phosphor screens prevent the feedback of output light to the photocathodes. The angular distribution of the output light, however, is very broad. An $f/1$ transfer lens of typical transmission can effectively reimage only about 3 percent of the phosphor output at unit magnification; for such a lens then has $f/2$ acceptance and output cones. Under these circumstances, an average of 2.5 blackened grains are produced on a baked Eastman IIa-0 plate for each photoelectron from the primary photocathode. Although there is some statistical variation in this quantity, most of the photoelectrons yield a record on the final plate. The lens might be stopped down to an effective speed of about $f/1.5$ ($f/3$ cones at input and output) before the loss of primary photocathode information would begin to be important. Even so, the demands on optical performance are very high.

In this connection, we should consider the degree to which various components of the system affect image resolution. A cascaded converter tube of recent type, if tested alone, has a limiting resolution of about 45 line pairs per millimeter. Over a field of limited size, perhaps 15 millimeters, an $f/1$ transfer lens might, if used alone, have about the same resolution as the converter tube. An Eastman IIa-0 plate may be capable of recording 70 line pairs per millimeter. When all these

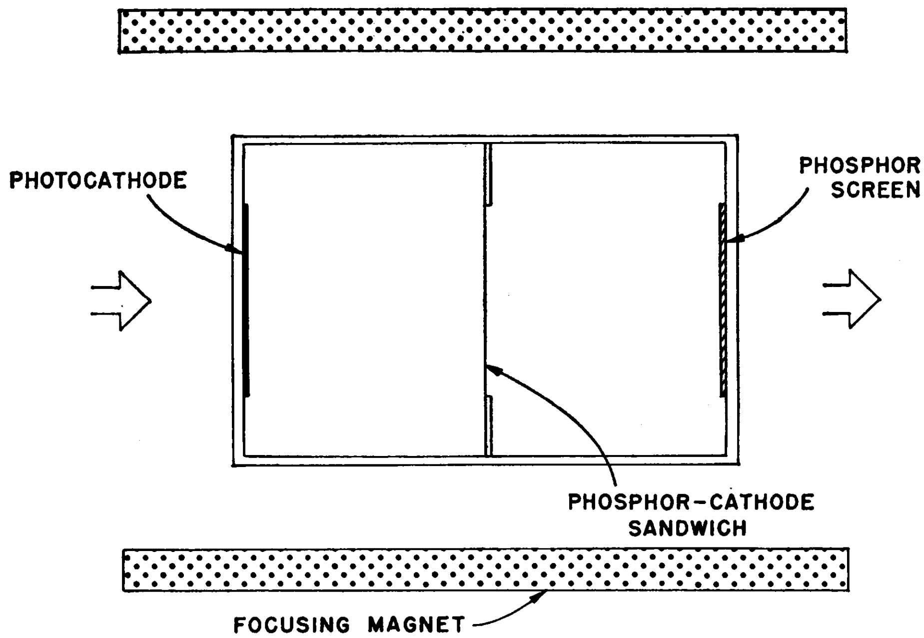


Fig. 6. Cascaded converter tube with parallel-field focusing. An optical image focused on the first photocathode is electronically re-imaged at the phosphor-cathode sandwich and is again re-imaged at the output phosphor screen. This output image is photographed with a camera.

components are combined, the central resolution of the system is somewhat lower than one might think—about 25 line pairs per millimeter—and the resulting images have a "soft" appearance. In other words, the resolution of the system tends to be much lower than that of the cascaded converter tube alone, and the image degradation introduced by the transfer optics is an important part. This situation can be understood in terms of the modulation transfer functions for the various components.

The optical problem becomes even more difficult if the full 40-millimeter field provided by current models of cascaded converters is to be utilized. For example, a transfer optical system of high resolution has been designed by I. S. Bowen, but its principal element is a spherical mirror about 20 times the diameter of the field to be reimaged. At present, the development of improved transfer optics is a more critical need than the development of improved cascaded converters.

Cascaded converter tubes with more than one intensifying membrane could, in principle, be used along with transfer lenses of more favorable focal ratio and performance, because a converter tube with three or more stages would produce many more output photons for each primary photoelectron. Unfortunately, additional stages in the converter tube tend to degrade the image at the same time they relieve the optical problem. Additional stages also tend to jeopardize success in meeting high specifications in tube production.

Exposures of an hour or two can generally be made before the spurious background emission in a cascaded converter itself adds substantially to the photographic fog in the final recorded image. Part of this emission is sometimes caused by ions that produce localized specks in the background. The enhancement of overall background due to local cathode illumination is usually not noticeable unless a part of the image is greatly overexposed.

With the support of the National Science Foundation, cascaded converter tubes of the type just described are being produced by RCA and are being distributed, together with auxiliary hardware, to astronomical observatories by the Carnegie Image-Tube Committee. Figure 7 shows the spectrum of a quasi-stellar object obtained with one of these tubes at the 72-inch telescope of Ohio State and Ohio Wesleyan Universities at Lowell Observatory. The dispersion on the original plate was 350 angstroms per millimeter, and the range covered by Fig. 7 extends from 4900 to 7300 angstroms. The converter had an S-20 photocathode and a P-11 output phosphor. The input image to the photocathode was provided by a special $f/2$ lens. The output image was relayed to an Eastman IIa-0 plate with an $f/1$ Burke and James transfer lens at unit magnification ($f/2$ in, $f/2$ out).

From photometric tests of current models of these cascaded converters, the rate of photographic blackening is found to be nearly 75 times faster than that of unaided photography when an $f/1$ transfer lens is used in combination with Eastman IIa-0 plates behind the tube. Since 2.5 grains are blackened, on average, for each primary photoelectron, the information gain would be a factor of 30 if the resolution of the system were comparable with that of unaided photography. In the spectroscopic case, the degradation of information is proportional to the factor by which image resolution has been reduced. The present information gain of the complete system is therefore a factor of about 11 in comparison with unaided photography. This gain is large enough to encourage

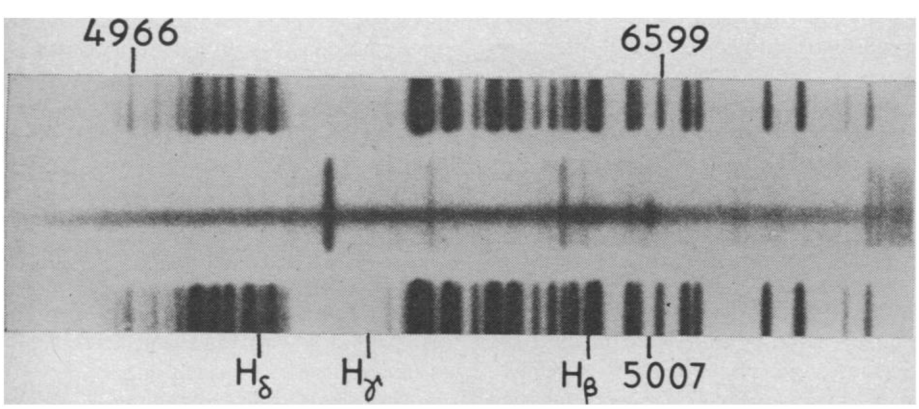


Fig. 7. Spectrum of a quasi-stellar object obtained by W. K. Ford, Jr., and V. C. Rubin with a cascaded converter tube on a grating spectrograph attached to the Cassegrain focus of the 72-inch Perkins reflector at Lowell Observatory. The spectrum in the center is that of the quasi-stellar object itself. The several long lines straddling the spectrum are due to night-sky emission which illuminated the full length of the spectrograph slit. A the top and bottom of the figure are comparison spectra produced by an iron-neon hollow-cathode lamp. Emission lines in the quasi-stellar spectrum itself indicate a red shift of 0.31.

wider use of cascaded converters in astronomical observation, and larger gains are to be anticipated if better optics materialize.

Imaging Photomultipliers

We have been discussing the type of cascaded converter that utilizes a phosphor-cathode sandwich for its intensifying membranes. There is another type of cascaded converter in which the intensifying membranes function like dynodes in a photomultiplier tube. These imaging photomultipliers have been referred to as TSE (transmission secondary emission) tubes. Early work on these tubes was carried out by E. J. Sternglass at Westinghouse Research Laboratories and by W. L. Wilcock at Imperial College in London. Current models of these tubes are available from English Electric Valve Company and from Twentieth Century Electronics.

Transmission secondary emission tubes require several membranes in order to have a useful overall electron gain, but the required accelerating potential per stage is only about 4.5 kilovolts. Following the last dynode membrane, a somewhat larger voltage (10 to 15 kilovolts) can be used for slamming electrons into the output phosphor. Thus an imaging photomultiplier with five dynode membranes may have an optimum overall operating potential of 35 kilovolts, and it may have a photon gain for blue light as high as 100,000. Primary photoelectrons from the cathode result in individual flashes of light at the output phosphor which are bright enough to be seen easily with an ordinary eyepiece.

Focusing is provided by a parallel magnetic field. The image resolution is about 50 line pairs per millimeter over a field 2.54 centimeters in diameter. The dark emission is typically about 100 scintillations per square centimeter per second.

Studies have been made of the multiplication statistics in TSE tubes, and the results have been somewhat disappointing. Although the average electron multiplication per dynode is fairly high, there is evidence that more than half of the primary photoelectrons may be absorbed and lost at the first dynode. Of the remaining fraction that succeed in producing secondary electrons at the first dynode, some yield much larger output pulses than others. Since the image "noise" tends to be dominated by the larger pulses, the final signal-to-noise ratio is somewhat lower than it would be if all output pulses were of the same size. This degradation is equivalent to an additional 50-percent loss in photocathode sensitivity. If these studies are correct, the TSE tube delivers less than one-fourth of its initial photocathode information to the output phosphor image.

Figure 8 shows the spectrum of a quasi-stellar object obtained at Kitt Peak Observatory with a TSE tube made by English Electric Valve Company. The dispersion on the original plate was 125 angstroms per millimeter, and the range covered by Fig. 8 extends from about 3200 to 5400 angstroms. This particular TSE tube had an S-20 photocathode and a P-11 output phosphor. It was followed by an $f/2$ Elgeet transfer lens at unit magnification ($f/4$ in, $f/4$ out). The output image was recorded on an Eastman IIa-0 plate, which was moved slowly during exposure at right angles to the direction of dispersion. This procedure was used for spectrum widening instead of the usual trailing of an object along the length of a spectrograph slit. A very short slit could therefore be used to minimize night-sky radiation and to minimize a light-dependent background emission that this type of tube tends to have. The S-shaped distortion in Fig. 8 is not an inherent feature of the TSE tube; it merely indicates that the focusing magnetic field was not uniform. The photovisual magnitude of the quasi-stellar object in Fig. 8 was 18.5, and the total exposure time was 3 hours.

Television Cameras

Television camera tubes comprise another family of image tubes that have been tested for astronomical purposes. Such tubes involve the scanning of an image with a narrow beam of electrons. The output current is consequently a point-by-point representation of image brightness. An output of this form lends itself to certain specialized applications, such as the telemetering of an astronomical image from a space telescope, or the "real-time readout" of a satellite tracker. Television-type tubes have also been used with feedback deflection coils to operate as a planet-image "tranquilizer" —that is, as a device for canceling

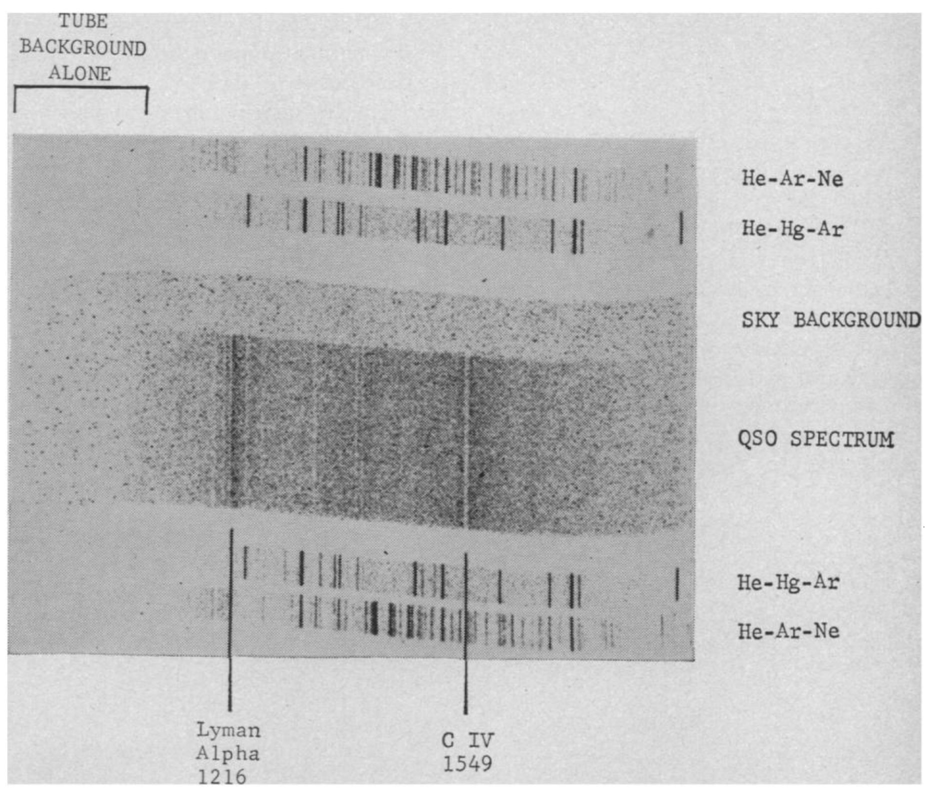


Fig. 8. Spectrum of a quasi-stellar object obtained by A. N. Stockton and C. R. Lynds with a TSE imaging photomultiplier on a grating spectrograph attached to the 84-inch reflector at Kitt Peak National Observatory. The spectrum was broadened by moving the plate perpendicular to the direction of dispersion during the exposure. The tiny individual flecks are the scintillations due to individual photoelectrons from the cathode. Comparison spectra are shown at the top and bottom of the figure. The displacements of lines in the quasi-stellar spectrum indicate a red shift of 1.95.

part of the image disturbance caused by atmospheric turbulence.

The image orthicon is a well-known type of television pick-up tube. Primary photoelectrons are accelerated to a thin target, where they eject secondary electrons that are collected by a grid. The image is therefore deposited on the target in the form of positive electric charges. When the back surface of the target is scanned by a slender electron beam, it acquires an equilibrium bias potential such that the scanning electrons land on the more positively charged portions of the target but are reflected by the less positively charged portions. After suitable amplification, the reflected current can be used to modulate a broadcast signal or to feed a kinescope in a closed-circuit system. In comparison with other types of image tubes, the image orthicon is at a disadvantage as a detector of faint light. At low levels of input light, inherent sources of noise tend to be appreciably greater than the fundamental limit set by primary photoelectron statistics. It is particularly unfortunate that output current, and therefore noise, is maximum in image areas where the input brightness is minimum.

Vidicon

Another type of television tube of astronomical interest is the SEC (secondary electron conduction) vidicon. In a vidicon, the output current is derived from the electrons that land on a target instead of from the electrons that are reflected by the target. In the SEC type of vidicon, the input optical image is focused on a photoemissive cathode and, as in the image orthicon, the ejected photoelectrons are accelerated to a separate target plate. In this case, the target is a "spongy" deposit of thin film of low density, somewhat similar to the dynode material in the TSE imaging photomultiplier already described. The impinging photoelectrons produce showers of secondary electrons within the target material, and these electrons can be conducted through the voids of the low-density layer to the target signal plate under the action of an electric field. In effect, this process converts each photoelectron of several kilovolts' incident energy into a large number of positive charges on the surface of the target, which is then scanned with a slender electron beam. From recent tests, the SEC vidicon appears to be a good choice for the readout of astronomical images obtained with a space telescope. For observations with ground-based telescopes, however, it is not yet clear whether scanning tubes, such as the SEC vidicon, can be developed to the point where they can compete in performance with functionally simpler image tubes such as cascaded converters and spectracons.

One of the side problems encountered in adapting image tubes to ground-based astronomy is the disturbance of images by the earth's magnetic field. During an exposure, any variation in a component of that field perpendicular to the flow of electrons through an image tube will cause a smearing of the image. Such variations must be limited to only a few milligauss if the smearing is to be negligible in most types of tubes. When a telescope tracks an object in the sky, an image tube attached to it slowly changes its orientation with respect to the earth's surface. The resulting variation of cross-fields is troublesome, even inside a steel dome. At a nonmoving focus, such as a coudé spectrograph, the dragging of the earth's field by a turning dome is sometimes enough to cause similar trouble.

An electrostatically focused image tube can be magnetically shielded rather easily by a close-fitting jacket of a material of high permeability, such as Mu-metal. We have already noted, however, that electrostatically focused tubes produce curved focal surfaces of very small area, and that parallel-field magnetic focusing is more attractive in that respect. Unfortunately, a parallel-field system, whether it is a solenoid or an array of permanent magnets, is more difficult to shield against stray external fields, because a steel enclosure for it has to be very massive so as not to be saturated by the flux of the focusing magnet itself. A material such as Mu-metal is not suitable. The problem is even worse for an array of permanent magnets than for a solenoid coil, because the shielding enclosure must then also be large enough to leave a large space around the magnet array. A proposed alternative solution is to use deflection coils for canceling cross-fields. This can supposedly be accomplished with feedback loops driven by magnetic probes of suitable orientation. A similar deflection-coil system shows promise for tranquilizing planet images and for maintaining automatic image centering.

Another side problem encountered in adapting image tubes to ground-based astronomy is their incompatibility with reflective optical systems of very short focal ratio that are used in the spectroscopy of faint objects. Whereas a tiny photographic plate can easily be inserted into such an optical system without being an excessive obstruction, an image tube cannot. However, encouraging progress has recently been made by I. S. Bowen and others in the design of suitable cathode input optics with speeds as fast as $f/1$.