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The 60 cm Ritchey-Chrétien Telescope and its Instruments

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Abstract

A 60 cm Ritchey-Chrétien optical system has been manufactured and installed in the tube of the 40 cm Schmidt telescope in replacement of the Schmidt optical system. The type of the main optical system is of the classical Ritchey-Chrétien whose focal ratio is 8.

A new type of corrector for the Ritchey-Chrétien focus has been developed. This consists of three spherical lenses and realizes a long back focal length. A correcting system which gives a 1.0 degree flat focal plane at a distance 120 cm after the last surface of the corrector was fabricated. Another system which secures a 1.5 degree flat field and also a 120 mm back focus has been designed.

A long back focus of the correcting lens system has enabled us to equip this small telescope with an aquisition/guiding assembly between the corrector and the observation instrument. This brought an additional advantage to make observation instruments free from loading their respective aquisition/guiding systems.

Wide-field imaging observation is performed with a photographic camera. A CCD camera is used for direct imaging and also for spectroscopy with a small slit spectrograph. SPECTRONEBULAGRAPH, i.e., an monochromatic imaging system has been developed by combining operation of the CCD camera attatched to the spectrograph and that of the telescope control system.

Another instrument is a multi-beam photoelectric photometer where micro-optics including optical fibers is adopted. With this apparatus, quasi-simultaneous observation of four objects seen in the Ritchey-Chrétien focal plane is possible to monitor variabilities with high accuraccy.

1. Introduction

The Ritchey-Chrétien system is a two-aspheric-mirror system giving a secondary focal image which is exactly free from spherical abbreation and coma. Field curvature and astigmatism remain as dominant abberations. Comparing with a Cassegrain system with the same set of Gaussinan optical parameters, the curvature is same and the astigmatism exceeds only slightly. Therefore, the Ritchey-Chrétien system gives a wider field of view than the Cassegrain system if the focal ratio is fixed, or a smaller focal ratio can be taken in the Ritchey-Chrétien system if the field size is fixed.

The implication of this is that Ritchey-Chrétien telescopes moderate in both field of view and focal ratio fit for imaging observations of faint extended objects such as galaxies. By benefit of high performance of CCD cameras which are currently available, even spectroscopic observation of bright extragalactic objects has become possible with small telescopes in addition to photoelectric photometry which has been common so far.

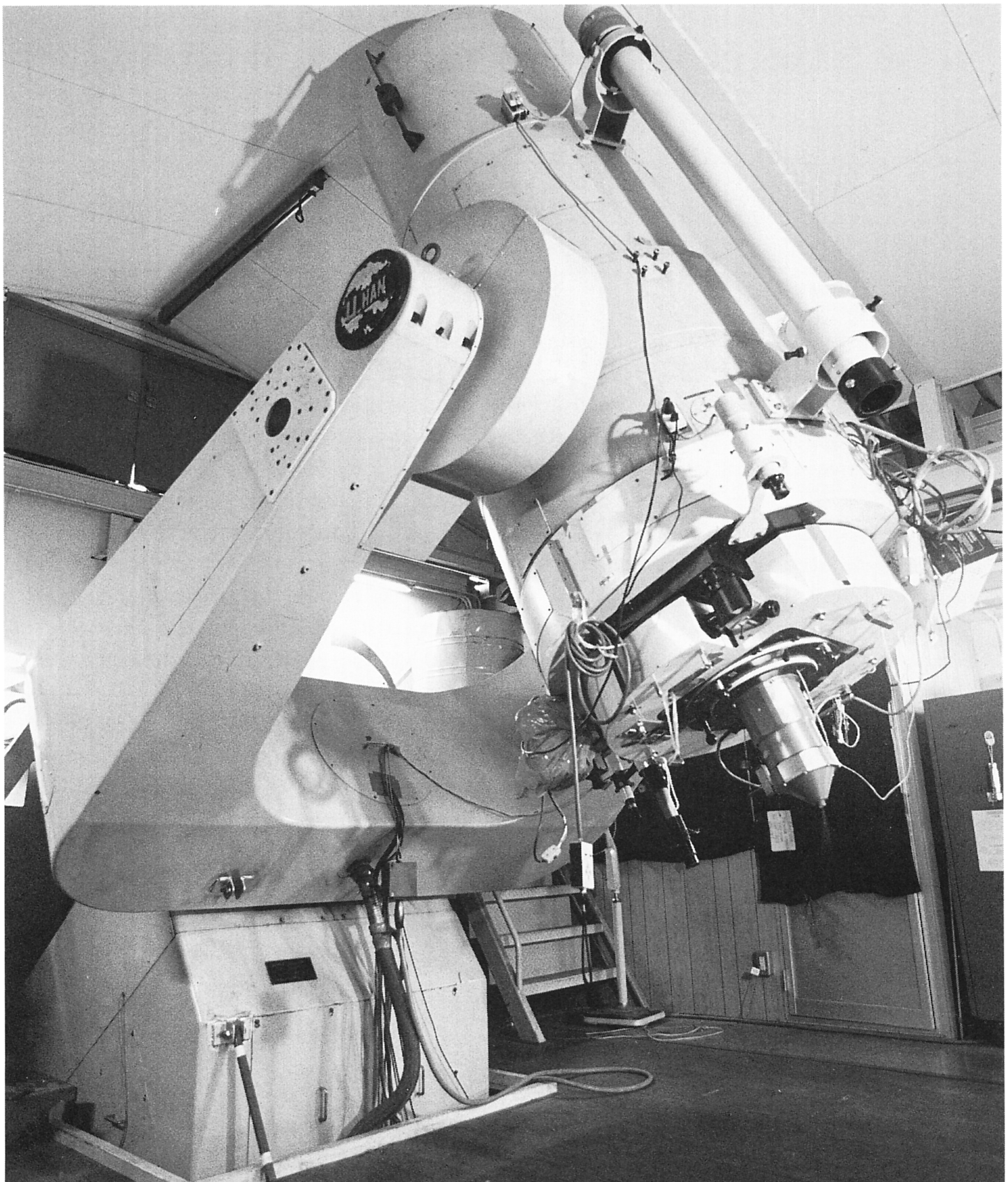

Fig. 1. The 60 cm Ritchey-Chrétien telescope equipped with a CCD camera.

From the above consideration, we have constructed a small Ritchey-Chrétien telescope for the purpose of extragalactic research as well as for studies of galactic objects. In the present work, mechanical construction of the telescope except mirror cells was not newly made, but the mounting and the tube of the exisiting 40/70/120 Schmidt telescope (Imagawa et al. 1977) at Ouda Station of Kyoto University has been utilized. That is, the Schmidt optical system has been replaced with a 60 cm Ritchey-Chrétien one. The removed optical parts and the cell with the mirror support are kept in a store so that they can be installed again when necessary.

This article is devoted for descriptions of the new Ritchey-Chrétien telescope (Fig. 1). The mirror system is first described together with the correcting lens. Descriptions are also given for observation instruments, i.e., a photograhic camera, a CCD camera, SPECTRONEBULAGRAPH, and a multi-object photoelectric photometer.

2. The Ritchey-Chrétien Optical System

2.1. Mirror System

The configuration of the Ritchey-Chrétien mirror system was determined under constraints from availabile basic material for the present work. The main mirror was made of a blank glass of aperture 60 cm which was available from Applied Optics Division of Institute of Government Industrial Research Institute, Osaka. Utilization of the tube of the Schmidt telescope brought a limitted range for the

Table 1. Formulae of the 60 cm Ritchey-Chrétien Optical System (Data in milimeter)

1.0 Degree Field System* (GRC32)			1.5 Degree Field System (GRC4513)		
Radius	Axial Separation	Material	Radius	Axial Separetion	Material
3600			3600		
	−1145.31	Air		−1145.31	Air
2095			2095		
	1486.5	Air		1486.5	Air
171.6			171.36		
	15	UBK7		15	UBK7
163.2			163.41		
	97.5	Air		98.35	Air
170.0			170.28		
	6	UBK7		6	UBK7
106.0			106.47		
	8	Air		7.13	Air
133.2			133.72		
	12	UBK7		12	UBK7
217.0			216.75		
	120.32	Air		119.50	
infinity			infinity		

*) BK7W (Ohara) is used instead of UBK7.

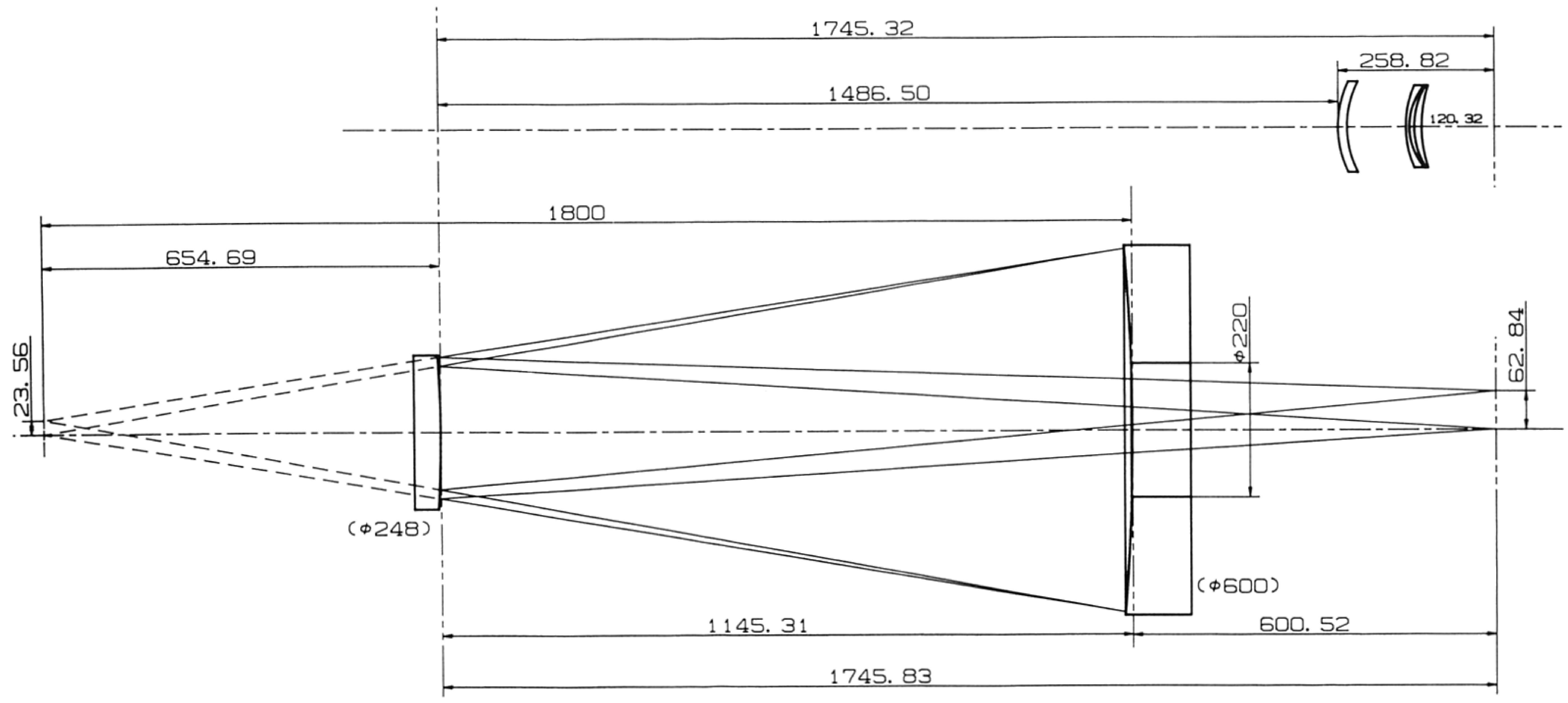

Fig. 2. Layout of the optical system of the 60 cm Ritchey-Chrétien telescope.

position of the seconsary mirror since it was the most conveinient to be set in replace of the plate holder.

Nevertheless the above limitted condition, it was quite fortunate that a Ritchey-Chrétien system of a typical configration was able to be installed. That is, an f/8 focus can be formed at a point backward by 60 cm from the vertex of the main mirror of f/3 (Table 1, Fig. 2). It is calculated by Bowen's formula (1967) that this configuration gives a flat focal plane of about 20 arcminutes in diameter within which size of stellar images does not exceed 0.5 arcsecond.

2.2. Corrector System

Various correcting systems have been devised so far to make the curved focal surface flat and to widen further the field of view of the Ritchey-Chrétien focus. Two-element systems comprised by spherical surfaces have been designed, giving field of view of about 1 degree (Wynne 1965, Rosin 1966). A successful example of this type is the corrector for the 150 inch telescope of KPNO (Wynne 1968).

Gascoigne (1965) has shown that further wide fields than the above can be obtained if an aspherical plate is introduced to suppress astigmatism. The figure of this correcting plate is similar to that of the Schmidt telescope. He has also suggested that a field is free from all of spherical abberation, coma and astigmatism if a correcting plate of this type is combined with a mirror system which is slightly modified from the original Ritchey-Chrétien one.

The idea of Gascoigne has been applied by Schulte (1966) to the 152 cm telescope at Cerro Tololo. The corrector system of this telescope is composed of a Schmidt type plate and a field flattener in front of the focal plane.

Optical systems of the 40 inch telescope and of the 100 inch telescope of Las Campanas Observatory designed by Bowen and Vaughan (1973) are also of a modified Ritchey-Chrétien type. The 100 inch telescope has a single aspheric correcting plate and therefore the focal plane is left to be curved. In the case of the 40 inch telescope, they suceeded in obtaining a flat field as wide as three degree with no flattener by setting the curvatures of the main mirror and the secondary mirror to be equal.

Focal ratios of the above mentioned telescopes are equal or close to 8 which is same as that of the telescope of the present work. We might select one of the above existing type of the optical systems for our telescope. However, rescaling the 100 inch telescope to a 60 cm telescope results in producing a focal surface with very large curvature which is incompatible with photographic plates. If the other systems with the flat focal surface are similarly rescaled, the back focus of the corrector system is found to be as short as 24 mm even in the longest case, i.e., in the case of the 150 inch telescope. Such a short length of back focus does not allow a small telscope not only to accomodate an aquisition/guiding assembly between the last surface of the corrector and the focal plane but even to attach

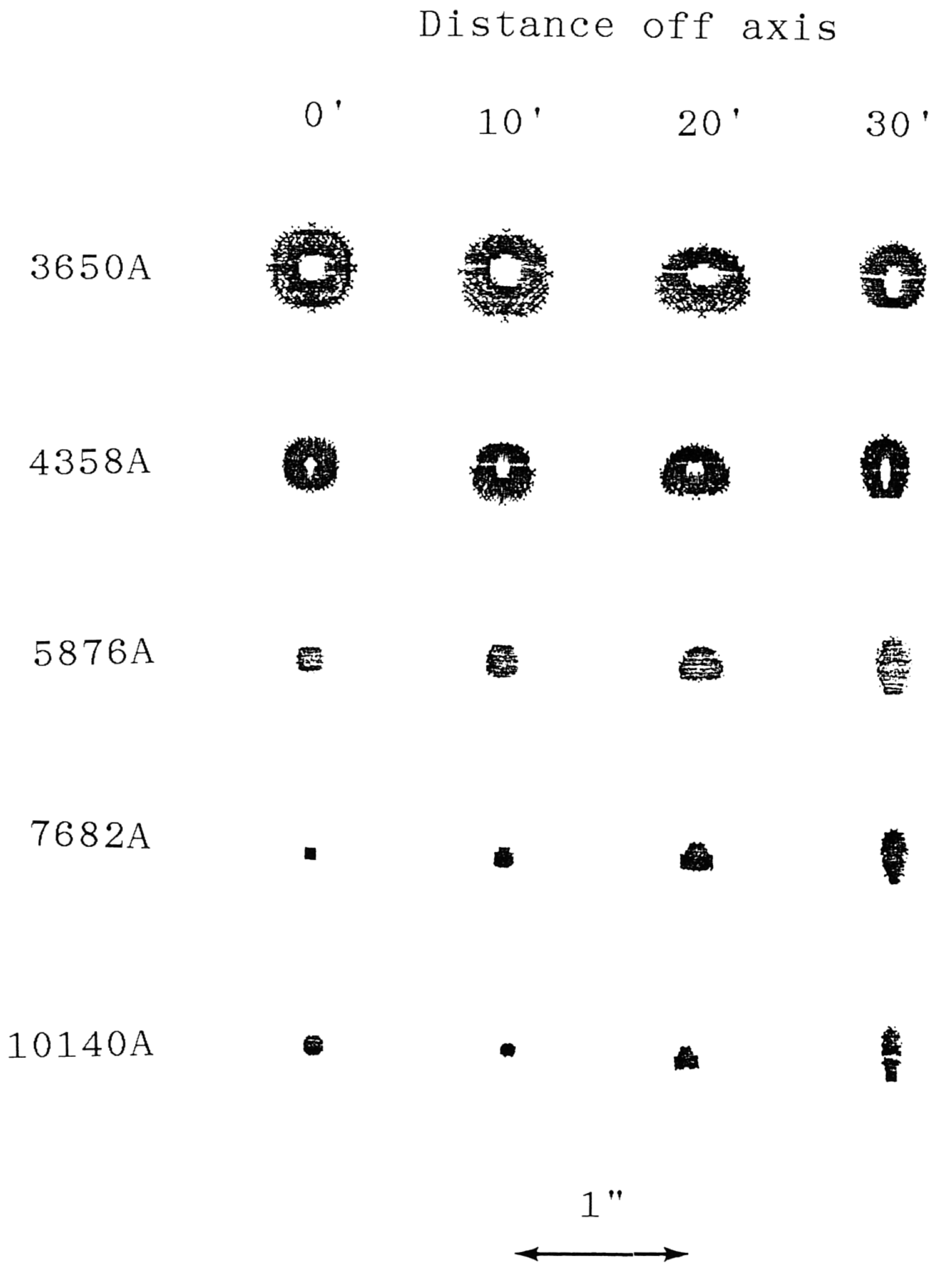

Fig. 3. Spot diagrams of the 60 cm Ritchey-Chrétien system with the one degree corrector.

more bulky instruments such as a CCD camera than photographic cameras.

In order to secure a much longer back focus than the existing type corrector, a three–lens system was examined. Considering easiness in figuring, designs with only spherical surfaces were considered. Material was assumed as UBK7 for good transmission for ultraviolet. For more details on the properties of the corrector of this type, readers should refer to Araya and Mitsutsuka (1990).

We manufactured a corrector which produces a flat focal surface of one degree. The formula of this system is given in Table 1. In Fig. 3 are shown the spot diagrams which were obtained by using a ray tracing program which was developed in this work. It is seen in Fig. 3 that the image size of a point source is smaller than 0.5 arcsecond over an optical wavelength region from ultraviolet to near infrared. It should be emphasized that we have succeeded in obtaining correctors having a back focus as long as 120 mm. A design of another corrector system which yields a plane focal surface as wide as one and a half degree is given in Table 1. A corrector of this design is to be polished.

2.3. Performance

Performance of the Ritchey-Chrétien system without the corrector was examined by means of the Hartmann test. Considering a fairly large fraction nearly up to a half of the diameter of the main mirror is covered by the cell of the secondary mirror, a triangular-grid distribution of the holes of the Hartmann screen was adopted rather than the classical radial distribution or than the modern square-grid distribution in order to project as many holes as possible over the clear part of the main mirror. Sixtyfour holes of diameter 24 mm were drilled on the screen. Exposures taken at points 30 mm off before and after the focal point give Hartman spots which do not interfare each other.

It has been recognized from simulation using the ray tracing program that even a slight deviation from the complete alignment of the mirror system causes an appreciable degradation of image quality. Taking this into cosideration, collimation of the two mirrors was made carefully as follows. At first, the secondary mirror was aligned to the axis of the telescope tube with aid of a laser beam. In the next place, the distance of the apexes of the two mirror was adjusted to the value specified by the design. Thereafter, the axis of the main mirror was so adjusted that the Hartmann constant was minimized.

To make adjustment in this way, we developed a system to perform Hartmann tests very quickly. A set of an inner exposure and outer one is performed by an integrating CCD video camera whose output is digitized and stored in a frame memory installed in a personal computer. The image data are processed in five minutes or so to give a Hartmann constant, a spot diagram at the point with the least dispersion and a diagram showing distribution of abberation vectros over the main mirror. Comparison of these diagrams with the results of the numerical simulation is very much useful to find how the axis of the main mirror is deviated from the axis of the secondary mirror. Then, the main mirror was corrected for the tilting by adjustment of the mirror support.

Thus, the optical system was aligned to attain a Hartmann constant 0.55. This implies that the image diameter is 1.1 arcsecond which is much smaller than the usual seeing size 2 to 3 arcseconds at the telescope site.

The corrector manufactured in the present work is of the type producing a one degree field as stated above. However, physical size of the lenses are extended to an aperture corresponding to one and a half degree. The insufficiently corrected outer part of the field is available for offset guiding.

The Hartmann test is inapplicable to the part of the focal plane off from the optical axis. Therefore, quality of the wide field image taken with the corrector was examined by eye inspection of stellar images on photogrphic plates. Satisfactory result was obtained over one degree field (Fig. 4).

3. Aquisition/Guiding Assembly

An aquisition/guiding assembly was constructed and was mounted on the back side of the main mirror cell. This brought additional benefit that we were allowed to make observation instruments free from loading aquisition/guiding systems.

This assembly consits of three parts, i.e., a movable small mirror, a relay optics and the re-imaging focal part. The mirror tilted by 45 degrees relative to the optical axis of the telescope is inserted immediately behind the last element of the corrector system. The mirror is movable in a plane perpendicular to the optical axis. Rays from any partial field of diameter of ten arcminutes are reflected by the mirror and introduced into a relay optical system. A transparent glass plate with an illuminated graticule is set at the focal plane of the reflected beam. The image of the partial field superposed with the graticule is re-imaged by the relay lenses at a fixed point relative to the mirror cell wherever the movable mirror is set in the plane behind the corrector.

When observer aquires a target object, the mirror is inserted on the optical axis of the telescope. After aquisition, the mirror is moved to an appropriate guiding star found in peripheral field of the object. Movement of the mirror is along right ascension and declination axe. The position of the mirror is displayed on a liquid-cristal panel attached on the telescope mirror cell. The resolution of the display is 0.05 mm, corresponding to 2.15 arcseconds.

At the re-imaging focal part, an eyepiece and a CCD video camera head are attached. Either eye monitoring or TV monitoring of the filed accessed by the inserted mirror is selected by turning a plane mirror. The CCD is thermoelectrically cooled in order to allow on-chip integration for five seconds or less.

4. Direct Imaging Cameras

4.1. Photographic Camera

A photographic camera with a 16 cm square plate is prepared for wide field observations. Glass fiters up to three can be inserted between the aquisition/guiding assembly and the camera. The plate scale is 43 arcseconds per milimeter. The field

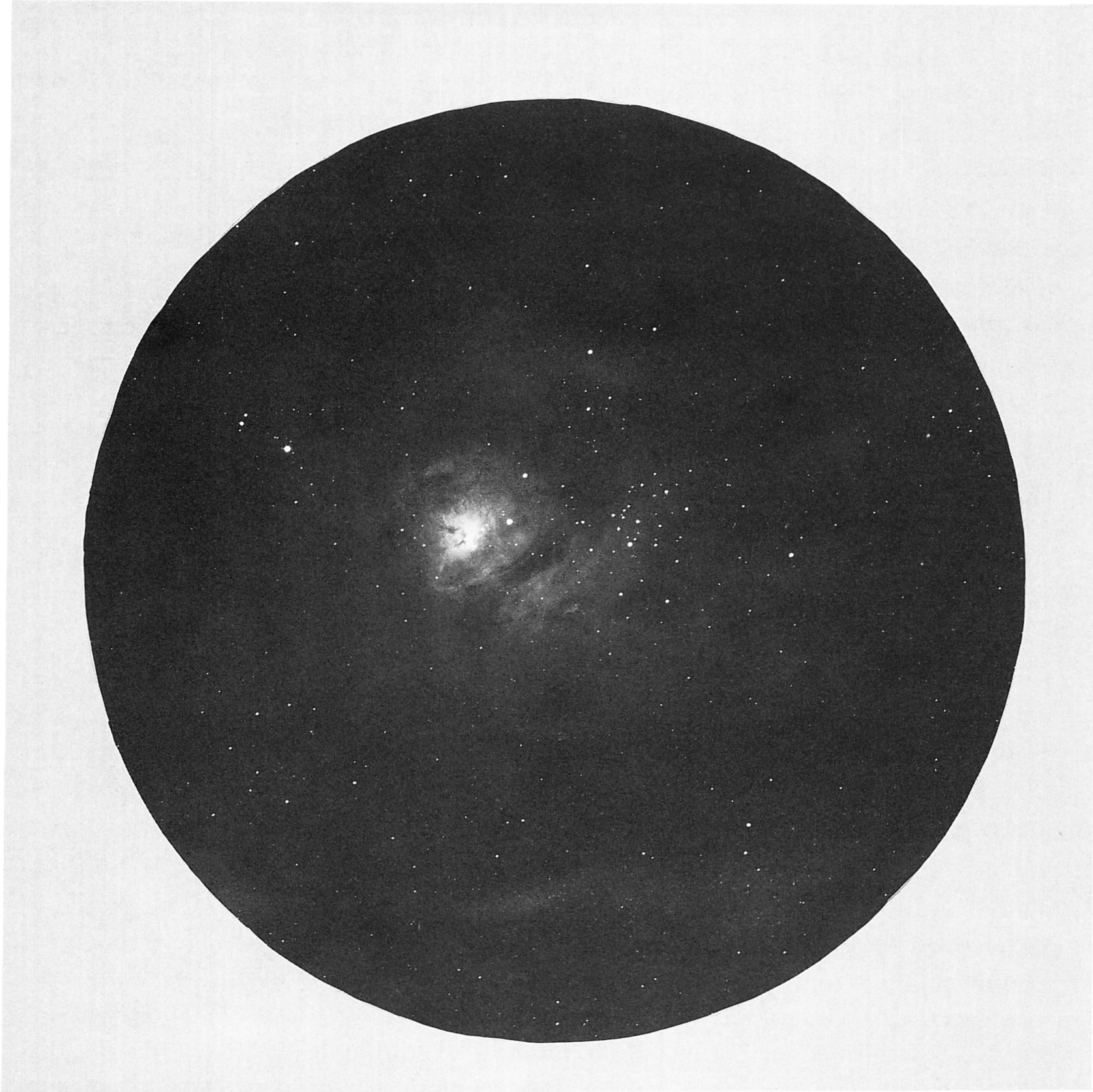

Fig. 4. Reproduction of a photograph of Messier 8 taken with 103*a*-E with a filter Hoya R64 to isolate Hα emission. The exposure time is 30 minutes. The field diameter is 1 degree with an original scale 43 arcseconds per milimeter. North is up and east to right.

coverd by the plates is 1.5 degree, although a field of only 1.0 degree is corrected for abberation by the current corrector. A reproduction of a plate of a wide field image is shown in Fig. 4.

4.2. CCD Camera

4.2.1. Hardware

A CCD camera of Series 200 of Photometrics Ltd. was introduced for the telescope (Fig. 1). A CCD of Thompson TH7882CDA in a cryostat is cooled down to $-120\,\mathrm{C}^\circ$ with liquid nitrogen. The pixel size is $23\,\mu$m square and the format is 576 by 384 to cover a 8.8 by 6.4 arcminutes field with a resolution of approximately 1 arcsecond per pixel.

The CCD is coated by Photometrics to have appreciable sensitivity in ultraviolet regions. The readout noise is as low as 7 electrons per pixel. However, to avoid loss of photoelectrons by the trap between the parallel register and the serial register, a preflash corresponding to 100 electrons is usually given for each exposure. Therefore, the noise is effectively increased to 12 electrons.

An electronic image made on the CCD is read out to be digitized into 14 bits at a rate of 50 kHz. Thereafter, the image is stored on the memory of the camera controller. The camera system is controlled by inputting various commands to the controller through RS232C or GP-IB, the latter of which is used also to transmit the image data to a host computer. A personal computer of NEC PC-9801 series has been connected to the GP-IB interface of the camera.

A series of wide-band filters was made so as to reproduce Johnson's system as possible. Taking into account the wavelength dependence of sensitivity of the CCD, interference band-pass filters for B, V, and I were designed, whereas a combination of colored glass filters was employed for R. The U band filter is a combination of a band-pass color filter and a $CuSO_4$ liquid filter which suppresses the red leak of the color filter.

Another series of narrow-band filters is prepared for the purpose to obtain emission line images of redshifted galaxies with recession velocities around 1,000 km/s. Filters tuned for the redshifted lines of [OII] λ3727, [OIII] λ5007, [OI] λ6300, and Hα + [NII] $\lambda\lambda$6548/84 are available. The bandwidths of these filters are from 70 to 100Å.

4.2.2. Obsevation Software

The Photometrics camera controller is equipped with a well developed software which consists of more than one hundred commands. Although observation can be pursued by sending sequentially several of these command to the controller, we have developed a computer program for more convenience in observation. This program consists of more than ten tasks each of which is selected to run on a menu on the console screen. These tasks are so developed that even a beginner can easily perform his or her observation interactively with the computer. The following are some examples of the tasks.

EXPOSURE

This is a task to obtain and to store an exposed image for a given exposure time. Some details of operation of this task is described below.

Immediately after selecting EXOSURE at the menu, the observer is prompted to key in an exopsure time. After confirmation of the input value, the system clears the CCD at first, then puts off the on-chip amplifier, preflashes and opens the camera shutter to expose the CCD to light. The observer is able to close the shutter whenever it is necessary to interrupt the exposure for some reason, say, passage of clouds. Thereafter, the observer selects either way to re-start exposure or to abandon to continue. In the case that the latter is selected, the system begins to read out the image as well as in the case that the exposure time programmed is over.

The image read out is automatically displayed at a video monitor for quick look of the result. The observer can evaluate the result by using a mouse or by inputing some graphic, statistics, or picture processing commands, each of which is selected on the computer screen. If the observer wants to evaluate extensively the result, he or she may select COMMAND mode under which any Photometrics command can be sent to the camera controller from the key board.

After evaluation of the result, the observer can store the image data in the FITS format on a hard disk. A serial number, some observation parameters such as exposure time, starting time, amplifier gain and so on are given automatically to the headder of the FITS files. Other parameters which are not sensed by the computer, i.e., object name, filters, and comments are input from the key board. Of course, the data can be discarded if it is unnecessary to be stored. Thus, the task EXPOSURE finishes and the system returns to the menu.

FOCUS

This task obtains and displays a series of several images of a partial frame of the CCD taken sequentially with a given exposure time. A part of the frame is determined on a test exposure prior to a series of exposures by using a box cursor on the video monitor so as to contain in the box appropriate star images for focus determination. In between every two exposures, there is a pause for a given time interval during which the observer can change the telescope focus. After finishing the all exposures, a series of the obtained images is automatically displayed on the monitor on which the observer can find the best image.

BIAS

This is to obtain and to store a bias frame or an average frame of two or more bias frames.

DARKS

This task is useful to obtain and to store a series of dark frames of a given integration time. In addition to the dark frames, an average frame of bias frames of a given number is obtained at the beginning, between each continual two dark frames and at the end of the task.

5. SPECTRONEBULAGRAPH (SNG)

For the purpose to obtain monochromatic images of line-emitting nebulosities such as galactic HII regions and active galaxies, we constructed a SPECTRONEBULAGRAPH (SNG), a system to opperate jointly the telescope drive and the CCD camera attached to a long slit spectrograph. The principle of SNG is essentially based on the spectroheliograph for observation of monochromatic images of the sun, and the structure of our system is similar to that of ASPECT of the AAT (Clark and Wallace, 1984).

The controller of SNG, a personal computer of NEC PC-9801 series, controlles the CCD camera and telescope as follows. An image of an extended object at the telescope focus is scanned by the slit of the spectrograph in the direction perpendicular to the slit orientation by movement of the telescope. The scan is step by step at a spacial interval, say, of the slit width. At each position where the slit is set, an exposure is given to the CCD camera. After each exposure, the CCD is read out and the data are stored in the computer memory. Thus, a set of two dimensional spectra is obtaind.

The set of the spectral data is re-arranged by data processing into a data cube, i.e., a three dimensional array of intensity of light; two of the three correspond to spacial coordinates of the celestial sphere and the other to wavelength (Fig. 5). From the data cube, monochromatic images of various emission lines and of continuum as well can be derived.

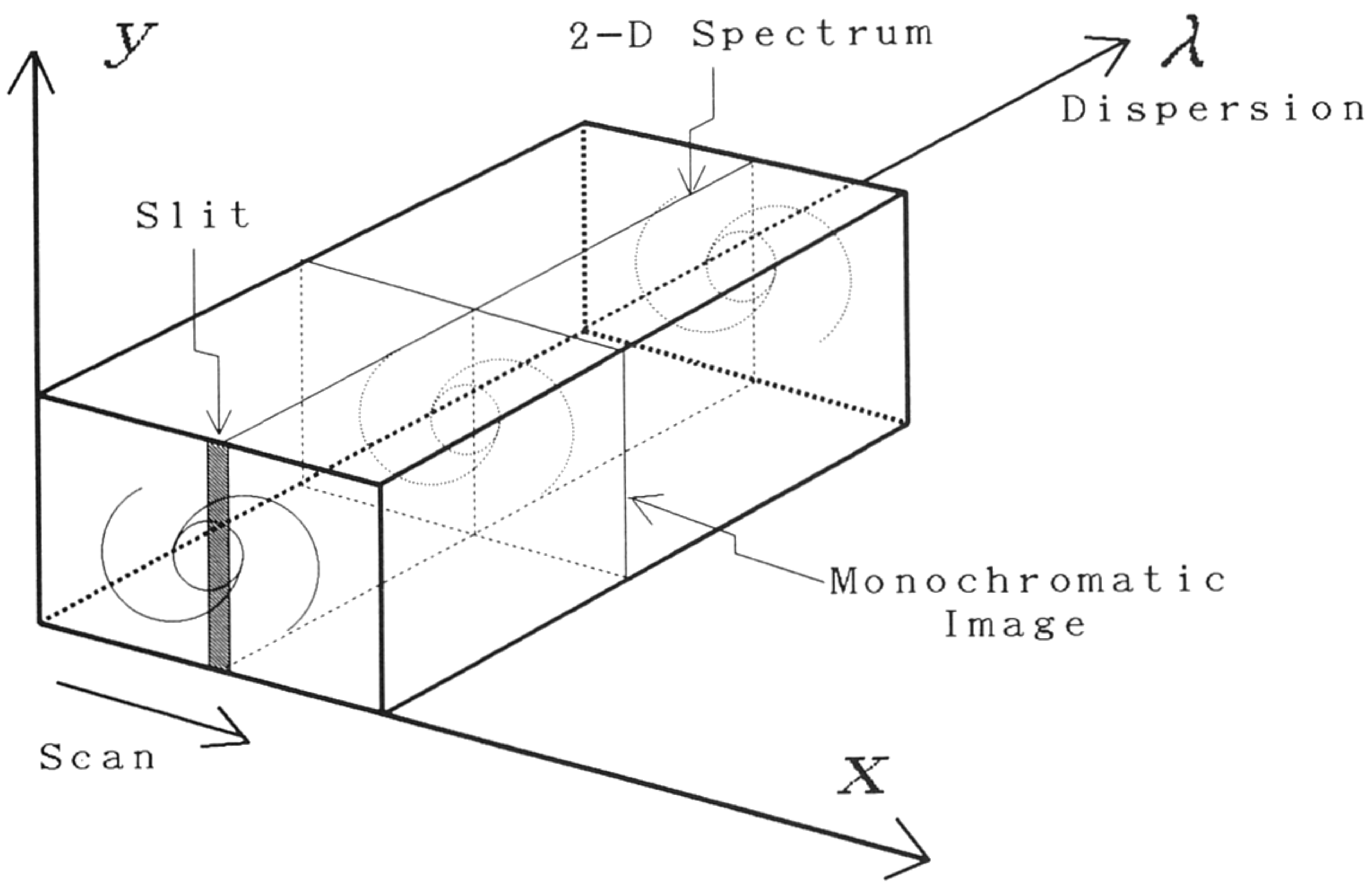

Fig. 5. Data cube obtained by SPECTRONEBULAGRAPH.

There are three advantages of SNG compared with currently existing means for observation of monochromatic images of extended objects, i.e., interference filter cameras and imaging Fabry-Perot interferometers. The primary advantage is the versatile flexibility of SNG. Since filtering for wavelength is digitally applied after aqusition of the all spectral data over the object image, suitable filters can be designed judging from inspection of obtained spectra. The flexibility also allows us to enjoy to observe images of any emission line for galaxies arbirarily redshifted.

The second advantage is that SNG can produce emission line images free from contamination of the continuum more accurately than the other means. This is possible by accurate subtraction of continuum contained in a passband for an emission line on the spectra. Inversely, continuum images free from emission lines can be also derived more accurately than by the other means.

The third advantage of SNG is that quite accurate distributions of relative line intensities over an object can be reproduced. This comes from the simultaneous aquisition of spectral information over a wide wavelength coverage for individual points of an object. Therefore, relative spectral intensity distribution is not seriously affected by changes of sky condition during a scan of an object.

An existing stellar spectrograph for another small telescope was remodeled so as to be suited to the new Ritchey-Chrétien telescope. All the optical elemtents except the grating, i.e., the slit, the collimator and the camera lens were relpaced with appropriate ones. The previous detector, a photographic camera with film, was also replaced with the CCD camera described above. The specifications of the spectrograph after remodeling are given in Table 2.

Table 2. Specifications of SPECTRONEBULAGRAPH

Spectrograph	
slit length	14 mm (9.3′)
slit orientaion	right ascension or declinaion
slit widths	0.043 mm (1.7″), 0.125 mm (5.0″), 0.250 mm (10.0″)
collimator	D=50 mm, f=170 mm, Achromat
grating	aperture 30×32 mm, 600 gr/mm, 7500 Å blaze
camera lens	f/1.4, f=85 mm (SMC Pentax)
spacial resolution	2.0″/pixel
spectral resolution	4.5 Å/pixel (1st order)
spectral coverage	2500 Å between 4000 Å (limit of the transimission of the camera lens) and 10000 Å (limit of sensitivity of the CCD)
Scanning	
direction	right ascension or declination
step	minimum 1″

Reproductions of images obtained by SNG observations are given in Figs. 6 and 7. The former is the Orion Nebula and the latter the Seyfert galaxy NGC1068.

It should be mentioned to the difference of SNG from ASPECT (Clark and Wallace 1984). SNG uses CCD as the detector, while ASPECT adopts an imaging photon counting device. Readout noise in photon counting is virtually zero and readout time is as short as a few ten miliseconds. These characteristics allow ASPECT to repeat many scans each of which is completed in a short time interval within which no appreciable change of sky condition occurs.

On the other hand SNG needs rather long dwell time at every slit position in order to reduce relative contribution to data from inherent read noise of CCD and also to total observing time from dead time of about ten seconds for readout. Therefore, SNG observations are easy to suffer from variations of sky condition during a scan over an object. However, appropriate data processing of a pair of scans whose direction are orthogonal each other could reproduce relative brightness distributions over an object free from effects due to variation of sky across the object. A reduction program to overcome the problem by this method is under development.

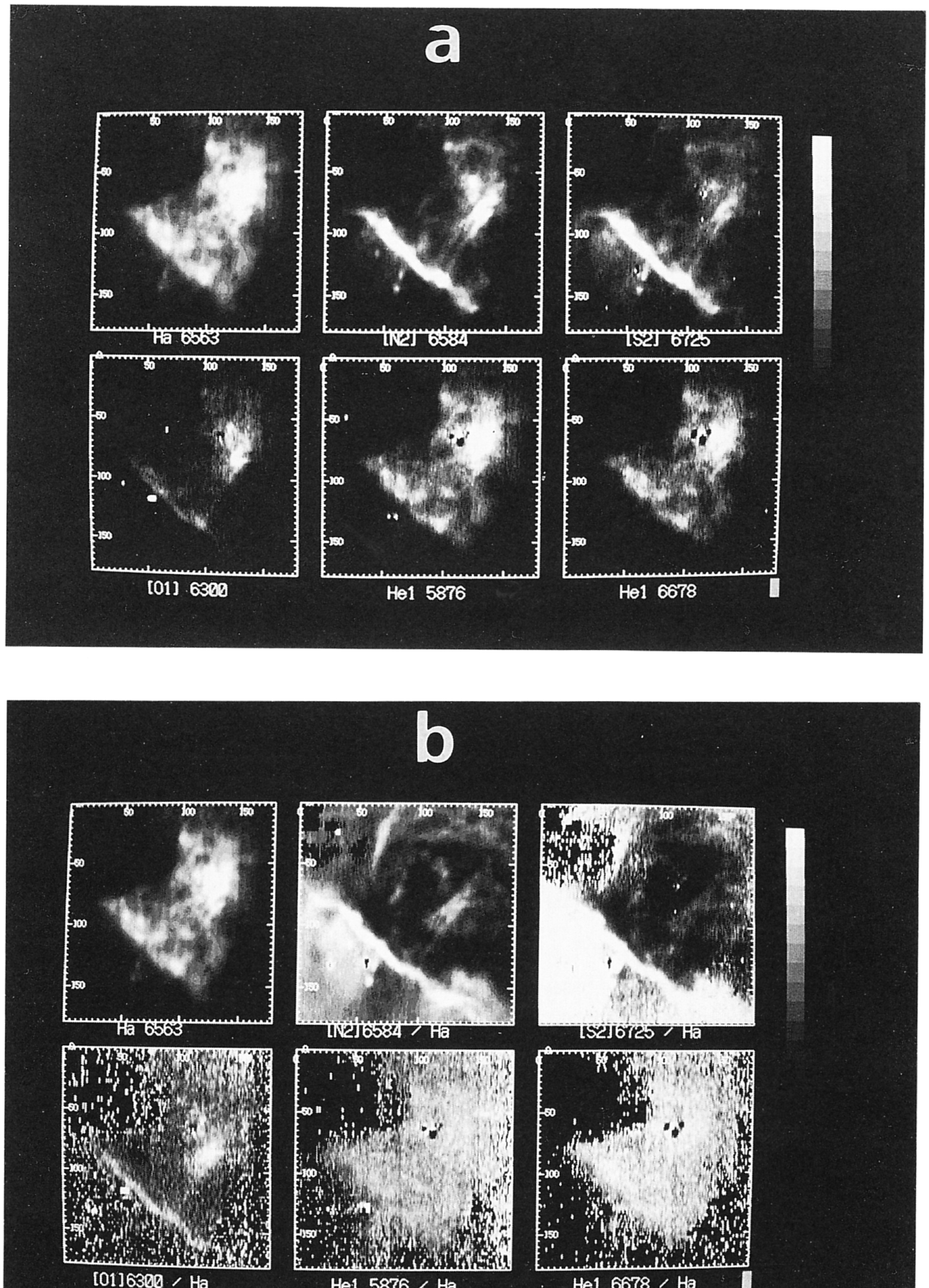

Fig. 6. Images of the Orion Nebula observed by an SNG observation. Figure *a* shows monochromatic images of emission lines H$\alpha\lambda$6563, [NII]λ6584, [SII]λ6716/31, [OI]λ6300, HeIλ5876, HeIλ6678. Figure *b* shows images of distributions of the relative line intensities derived from the above images. The upper left image is the same as that of figure *a*, but the others show intensities of the respective lines relative to Hα. The dwell time for exposure at each step of the scan is 2 minutes.

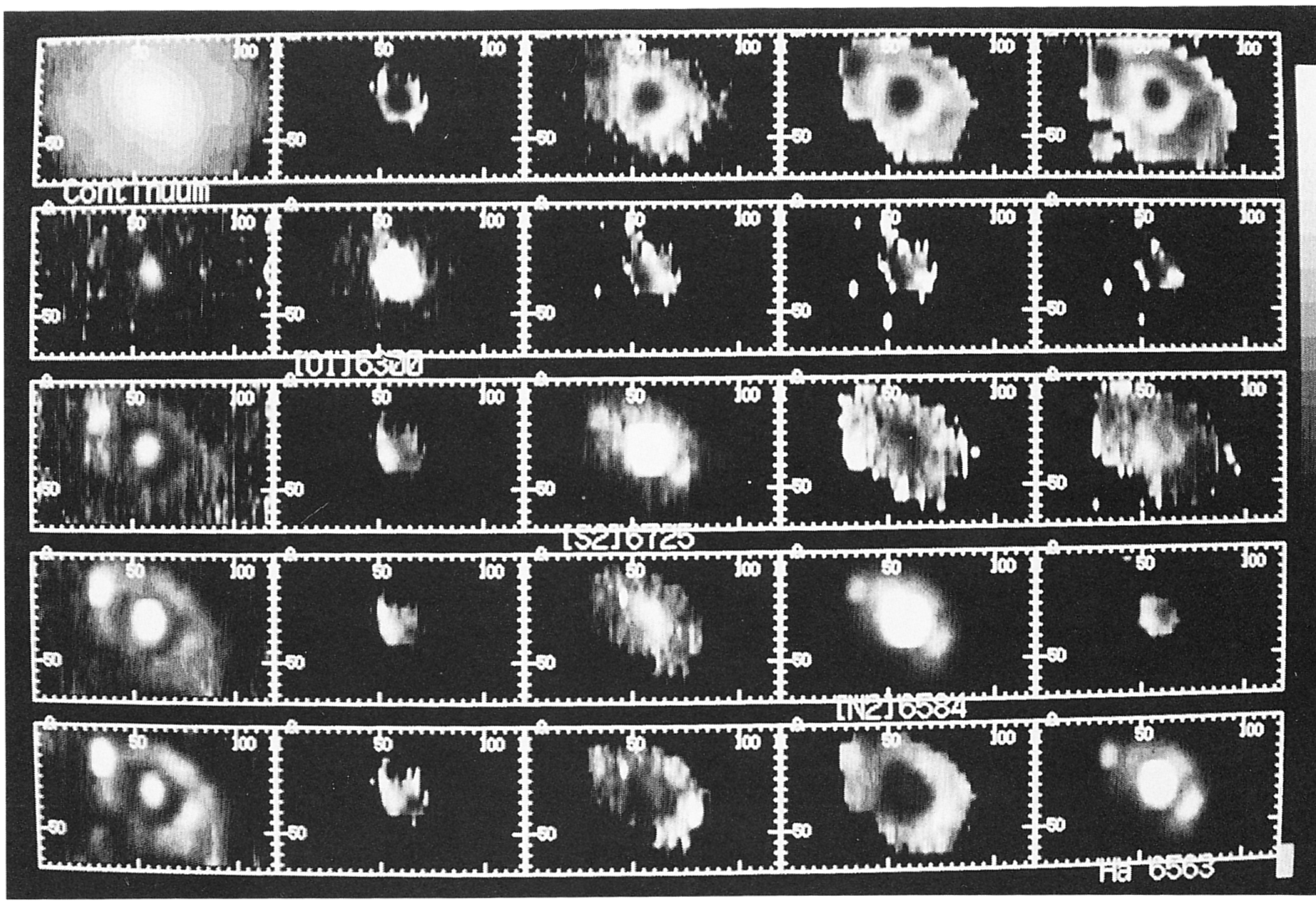

Fig. 7. Monochromatic images of the Seyfert galxy NGC1068 are shown along the diagonal of the picture matrix. They are, from the upper left to the lower right, images of a red continuum, [OI]λ6300, [SII]$\lambda\lambda$6716/31, [NII]λ6584, and H$\alpha\lambda$6563. The other images are of relative intensities to one another. The matrix is so ordered that the upper right image is of the continuum divided by Hα, the lower left is of Hα divided by the continuum, and so on. Exposure for each step in the SNG scan is 25 minnutes.

6. Multi-object Optical-fiber Photometer (MOP)

A wide field of view is useful for observation of fast light variations of celestial objects, for it is possible to measure a target object simultaneously with reference objects seen in the same field of view. From this standpoint, a multi-object photoelectric photometer has been developed after Walker (1984).

This apparatus has four beam channels, each of which corresponds respectively to a target object, the sky background, and two comparison stars. Flux of light through each channel is measured sequentially in a short time interval to obtain a set of quasi-simultaneous measurements. The photometer consists of five units, i.e., a manipulator, a set of four fiber-optics assemblies, a light detection unit, pulse counting electronics and the host computer (Fig. 8).

The manipulator is attached to the focal part of the telescope. An xy-stage on which a finger is mounted on each of the four sides of the base plate of the manipulator. Any point in a half area of the focal plane is accessible by one finger tip where a diaphragm plate is installed. One of three diaphragms corresponding to 10, 13 and 26 arcseconds is selected. Setting the finger is made by moving the xy-stage so that a star is seen in the diaphragm by inspection through a movable

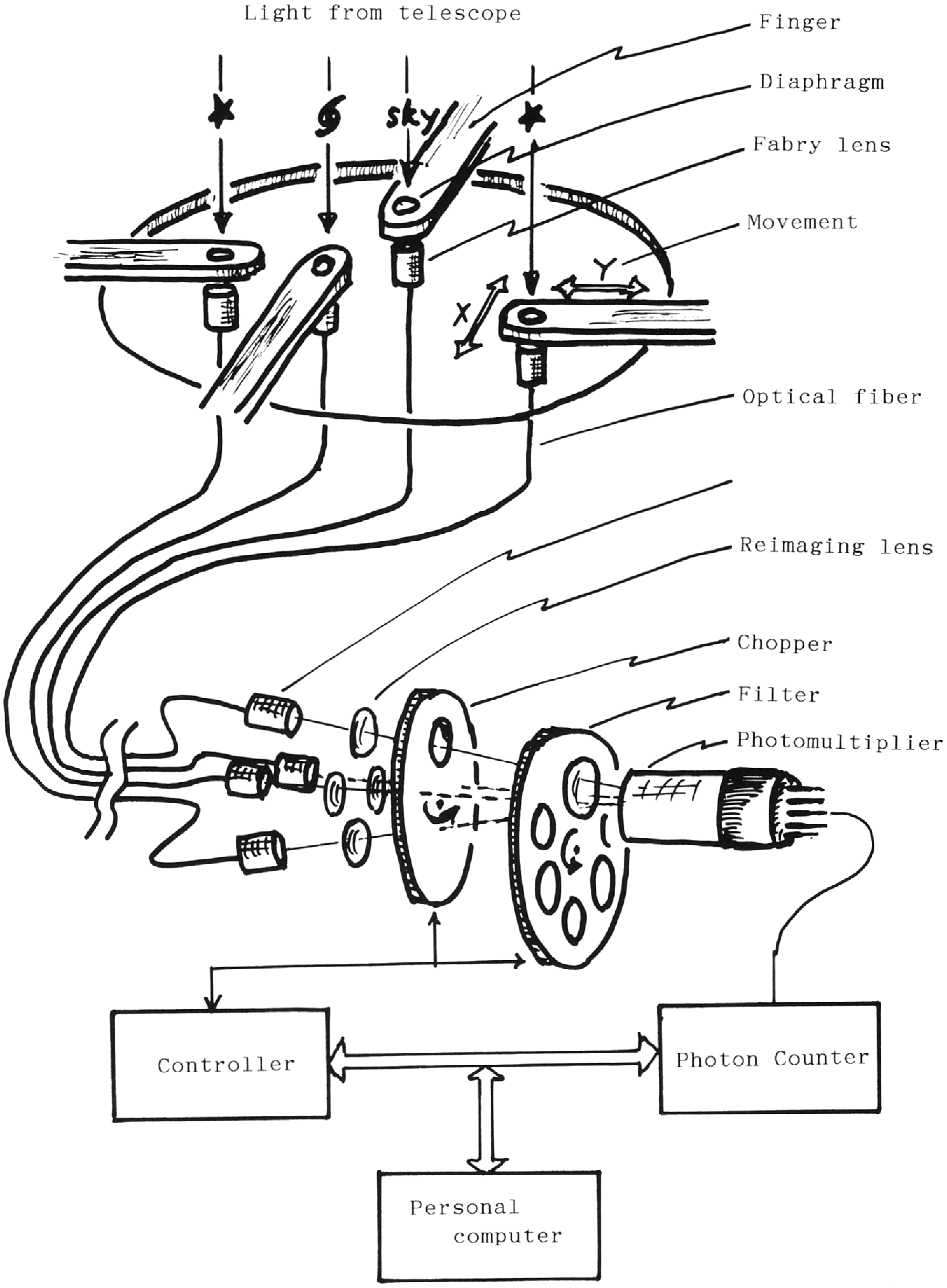

Fig. 8. A sketch of the concept of the multi-object optical-fiber photometer.

eyepiece attached on the manipulator. Thereafter, a fiber-optics assembly described below is inserted into a sleeve behind the diaphragm (Fig. 9).

Each fiber-optics assembly consists of a Fabry lens, an optical fiber, a collimator lens and re-imaging lens. We used a SELFOC micro lens (a rod lens with variable refractive index with radius) as the Fabry lens. The diameter of it is 2 mm. The pitch of the SELFOC is selected as a quater in order to make the exit pupil of the main mirror at the exit surface of the rod lens. The effective focal length is 2.59 mm, the diameter of the pupil being 0.324 mm.

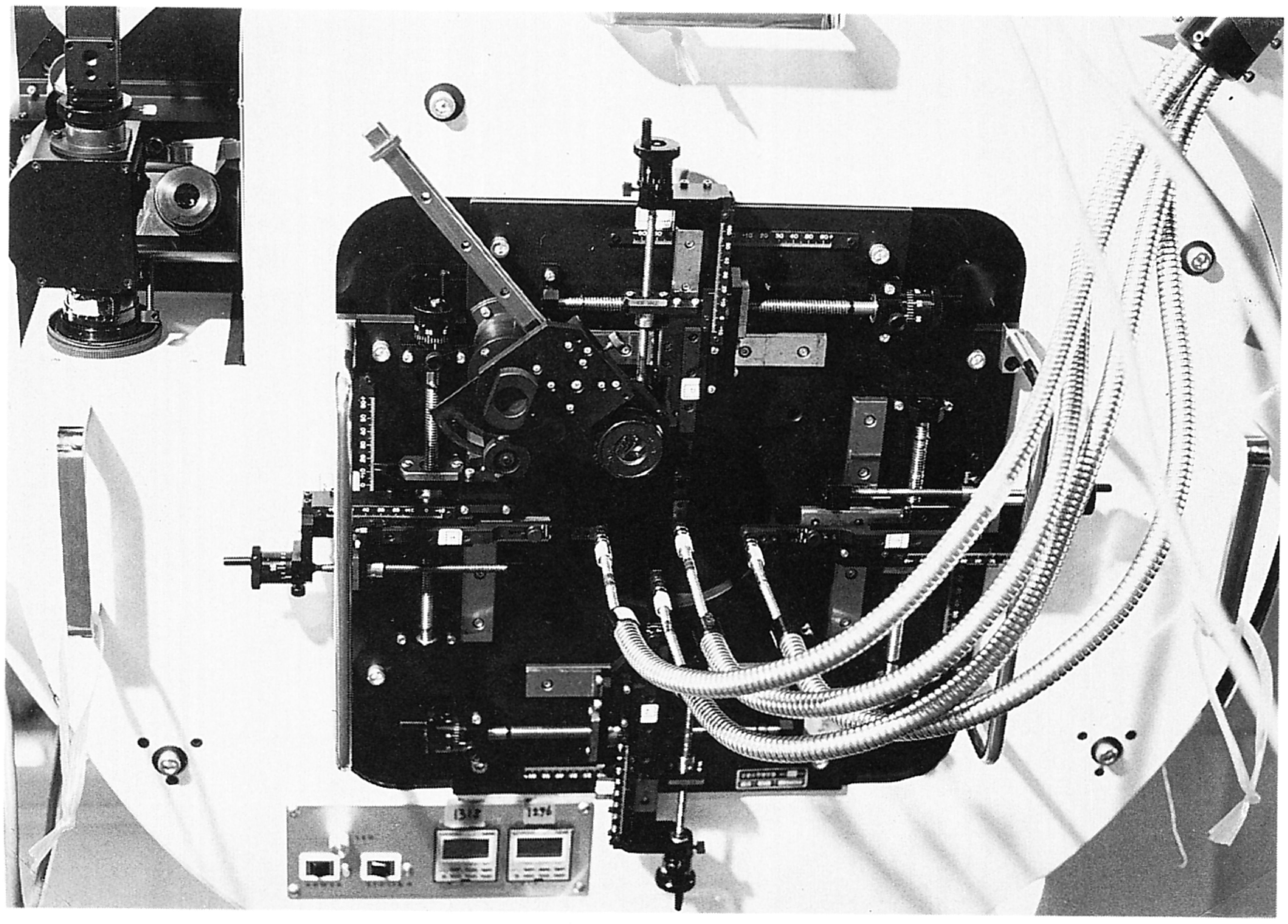

Fig. 9. The manipulator with the four fiber-optics assemblies.

An optical fiber is connected in contact with at the end of the SELFOC. The fiber, Mitsubishi DIAGUIDE ST400E-SY, is of step-indexed type whose core radius and the numerical aperture are 0.4 mm and 0.2, respectively. These parameters imply that whole beam through the exit pupil made by the SELFOC is accepted by the fiber. The length of the optical fiber is 1 m.

Due to modulation in transmitting through the fiber, the beam is expected to be distributed uniformly over the whole cross-section of the core at the exit end of the fiber and to divert within the numerical aperture of the fiber. In order to collect the divergent beam, another SELFOC of the same type as the Fabry lens is connected to the exit end of the fiber. Since the beam is incident into the SELFOC at its focal plane, the SELFOC collimates the beam. However, it is not completely parallel because of the finite core size of the fiber. Therefore, a small lens is set in order to project the image of the exit surface of the collimator onto the photocathode of a photomuliplier.

In the light detection unit, the four fiber-optics assemblies described above are bundled at the part of the re-imaging lenses so in a converging manner that the all four images are projected on a same place of the photocathode. Between the re-imaging lens and the photomultiplier, a chopper and a filter turret are inserted. The chopper is a rotatable circular metal disk with a hole which allows only one beam at a time. A filter turret which can accomodate six filters is inserted between the chopper and the photomultiplier.

It should be noticed that any diverting beam incident into the SELFOC from an arbitrary point of the cross-section of the exit end of the fiber is converted into a collimated beam which passes a fixed area of the exit surface of the SELFOC, because its pitch is a quater. The illuminance of the area is expected to be uniform since the illuminance of the exite surface of the fiber is expected the be uniform as mentioned above. Therefore, the distribution of the illuminance at the photocathode is not changed with change of the position of a stellar image within the input diaphragm at the focal plane of the telescope. Thus, a quasi-pupil is formed on the photocathode.

The photomultiplier, Hamamatsu R943–02, cooled with dry ice is capable for observation in Jhonson's UBV and Kron's RI. The output is measured in photon counting mode. A pulse counting system for nuclear physics experiments is adopted. The band width of the system is 100 MHz.

The counter, the chopper and the filter turret are controlled by the host computer through GP-IB. Counts for one tenth of a second at every one second can be read out from the counter by the host in the fastest mode, while it requires about five seconds to change the combination of the beam and the filter. For observatons, a sequence of various combinations of the beam, the filter and the integration time is programable at the host computer.

The performance of this photometer is demonstrated in Fig. 10 with a result of a test observation. In this observation, a target object ι Boo ($V = 5.3$, nonvariable) was monitored relatively to two nearby comparison stars seen in the same field for one and a half hour. The raw counts from the four beams at every 10 seconds are plotted in the upper figure, ι Boo giving the secondary highest counts and the sky the lowest. The counts of the three stars show deep depressions due to passing clouds across the observing field, while sky level was somewhat raised.

However, as is seen in the lower figure, the ratio of the counts of ι Boo to those of the brighter comparison star (both subtracted the sky counts) is found to be constant within a few tenths of one magnitude. Moreover, the average of the relative magnitude for every ten minutes interval is as stable as within much less than 0.1 magnitude. Thus, with this photometer, observation of variable objects could be well performed even under nonphotometric sky condition.

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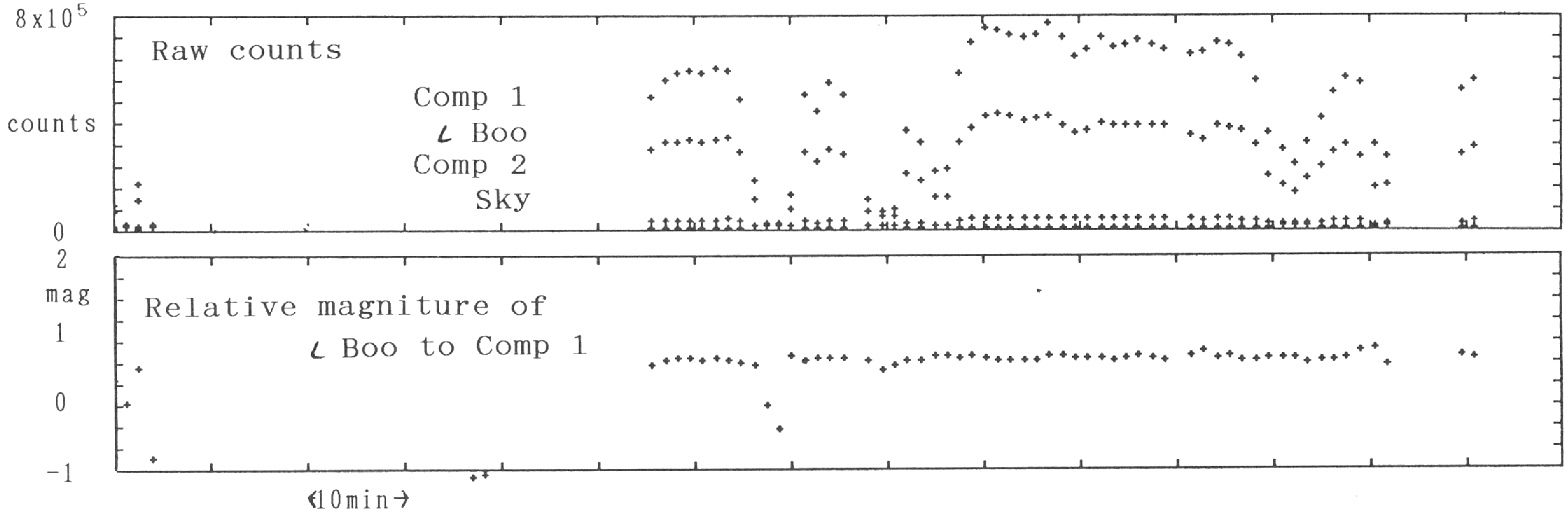

Fig. 10. An example of observation made with the multi-object optical-fiber photometr. In the upper diagram, raw counts of ι Boo ($V = 5.6$, nonvariable) are plotted together with those of two comparison stars and sky in a focal plane. The counts are heavily affected by passage of clouds, while magnitude of ι Boo relative to the brighter comparison star is scarcely affected.

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