A STUDY OF THE OBSERVATIONAL PERFORMANCE OF THE WILLIAM PITT 27-INCH TELESCOPE

by

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INTRODUCTION

Modern astronomical research depends primarily upon the observation of celestial objects such as the moon, the sun, the planets, meteors, comets, stars and nebulae. Theoretical and laboratory research lend invaluable aid in interpreting what is observed. Theoretical work is frequently a guide for organized and systematic observation. Again, history has shown the need for testing advanced theoretical reasoning by direct observation. Indeed, some observational data are needed before any theoretical research can be attempted. Astronomical study is quite dependent on the accuracy and power of observation.

Astronomical observations may be performed with the most diverse equipment known to science. Valuable contributions may be made with the unaided eye of meteors, comets, and novae (temporary stars which burst forth occasionally to naked eye brilliance). At the other extreme, studies of the most remote spiral nebulae and spectra of very faint stars are possible only with the largest telescopes whose cost of production approach and exceed a million dollars. In the former case valuable service is rendered to the professional astronomer by reliable amateurs. However, such research is quite limited. Discoveries of comets and novae must be followed by study with elaborate equipment. In the latter case, the largest telescopes, which are very sensitive to atmospheric conditions and temperature, are quite unsuited for many kinds of astronomical investigations because they are too large. Indeed, most astronomers expect the new 200-inch telescope to be confined to a few special fields of study in its usefulness. We seem to have here the Law of Diminishing Returns coming into play.

Experience has shown that telescopes with apertures from 20 to 40 inches arequite ideal for many kinds of astronomical work. However, if they are located in stormy regions, or on low land where disturbed air and haze prevail, or if situated where they are subjected to flashing air-way beacons, glaring street lights and car lights which rapidly fog very sensitive photographic plates, such telescopes cannot do very much useful work and cannot compete with those which are more favorably located.

There are two kinds of telescopes used in astronomical observations. One kind is the refractor which employs an achromatic objective to converge parallel rays of light. The other kind is the reflector which uses a concave mirror to bring parallel rays of light to a focus. The latter has the advantage in that only one optical surface needs to be ground, polished and figured. Moreover, high-grade-optical glass is not needed. Hence, the cost of producing a reflector is much less than that for a refractor of the same size. The reflector by nature is perfectly achromatic. The reflecting coat produced by the modern aluminizing process reflects 89% of the incident light in the visual part of the spectrum. Moreover, the reflectivity of an aluminum coat is high in both the ultra violet and infra-red. Herein is the great advantage of the reflector over the refractor.

Two kinds of driving are used on modern, equatorial telescopes. One kind makes use of the gravity clock, which with its gears for reducing speed from a rapidly whirling governor, is propelled by the running down of heavy weights. The other kind uses an electric motor which is likewise equipped with a complicated set of reducing gears. It is kept at the right speed by electric control from a sidereal clock. Each kind has technical advantages and disadvantages.

BRIEF HISTORY

OF THE WILLIAM PITT 27-INCH TELESCOPE

CONSTRUCTION OF THE WILLIAM PITT TELESCOPE

The large telescope located on the campus of the University of Kansas is the result of a dream by a former member of the faculty, Dr. Dinsmore Alter, who was then Professor of Astronomy. It was his plan "to obtain an observatory and a computing staff, to work principally on the asteroids which already had been discovered". He felt that such an institution was needed in this country. Although the computing bureau which he had in mind did not materialize, yet the telescope has now reached completion. Dr. Alter intended to photograph various asteroids, measure their positions very accurately and check their ephemerides with the view of improving their orbital elements. For this kind of work the telescope is admirably suited.

Back about 1926, Dr. Alter was introduced to Mr. William Pitt, who showed great interest in the proposed telescope. The grinding engine for the mirror was built in the Anderson-Pitt shops in Kansas City, and the grinding, polishing, and figuring was done in Mr. Pitt's emptied swimming pool. Mr. Pitt's skill as an optician resulted in the production of a very fine mirror.

The mirror is a moderately large one, having a diameter of 27 inches. It is nearly 4 inches thick and weighs about 200 pounds. The surface of the mirror was ground to a radius of curvature equal to 297 inches. For parallel rays of light, this curvature gives a focal length of about $148\frac{1}{2}$

inches. The ratio of aperture to focal length is 1:5.5, which is about the ratio customarily given reflecting telescopes. The sagitta of the curve, or the depth of the center of the mirror below its edge, is equal to 0.31 inches. The mirror is made of "Pyrex", which has a very low coefficient of expansion. Dr. Alter was quick to realize the advantage of using a mirror made of this substance in that it would greatly reduce the troublesome disturbance in figure resulting from the considerable changes of temperature, such as occur in Kansas. It is interesting to note that this was probably the first large telescope concave mirror to be made of Pyrex. Also, that the giant mirror of the new 200-inch telescope (not yet completed) is made of Pyrex. So it might be said that Dr. Alter was a pioneer in the use of Pyrex mirrors for astronomical telescopes.

The general design of the telescope was Dr. Alter's, but all of the dimensional design was done by Mr. Manley Hood, who at the time was a student in Mechanical Engineering. The patterns were all built at the University, and all but two of the castings were made here. Those two were made in Kansas City. So it may be said that the telescope is home-made.

Final completion of the telescope was greatly delayed because of lack of funds during the trying years of the depression.

The William Pitt 27-inch telescope is equipped with a modified Gerrish electrical drive and control. Mr. William

Edson, a student in Electrical Engineering, made a study of the electric drive in his Master's Thesis in 1935. He added an original slow motion attachment which operated through the Gerrish Drive. This was later found to be inadequate, but Dr. Storer made changes in the connections so that it now operates satisfactorily. A little later a motor-generator was installed to run the motor on the telescope drive.

In 1935, Dr. Alter obtained a year's leave of absence from the University of Kansas. A year later he resigned to become the Director of the Griffith Observatory and Planetarium in Los Angeles, California.

In the fall of 1935, Dr. N. Wyman Storer took Dr. Alter's place in teaching Astronomy at the University. After Dr. Alter's resignation the following year, the future of the telescope and its use passed into the hands of Dr. Storer. One of the first things he did for the telescope was solving the problem of a suitable cover for the mirror. Since the inside diameter of the tube was only 1 1/4 inches greater than the diameter of the mirror, it was apparent that the cover would have to be made so as to fit closely to the side of the tube during observation. In May, 1937, he designed and had constructed, a cover of ½ inch wood in five longitudinal sections hinged together, which folded up into a concave cylinder against the inside of the tube when the telescope was to be used. A system of springs and strings performed this act automatically, and so well that scarcely any of the mirror surface is hidden from a star.

This cover fits tightly against a cylindrical wooden pot nearly five inches deep, which in turn fits fairly tightly to the edge of the mirror. Both top and bottom of the pot is lined with felt so that close contacts are made with the edge of the mirror and cover, thus excluding dust from the mirror's surface when not in use. The pot reduces the aperture of the mirror by one half inch, but this is no loss as the figure of a narrow zone at the very edge is usually not so good.

In July, 1937, Dr. Storer sent the mirror out to California. There it received a beautiful reflecting coat of aluminum by Dr. John Strong, independent inventor of the aluminizing process for mirrors, and an alumnus of the University of Kansas.

The problem of a suitable observing platform on which the observer could work at the primary focus of the telescope was complicated by the cone-shaped dome and its light structure. The question whether the lower wall would stand the additional weight was troublesome. Yet there seemed to be no other convenient way. Accordingly, Dr. Storer designed a platform built on the lower ring of the dome and revolving with it. A prop placed under the floor at one point seemed to give the necessary additional support. The observing platform was built in April, 1938, and has since proved satisfactory.

OBSERVATIONS MADE WITH THE WILLIAM PITT TELESCOPE PRIOR TO SEPTEMBER, 1938

No provision had been made up to this time for visual observations with the 27-inch. The first observations were photographic. The plates then as now were placed in a box suspended in the center of the upper end of the tube by a "web".

In August, 1934, before the mirror was aluminized, Mr. James Brown Edson, a student in Astronomy at the University, was anxious to do something with the new telescope and attempted photographing the Moon. Although only about 5% of the incident light is reflected from a glass surface, yet the Moon's image on the plate was bright enough to be recorded in a second or two of time. The writer found 13 of these negatives in a box and several of them are of excellent quality, comparing quite favorably with photographs of the moon taken in the primary focal plane of the 24-inch Lowell Refractor at Flagstaff, Arizona.

On December 12, 1937, Dr. Storer and Mr. James Edson made a 25 minute exposure on the Orion nebula. The mirror was now aluminized. However, the work had to be done on a ladder as the observing platform had not yet been built. Unfavorable circumstances prevented getting the plate-holder in good focus, and the seeing was very unsteady; there were no facilities for guiding. The exposure brought out the faint nebulosity fairly well, but the star images were diffuse.

On January 4, 1938, Edson made two exposures on the Pleiades. The first one was a 30 minute exposure, but the images of the stars were badly trailed, because there was no way of watching a star during the exposure, and the Gerrish drive seems not to have been working properly. The second exposure was 14 minutes long, but the stars were somewhat out of focus. Nevertheless, it was a fair photograph compared to the first one. The drive seems to have been working better as the images are fairly round.

On May 8, 1938, Dr. Storer made two Hartmann plates with which he made a provisional test of the mirror's figure under working conditions.

On May 9, 1938, Mr. R. Stanley Alexander and Dr. Storer took two photographs each of the moon with an improvised focal plane shutter whose frame was attached to the plate-holder box. On May 14, 1938, they took 13 photographs of the lunar eclipse; most of them were of pretty good quality.

EXISTING DEFICIENCIES IN THE WILLIAM PITT TELESCOPE AT THE BEGINNING OF THE SCHOOL YEAR, SEPTEMBER, 1938.

1. Although the Gerrish drive by this time was working fairly well, no "button control" had been made to alter the rate of the driving clock. Adjustment is needed in long exposures to correct for refraction and irregularities in the driving rate.

2. There was as yet no device or means by which a star could be watched for guiding the telescope on long exposure

photographs.

3. A salvaged U. S. Army periscope had been obtained by Dr. Alter several years before for the purpose of examining the focus with the knife-edge test. Only a very small amount of the mirror's surface could be seen with it. Then, too, it had to be fastened along one radius of the web, and the barrel being about $1\frac{1}{2}$ inches in diameter all along the radius, it obscured an appreciable area of the mirror unnecessarily. In more ways than one the periscope was unsatisfactory, but it was the only way of testing for the focus prior to taking photographs.

4. There was no way of keeping the plate-holder box at a constant orientation. Every time the focus required slight changing, the plate-holder box could be re-oriented carefully only by tedious measurement of the distance from the sides of the box to the side of the tube.

5. All of the controls for manipulating the telescope were situated near the bottom of the tube, and quite inaccessible for work at the focus near the upper end.

6. The dome could be revolved only from the floor by a dangerous knife-switch fastened to the lower wall.

7. There was no light shutter to begin and end exposures. Pulling out the slide in the plate-holder causes small, jerky movements of the telescope, consequently giving star images a trail of wiggles. The slide must fit fairly tightly to be light-proof. To dodge this trouble the observer had to reach into the tube and hold a large card in front of the plate to

shield it from the motion caused in pulling out the slide. After waiting a few seconds for the vibrations to damp out, the observer withdrew the card and the exposure began. Because of the numerous struts of the tube, care had to be taken in removing the card. With two hands so occupied it was difficult to time the exposure exactly. In finishing the exposure the observer had to reach in with his card again and shield the plate before he dared to insert the slide. Finding the right place to insert the slide was not easy in the dark.

8. To make matters worse, cars would suddenly swing around the curve and shoot their lights into the dome without much warning, thus fogging the plate before the observer could reach in to shield it. The number of car lights flashing into the dome from the various roads to the intersection near the observatory amounts to about 15 or 20 in the course of a half hour on a moderately quiet evening on the campus. Naturally such circumstances were very disheartening.

9. To develop the plates safely, one had to climb down a ladder into a small, enclosed room below the dome housing the 6-inch refractor. The place had no running water, so necessary in photographic work, and all solutions and washing water had to be carried down the ladder. Moreover, the place was prone to acquire dust and cobwebs, as it was not suited for janitor service.

So it is seen that much improvement was needed before the telescope could be pronounced ready for use.

THE CONSTRUCTION OF APPARATUS DURING THE YEAR
SEPTEMBER, 1938 TO JUNE, 1939

CHANGING OF THE TELESCOPE CONTROLS

In September, Mr. Page changed the Right Ascension and Declination slow motions and clamps so they could be operated from the upper end of the t elescope.

The polar axis was found to have become so stiff that one could hardly move the telescope. After much work by various helpers, it was made to move very easily and smoothly.

THE 5-INCH OPTICAL FLAT MIRROR

It has been stated that there was no way of watching a star for guiding during the exposure. Most of the large reflecting telescopes are of Newtonian form, in which a "diagonal flat" mirror is used to intercept the converging cone of light so that the rays come to a focus at the side of the tube. There the images of celestial objects can be conveniently examined photographically or visually. The distance inside the focus at which a diagonal flat is placed should be about two inches greater than the radius of the tube. It is customary to guide Newtonian reflectors by setting an eyepiece on some faint star which happens to be just off the field covered by the plate.

The Observatory has a circular 5-inch flat mirror, which was aluminized by Mr. Stanley Alexander in Blake Hall in the spring of 1938. The writer made a short study of the feasibility of using this mirror for a diagonal flat and converting the 27-inch telescope into Newtonian form.

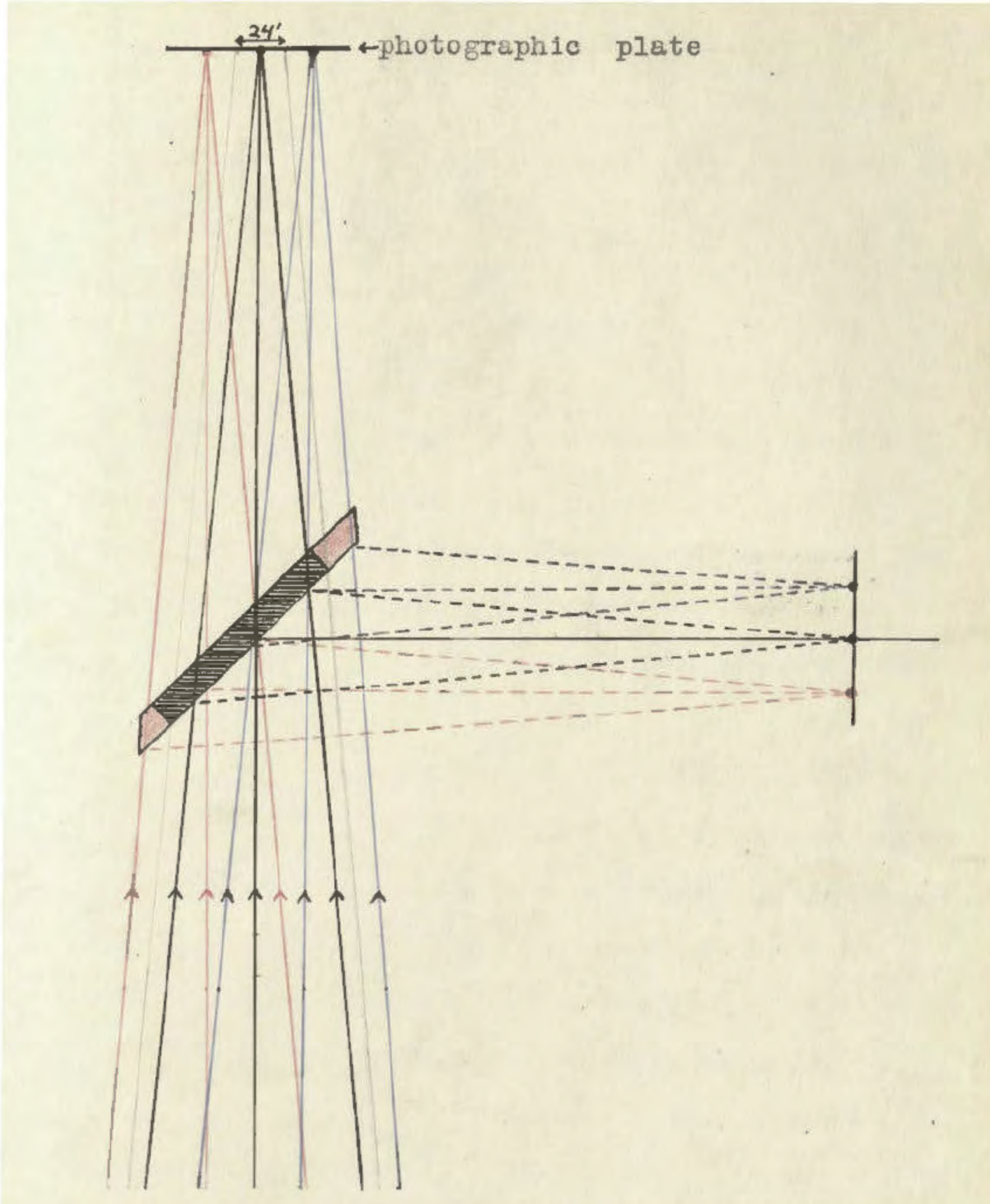

Figure 1. Diagram showing the relationship of the converging beams of three stars to the diagonal flat placed 14 inches inside the focus.

Scale : 1/4 th actual size .

In Figure I, the black lines indicate the converging paths of two rays striking the opposite edges of the mirror coming from a star in the direction of the principal optical axis. The red and blue lines indicate similar paths for two stars in the directions $\frac{1}{2}^{\circ}$ to the right and left of the principal optical axis, respectively. (A concave mirror inverts the image.) The dotted lines indicate respective paths when a diagonal flat mirror is used to reflect the light rays to the side of the tube. The shaded portion of the diagonal represents the actual 5-inch flat mirror. The red-colored portion shows the extension necessary for a diagonal flat mirror to intercept the entire cones of light from stars $\frac{1}{2}^{\circ}$ from the principal optical axis.

In photographic work with the William Pitt Telescope the diameter of the field of good images is about one degree. Measurements of the diagram give the following approximate results: To get all of the cone from stars $\frac{1}{2}^{\circ}$ from the principal optical axis would require a flat 5 by 7 inches in size. Owing to fore-shortening in one direction, the elliptical form would be best. With the 5-inch circular flat, all of one diameter of the cone from a star $\frac{1}{2}^{\circ}$ off the principal optical axis would be intercepted. But at right angles to this diameter the flat would intercept all of the cone for stars only 12 minutes of arc from the principal optical axis. Thus the diameter of the field of view in which the whole mirror is used, is 24 minutes of arc.

For visual work the lowest power that can be used on a telescope requires that the emerging pencil of light must not be larger than the pupil of the eye; otherwise, the full aperture is not utilized. Experiments show that the pupil of the eye is about $\frac{1}{4}$ of an inch in diameter when it is dark adapted. This means that a magnifying power of 4 diameters per inch of aperture is the correct one to use. The clear aperture of the mirror in the tube of the William Pitt Telescope is $26\frac{1}{2}$ inches. Hence, for visual work with this telescope, the lowest magnifying power that should be used is 106 diameters. With this power, the diameter of the field of view in a wide angle eyepiece would be about 23 minutes of arc. Thus the 5-inch flat is large enough for visual work. However, the flat has not yet been actually tried for visual work on the telescope.

THE ATTACHMENT OF A 12-INCH TELESCOPE FOR GUIDING THE 27-INCH TELESCOPE

It was hoped that it would be possible to guide the 27-inch telescope by a star on the cross-wires in the eye-piece of a smaller telescope attached to the side and parallel with it. The success of this scheme depends on the rigidity of the tube, the rigidity of the optical train in the smaller telescope, and the absence of minute sliding or rolling of the big mirror in its cell.

Accordingly, in October, 1938, the writer fastened a long-focus 12-inch mirror of his own on to the north side of the tube of the 27-inch telescope. Since the focal length of the 12-inch telescope is $148\frac{1}{2}$ inches, almost exactly that of the 27-inch, the diagonal and eyepiece assembly were attached to the upper end of the tube of the 27-inch, and the 12-inch mirror to its lower end. Much time was spent in orienting and adjusting the two separate parts and setting them parallel to the principal optical axis of the larger telescope. It seemed reasonable that the idea of guiding the 27-inch with the 12-inch might be fairly successful, even in case there should be some flexure of the big tube, because both mirrors were at about the same level on the lower end, and the plate-holder and eyepiece were at about the same position at the upper end. Such a combination might be expected to work successfully, when a guide telescope of half the focal length would not.

In early December, a guiding eyepiece with illuminated cross-wires was made. It had a magnifying power of about 320 diameters. On December 13th the writer made his first photograph with the William Pitt Telescope. The exposure was ten minutes on the Pleiades. A slight drifting of the guide star was noticed, and the telescope was corrected now and then when accumulation of the drift became perceptible. The plate was examined after it was developed, and the star images were found to be elongated. The following evening another plate was taken of the Pleiades, with an exposure of 30 minutes. The star images on it were short trails. Differential flexure was undoubtedly the source of the damage. It takes so little bending to be damaging in a

(Figure 2. has been omitted.)

large telescope. A differential flexure of only 0.000,7 of an inch is sufficient to shift the star one second of arc in the eyepiece of the 12-inch, which is a perceptible amount.

It was thought at first that the support for the small diagonal mirror on the 12-inch was not rigid enough. In February, the writer re-built this part into a much more rigid form. Also, felt was wedged around the 12-inch mirror in its cell to prevent slipping.

In March, guiding with the 12-inch was attempted again. These exposures had short trailed images also. The amount of trailing seemed to be proportional to the time.

A still untouched source of the flexure may have been in the attachment of the cell of the 12-inch mirror to the 27-inch tube. This would have required radical change, involving much time and expense, to insure elimination of the trouble. Since the writer intended to remove his 12-inch at the end of the school year, the change hardly seemed justified. So guiding with the 12-inch had to be given up.

Two other possible sources of elongated images may be:

1. A slight slipping of the 27-inch mirror in its cell, or

2. A slight flexure of the plate-holder box or web with changing hour angle.

While this experiment does not prove that it is impossible to guide the 27-inch with an auxilliary telescope attached to the side, further attempts in this direction must be considered as rather unpromising. The writer very much doubts whether the 27-inch tube is heavy and rigid enough. Stars have been observed to dance about when even little gusts of wind blew in on the telescope. Later experience has shown the futility of trying to make photographs under such conditions.

GUIDING WITH OFF-AXIS STARS FROM THE 27-INCH MIRROR

The only way left for the guiding of the 27-inch was to use field stars a little off the edge of the plate from the big mirror itself. Since the telescope was not Newtonian form, some device had to be employed to project the star's image to the side of the tube where it could be watched at the intersection of illuminated cross-wires in an eyepiece. The lack of a small achromatic lens of the right focal length to do this, was strongly felt. Much time was spent in experimenting with some short focus single lenses. One spectacle lens of 5.5 cms. focal length was found to work best, out of the lot. Another problem was to install a small mirror and set it at a 45° angle for the purpose of reflecting the light of the guide star to the guiding eyepiece at the side of the tube. This small mirror had to be mounted so that it could be adjustable without being cumbersome or sacrificing rigidity. The writer mounted one of his small circular flats ($1\frac{1}{2}$ inches in diameter) for the purpose.

At first, the lens was so placed as to form a conjugate focal image at the side of the tube directly in the focus of the guiding eyepiece. However, this amplified the image about six times and gave too high a magnifying power to be practical in guiding. Accordingly, the position of the lens and mirror was slightly changed, so that the beam of light was made to emerge nearly parallel (slightly converging) to the side of the tube. Here the beam entered through a small seven inch focus, achromatic lens which served as the objective of the small telescope for the guiding eyepiece, giving a magnification around 200 diameters.

There is no way of moving tha guiding apparatus about to enable the observer to choose guide stars. Consequently, if no field star happens to be in the right place, the desired object to be photographed must be displaced from the center of the plate in order that a guide star may be found and used.

The adjustment of all of the optical parts in this guiding arrangement is rather critical. Otherwise, the full beam of the 27-inch mirror will not be utilized, nor will the star image have a good point for guiding. Even at best, off-axis star images are pointed flares, the inevitable result of parabolic mirrors. The appearence of the star in the guiding eyepiece is like that shown in Figure 3. The subject of guiding has given more trouble and the experimenting has consumed more time and effort than any other one problem.

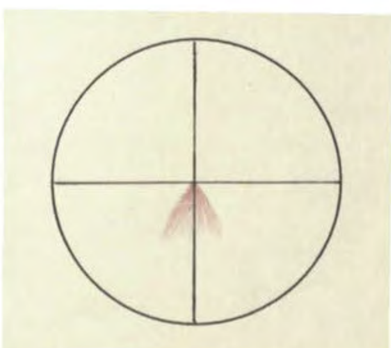

Figure 3.

The present set-up is none too satisfactory. Further improvement does not seem likely without some high grade achromatic lenses designed and made for the purpose. It would also be desirable to have the guiding parts mounted on a frame in a machined sliding way for better selection of guide stars.

In spite of these difficulties, a few successful long exposures have been made. These will be described in a later part.

THE MAKING OF INSTRUMENTS ON THE PLATE-HOLDER BOX AND THEIR PERFORMANCE

As mentioned before, the periscope as a means for making the knife-edge test, was unsatisfactory. Also, it was not possible to view the star field with the 27-inch itself. The writer made a study of the problem to see if some sort of arrangement could be made by which both could be accomplished with the same apparatus. It was desirable to construct the device so that the knife-edge test and the star field view could be easily and quickly interchanged. Then too, it was desirable to get rid of the occulting tube of the periscope.

The large right-angle field prism was removed from the periscope and mounted on a stub tube, which in turn, was soldered to a brass plate, as shown in Figure 4.

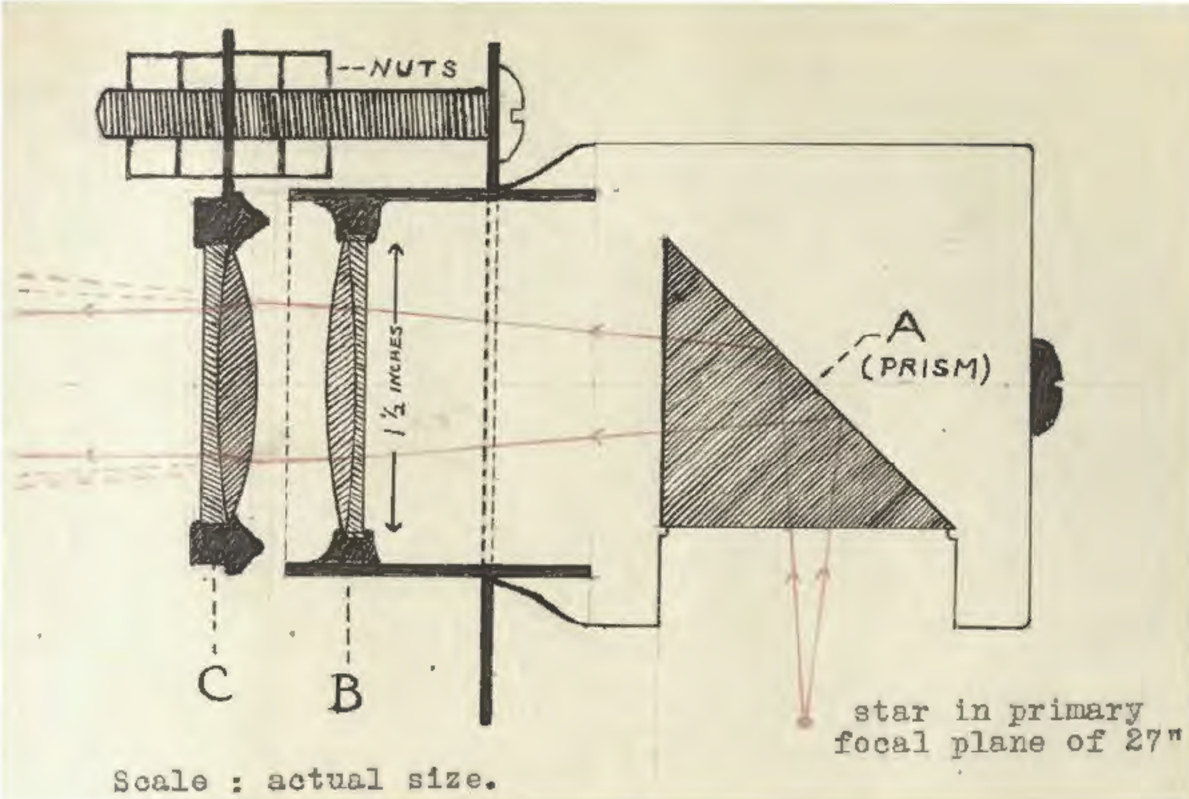

Figure 4.

Threads were cut on the inside of the other end of the stub tube to accomodate a projecting lens taken from an old, discarded lantern projector. This lens is an achromatic one, with a focal length of ten inches. The cementing has failed some around the edges. Although it has a somewhat longer focal length then desired, yet it is admirably suited to the purpose. The function of this lens (lettered "B" in Figures 4 and 5) is to reduce the rapidly diverging rays of light coming from the primary focal plane to a more nearly parallel beam.

Although the rays are still diverging, the objective of the little telescope (lettered "D" in Figure 5) for the visual eyepiece is large enough to intercept most of the beam, enabling one to see about 2/3rds of the whole diameter of the mirror. Use of this extra area of the mirror is quite an advantage when knife-edging, compared to the more restricted area of the mirror seen under the old periscope. For determining the position of the focus, a safety razor blade is mounted tightly against a glass plate in the plate-holder. The edge of the razor blade occupies the position of the emulsion of the plate in photographic observations.

The lens by which the knife-edge test is converted into a visual view of the star field with the 27-inch, is marked "C" in Figure 5. The change is accomplished merely by swinging lens "C" on its pivot into the optical path of the knife-edge arrangement. Only about two seconds of time are required to make this change. Of course, the razor blade restricts part of the field of view. By simply removing the plate-holder, a pleasing view of the entire star field may be obtained. Thus, the 27-inch is prepared for visual observations.

The function of lens "C" is to converge the diverging rays from lens "B", so that the full aperture of the mirror may be utilized not only for a star practically on the principal optical axis, but also for those stars near the edge of the field of view in the eyepiece. Actually, the rays come to a focus in a secondary focal plane about 15 inches beyond the edge of the 27-inch tube. As a consequence, the focal length of the eyepiece telescope is shortened somewhat, and the eyepiece is a little nearer the objective than it would be if the rays were in parallel propagation.

This part of the apparatus has proved to be particularly gratifying in its performace. A similar arrangement on

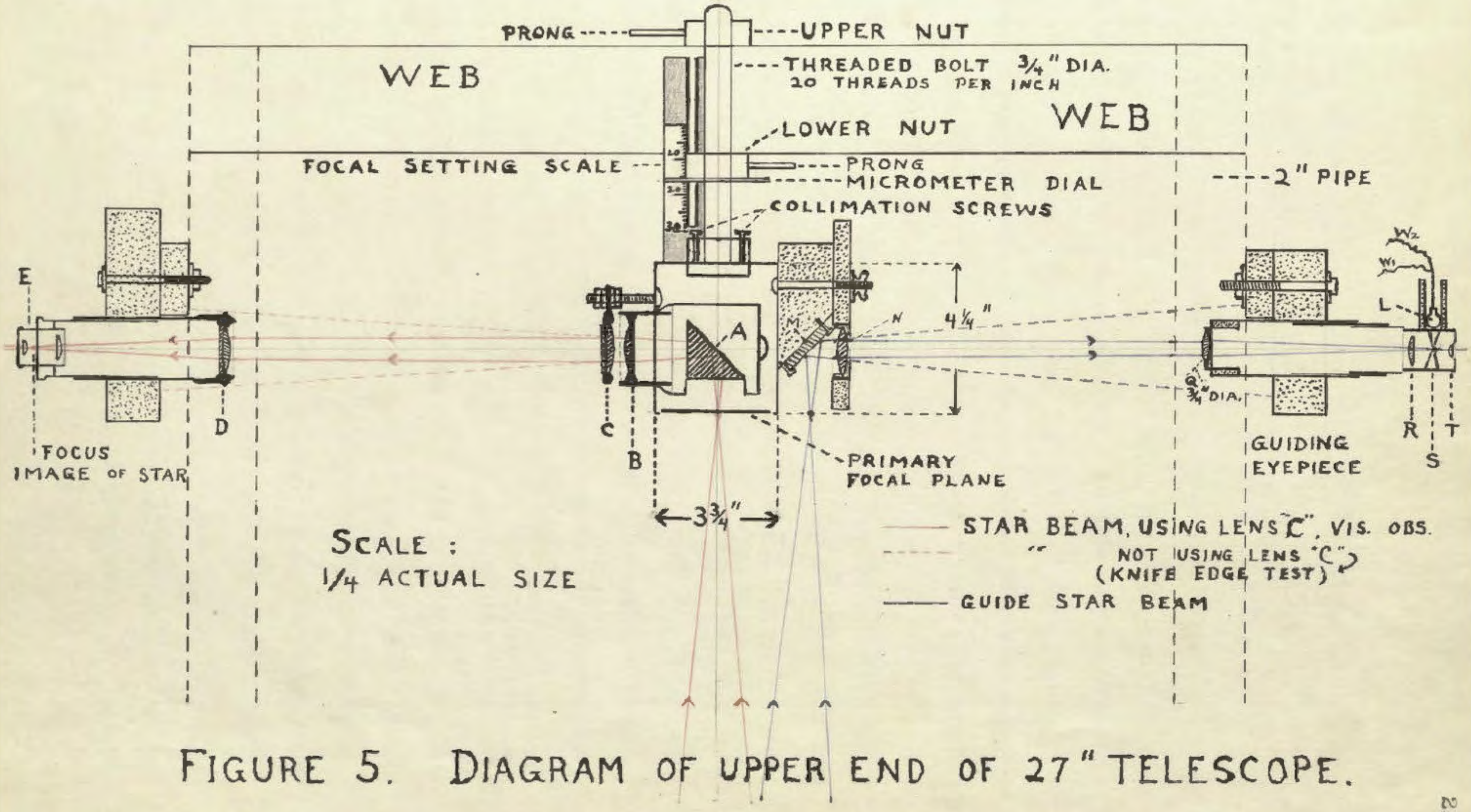

FIGURE 5. DIAGRAM OF UPPER END OF 27" TELESCOPE.

telescopes elsewhere is unknown to the writer and Dr. Storer, and is original with the writer.

One of the prime necessities in the operation of a telescope is some kind of shutter to begin and end photographic exposures. It must be light enough so that its manipulation will not cause any vibration or misplacement of the plate with respect to the star images. The slide in the plate-holder fits too tightly for freedom of motion; neither can it be handled quickly enough.

A shutter was designed and constructed for the plate-holder box of the 27-inch. It was made of thin tin and was soldered on to a hinge, which in turn, was soldered on one side of the plate-holder box. A small, short bolt was soldered on to the side of the shutter. A rubber band connecting this and a similar bolt on the plate-holder box, keeps the shutter in either of two positions--shut or open. The shutter has to operate through 270° in order to be out of the way when exposures are made. A string was tied to the small bolt on the shutter so that the shutter could be closed in a second of time. This makes it possible to get rather accurate exposure times, and also affords protection from approaching car lights shining into the dome. This shutter has proved to be fairly satisfactory in its performance.

Another desideratum was some means to keep the plate-holder box in a constant orientation, preferably north and south, or east and west. Such a device was easily made. A piece of strap-iron 1 3/4 inches wide and about 9 inches long had a narrow slot open at one end, cut in it. This strap was bolted on to the plate-holder box so that one web fitted into the slot, and in such a position that the desired orientation was obtained. This was found to work satisfactorily.

At a regular meeting of the Society of Sigma Xi on February 17, 1939, the telescope was formally dedicated as the "William Pitt 27-inch Telescope". Most of the apparatus described above had been constructed at this time.

MEASUREMENT OF FOCAL SETTINGS

In order to make a study of the changes of focal length of the mirror with changes of temperature, some sort of micrometer was needed to measure slight changes in distance of the plate-holder box from the big mirror. The 3/4-inch bolt of the plate-holder box was found to have 20 threads to the inch. The solution of the problem was obvious. The bolt was used as the micrometer screw. A thin, round plate of brass for a dial, 3 inches in diameter, was cut and graduated in fifths of a revolution. Each division was sub-divided into tenths, thus giving readings in one thousandths of an inch. This plate was fastened on to the lower side of the lower nut by three screws. Readings are taken by sighting along the south side of the northeast web. As a means of keeping track of the revolutions, a thin metal strip was cut and graduated into tenths of an inch. This was fastened to the inside face of the strap-iron used for keeping the plate-holder box oriented. This graduated strip is read by sighting the mark nearest the lower edge of the southeast web with one's eye level with the web. There are two revolutions of the dial to each tenth of an inch graduation. The correct 1/20th of an inch is easily interpolated.

THE PHOTOGRAPHIC DARK ROOM

Dr. Storer and the writer made a study of the requirements of an observatory dark-room in December and January. In making photographic observations with the telescope, a place where one can develop, "fix-out", and wash negatives, make prints and enlargements, is a necessity. The northeast corner of the laboratory room under the William Pitt Telescope seemed to be the best place for partitioning off a dark room. The dark-room is 7½ feet square in floor size. The sink is covered with sheets of acid-resisting lead. A wide, wooden bench at waist height was built on the west and north sides. The dark-room was constructed by the Buildings and Grounds Department in January.

PHOTOGRAPHING THE SUN

A very rapid and light focal plane shutter was designed and made for the photographing of the sun. The whole mechanism--track, shutter, and tension power--is mounted on a thin brass plate which takes the place of the slide in the regular plate holder.

The size of the Sun's image in the primary focal plane of the 27-inch mirror is about 1 3/8 inches in diameter. A circular hole a little larger than this was cut in the brass plate to allow the Sun's image to fall upon the photographic plate at the moment of exposure.

Owing to the exceedingly intense image of the Sun from the 27-inch mirror, the aperture of the telescope must be greatly reduced to prevent setting fire to the dome, as well as reducing the brilliancy in order to better control photographic exposure. A diaphragm with a one inch aperture, placed over the top of the tube was found to give about the correct exposure when used with the present focal plane shutter and the very slowest photographic plates. These slow plates are Eastman lantern slides with very fine grain. For this purpose they possess a two-fold advantage. One, the very fine grain means fine definition in the recorded image. Two, they assist in reducing the effect of over exposure. It is resonable to assume that these plates are about 1/15th or 1/20th as fast as Verichrome film. These data, plus some calculations seem to show that the exposure time of the focal plane shutter is in the neighborhood of 1/5000th or 1/10,000th of a second of time. Since the width of the narrow, traveling slit in the shutter is 1/50th of an inch, and the distance traveled is two inches, it means that the shutter travels the two inches along the track in about 1/50th or 1/100th of a second after the trigger is pulled.

The focal plane shutter was prepared for taking photographs of the partial eclipse of the Sun on April 19th. Unfortunately, cloudy skies prevented preliminary trials and rehersals. The sky was clear on the morning of the eclipse, and some experimenting had to be done during the eclipse. However a fair photograph of the latter stage of the eclipse was secured. Solar photography of the same quality might be obtained with the 6-inch refractor with less trouble and preparation.

OTHER IMPROVEMENTS

A very convenient two-way switch was installed for revolving the dome. One switch was placed on the lower east wall of the dome; the other was attached to a long cable which could be moved about somewhat and hung on the upper end of the telescope tube near the guiding eyepiece. The dome can be revolved from either place. The button switch at the upper end is especially essential, in that the observer does not need to interrupt his exposure and run down stairs to revolve the dome, as was formerly necessary.

In February, Dr. Storer designed and made a "button control box", an electrical device for making small corrections to the driving of the telescope. This is quite essential in making photographic observations with exposures longer than ten minutes. It enabled the writer to obtain a very good plate with a one hour exposure of the beautiful spiral nebula, M 99. Very small corrections in Right

Ascension had to be made from time to time during the exposure.

The Declination clamp gave trouble all year. It simply would not grip the Declination wheel tight enough to hold in making fine adjustments with the Declination hand-slow-motion control. Such means of fine adjustment in Declination is an aid in guiding the telescope as well as for setting the telescope accurately on celestial objects.

First, a leather strap was screwed on to the clamp shoe. But the clamp held sometimes and not at others. Next, the leather was replaced by a thick, rubber pad. This failed to hold at all. Finally, a better leather strap was impregnated with resin and screwed on to the shoe. The clamp now holds fairly well.

One difficulty is that the Declination axis turns stiffly when the telescope is pointed near the zenith. If this stiffness could be removed, and a longer clamp shoe made to give more gripping surface on the wheel, the trouble with the Declination clamp would probably be eliminated.

An arrangement was considered for taking enlarged photographs of the Moon in a secondary focal plane at the side of the tube, in the position normally occupied by the visual eyepiece. To get the secondary focal plane to come at the side of the tube, required screwing the plate-holder box with its lenses about an inch or more toward the web. The enlargement of the Moon's image from the primary focal plane was about $2\frac{1}{2}$ diameters. After projecting the Moon's image on to a card, and making a study of the situation, the project was temporarily abandoned.

Besides the construction of apparatus and experimenting described above, many minor jobs have been done, such as: collimation of the finder on the 27-inch, adjustment of the Declination circle, "squaring-on" the plate-holder to the 27-inch mirror (March 12), and others too numerous to mention. Yet all of these were necessary to the success in operating the William Pitt 27-inch Telescope.

" SEEING "

MEANING OF "SEEING"

There are two different factors that go together to make up the quality of "seeing", or atmospheric observing conditions. One, called the 'steadiness' factor seems to be unknown to the general public, as is evidenced by their expectation that any clear night is suitable for telescopic observation. The other factor, the 'transparency' of the sky, affects the magnitude reach of faint stars in a most sensitive manner. The latter is fairly well understood by the public, although the writer has come into contact with a few visitors who thought that the telescope could penetrate through any cloud, no matter how thick. Fairly satisfactory views may be had of the Moon's surface and the brighter planets, when observing through thin clouds or general haze. But the best transparency available, is required to observe nebulae, faint stars and very delicate planetary detail, whether the observations are visual or photographic.

Unfortunately, the astronomer lives at the bottom of an ocean of air, which is never in perfect tranquillity for the magnifying powers he uses on his telescopes. Indeed, there are but a few nights in a year which he can really call fine. The air has some optical density, and hence is capable of refracting the rays of light. Minute differences in the optical density of the air are found to exist within the comparatively small pencil of light intercepted by his telescope. Atmospheric currents are continually shifting unhomogeneous patches about, so that the rays of light are irregularly refracted and deflected from their original parallel course. This must necessarily result in blurred and ill-defined images in his telescope. The seriousness of these conditions is proportional to the magnifying power and the size of the telescope used.

The quality of steadiness is different on different nights; it varies from hour to hour, and even from moment to moment. The most superb views of planetary detail are seen in fleeting glimpses less than a second of time in length. Certain regions in the world are more favored in these respects than others. Both the steadiness and the transparency at Lawrence are about average.

It is only in the especially favorable regions of the world as on the highlands of northern Chile, South Africa, Australia, Mexico, the southwestern section of the United States, and around the Mediterranean Sea, where the steadiness is good enough at times to exhaust the defining and resolving powers of apertures as large as 20 inches. Consequently, too much should not be expected with the 27-inch telescope at Lawrence in seeing fine planetary detail or resolving very close double stars. Only at rare times is the steadiness good enough to even approach the latent magnifying power of the 27-inch.

The quality of steadiness also affects the magnitude reach of faint stars. If the atmospheric conditions are turbulent, an ill-defined and expanded image results. If a very faint star, appearing as a small point, is just visible under good conditions, it must become invisible when diluted to a sizeable patch by unsteady conditions. From the writer's own experience, this effect holds for both visual and photographic observations.

COMPARISON OF "SEEING" AT LAWRENCE WITH THAT AT FLAGSTAFF

At Flagstaff, the writer made a series of visual observations with a 12-inch reflecting telescope of his own. The long focal length ($12\frac{1}{2}$ feet) was well suited to using high magnifying powers and detecting small differences in the "seeing". The observations were begun on March 4, 1937 and extended through August 26, 1938--a span of 540 days. The 12-inch was not used on all clear nights, and generally not more than an hour on nights when it was used, due to other work. The principal objects of observation were the moon and the planets. A complete record was kept of the seeing, including the factors of steadiness, transparency; also the wind, barometer, objects viewed and their elevation, time of observations, magnifying power used, etc.

The 12-inch was brought to Lawrence and attached temporarily to the tube of the William Pitt 27-inch telescope. A similar record of the seeing at Lawrence was kept from September 20, 1938 to May 11, 1939. The seeing record was frequently furnished by the 6-inch refractor. It is interesting to compare the seeing at the two localities. Such a comparison is of some value in furnishing information on what to expect of the 27-inch in certain observing programs of work.

At Lawrence, during the fall semester, observations were not made as frequently as they could have been. A close record was not kept of the state of transparency on nights when observations were not made. But indications are that about 40% of the nights were good, and another 10% were fair. The first two months of the fall semester were very good, perhaps 65% of the nights were clear. December and January were very poor. From the First of February to May 11, (100 nights) a close record was kept of the transparency of the sky at night, whether telescopic observations were made or not. About 21% of the nights were good, 25% were fair, and 54% were poor or very cloudy.

About 2/3rds of the nights at Flagstaff are clear.

In describing the state of steadiness in seeing, a series of numbers between 0 and 10 is generally used. While various observers differ somewhat on rating the steadiness, partly because it is a conventional system, yet it is reasonable to expect that the record kept by any one trained observer would be consistent. The writer defines his "seeing" numbers as follows:

In the seeing scale, "0" represents the very poorest seeing. The image of a star in the telescope is unduly large from diffusion and is generally in violent motion--literally wriggling and "boiling". Stars less than 4 or 5 seconds of arc apart cannot be resolved, and craters on the Moon smaller than 5 miles across cannot be seen. Such nights are almost totally worthless for telescopes with apertures greater than 6 inches.

At the other end of the scale, "10" represents perfect seeing. Most observers never use this number because it is regarded as an unrealized ideal. There are differences in opinion as to just what it would represent. Anyway, when seeing is rated at "9", the latent defining power (for planetary detail) and resolving power (for close double stars) of the highest quality telescopes may be realized for apertures as large as 25 or 30 inches. The telescope then fulfills what theory would expect of it. Such occasions are extremely rare. It is perhaps safe to say that there are not more than two or three nights in a year in the best of localities, and even then only for moments, when such fine seeing occurs. Under such conditions one can see craters on the Moon which are less than 700 feet across, and divide double stars with components as close as one-tenth of a second of arc apart.

Seeing equal to "8" is also rare in the best localities and probably never occurs in the central and eastern parts of the United States. The writer has seen such seeing on several occasions at Flagstaff, but not once during the five years spent at Lawrence. With such seeing, the double Encke division in Ring "A" of Saturn when the ring is well open, is distinctly visible as two very delicate, dark hairs close to each other. Also, one is able to see a great number of fine, delicate "canals" on the surface of Mars when the disc subtends 15" or more.

Seeing equal to "7" is fairly plentiful in the southwestern section of the United States, but is very rarely seen in the other sections of the country. With this seeing, the delicate double Encke division in Saturn's ring becomes fused together as a single, faint, delicate streak. Craters on the Moon as small as 1,400 feet across may be seen, and double stars whose components are about one fourth of a second of arc apart may be divided.

The writer has seen seeing equal to "6" about half a dozen times at Lawrence in the five years he chanced to be observing. With this seeing, on Mars the two tips of the Dawes Fork Bay and the two canals running out from them, constituting the double canal, the Gehon, can be seen. Only the wider double canals can be resolved, and the more prominent single ones seen, with the disc of the planet subtending on angle 15 seconds of arc. Craters on the Moon a little less than one half of a mile across can be perceived. The true disc of Saturn's largest satellite, Titan, can just be made out when Saturn is near opposition. Such seeing is considered good at Flagstaff, and extra-ordinarily good by central and eastern observers.

Seeing equal to "5" is considered just "average good" at Flagstaff. Craters on the Moon 2/3rds of a mile across can be seen, although slender streaks of fair contrast to the background no wider than half this amount may be made out.

This seeing is good enough to see only a few of the strongest canals on Mars when the disc is large. Double stars one half a second of arc apart can be divided.

Craters on the Moon one mile across can be seen with "4" seeing. Such seeing is very common in the Southwest and is by no means rare in less favorable localities.

Seeing equal to "3" enables the observer to divide a double star whose components are one second of arc apart. With seeing equal to "2", one may see craters on the Moon two miles across, and three miles across for seeing at "1".

"Seeing-level" is a new term which the writer proposes for general use. For any given night, or "spell" of observing an hour or so in length, the seeing has been observed to fluctuate about a mean. The seeing is near that of the mean most of the time, occasionally fluctuating 2 or 3 points below and above this mean, which the writer defines as the "seeing-level". A quantitative comparison of the steadiness of seeing may be made of two different localities, or the same locality for different seasons, by getting the average seeing-level of the series of observations. This is of particular value in determining what to expect in long exposure photographs on star-fields and nebulae. The short fluctuations below and above the seeing-level do not register in the images of the fainter stars.

In visual observations the case is somewhat different. For seeing fine planetary detail or separating the components of a very close and difficult double star, it is the fluctuations or surges above the seeing-level that mean success. The best seeing-levels are generally of mediocre seeing. Often the best seeing for this kind of work occurs when it fluctuates two or three points on either side of the seeing-level. Seeing has hardly ever been seen to vary more than this from the seeing-level. On the really fine nights the seeing-level is about "6". On poor nights, it is "1" or "2", and good moments of seeing cannot be expected. Every locality has times of bad seeing, and so the average seeing-level is cut down.

To one interested in visual work involving high magnifying powers, a statement of the seeing-level is not enough. He wants to see a tabulation of the number of nights when the seeing reached various states of steadiness represented by the higher numbers in the scale. Generally, the seeing corresponding to "7", "8", or "9" does not hold up for longer than a second of time. Indeed, the superb moments are often less than a second long and afford only fleeting glimpses. To see the very finest detail under such conditions requires great skill, which comes only with good eyes and an enormous amount of practice in such observing. Most men in astronomy have not mastered this particular art because their own kind of work does not demand it. Herein lies the source of disappointment to the observatory visitor and the skepticism among some of the other astronomers not dealing in this particular kind of work. Some astronomers who have access to the very largest reflectors make the mistake of using the full aperture, which is only more sensitive to atmospheric disturbances, and therefore, hinders, rather than helps. The seeing never gets good enough to realize on their latent defining and resolving powers, otherwise, they would be justified in using such large apertures. It is very rare when such superb seeing holds constantly for five seconds of time.

The problem of photographing fine planetary detail or close double stars is similar to that encountered in visual work. The images in the primary focal plane of the telescope must be amplified about five times in scale to dodge the diffusion effect of the grain of the plates, and for a planetary disc, this means reducing the intensity. Exposures cannot be made less than from one to several seconds--depending on the brightness of the object. Hence, the best seeing for short photographic exposures is generally a step or two below that for the visual observation.

In recording the steadiness of the seeing, the writer has consistently recorded the different steps of seeing in proportion to their relative times of duration by the use of different sized numbers. Examples:

0, 1, 2 ; 3, 4, 5, 6 ; 4, 5, 6, 7, 8

The large numbers represent the "seeing-level", referred to previously. In tabulating the steadiness of seeing for a season or a year, the number of nights or spells of observing during the night, in which a particular step is reached is counted, and this, in turn, may be reduced to percentage if desired. The largest numbers, representing the "seeing-level" are added together and divided by the number of spells of observing to get the average "seeing-level".

Table I shows the frequency of the different steps of seeing.

Row 1, is a record of the seeing at Flagstaff in 49 spells of observation on 28 different nights from March 4 to April 22, 1937. This is a sample of a good observing season.

Row 2, is a record of the same in 16 spells of observation on 16 nights between March 4 and April 22, 1938. It is a sample of a poor season.

Row 3, is a record of the seeing at Flagstaff in 375 spells of observation on 236 nights from March 4, 1937 to August 27, 1938.

Row 4, is a record of the seeing at Lawrence in 71 spells of observation on 68 nights from September 20, 1938 to May 11, 1939.

Table I.

	9	8	7	6	5	4	3	2	1	0	Seeing Level
1_F	1	3	6	17	31	32	30	17	5	2	4.1
2_F	0	0	0	1	3	12	16	12	4	0	2.2
3_F	1	4	17	72	178	278	316	232	81	12	3.2
4_L	0	0	0	2	7	23	49	56	45	20	2.0

Table II shows the same record in percent, obtained by dividing the frequency by the number of spells of observation.

Table II

	9	8	7	6	5	4	3	2	1	0	Seeing Level
1_F	2	6	12	35	63	65	61	35	10	4	4.1
2_F	0	0	0	6	19	75	100	75	25	0	2.2
3_F	$\frac{1}{4}$	1^{+}	$4\frac{1}{2}$	19^{+}	$47\frac{1}{2}$	74	84	62	22	$3\frac{1}{5}$	3.2
4_L	0	0	0	3	10	32	69	79	63	28	2.0

Thus, at the average "seeing-level" at Flagstaff, an observer could just resolve a double star whose components are about 0.9 seconds of arc apart. At Lawrence, a double star 1.5 seconds of arc apart could just be separated at the average seeing-level.

It is interesting to note that the value of the seeing-level (which was obtained by adding the large sized numbers) coincides with that quality or step of seeing which had the highest frequency in occurrence, in three out of the four cases. The second case departs from this by less than one step.

Row 4 in Table II shows the lack of high quality seeing, which is so essential in planetary and close double star work. Therefore, the William Pitt 27-inch telescope at Lawrence cannot successfully compete with the observatories in the Southwest, where better seeing is universally experienced.

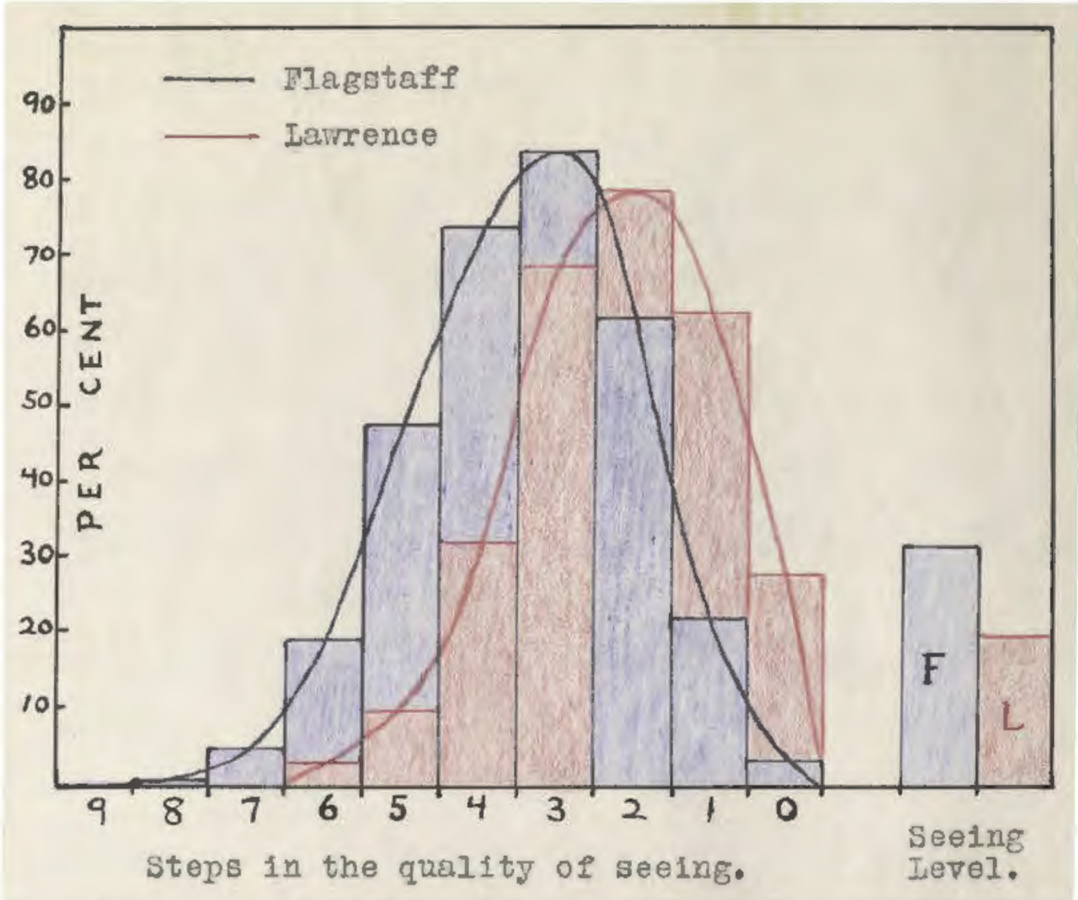

Figure 6. Comparison of the Steadiness Factor in Seeing.

From Table II a histogram was constructed for the quality of seeing at Flagstaff (Row 3) and a similar one for the seeing at Lawrence (Row 4). These were combined in Figure 6. A curve was traced through the mid-points of each column. It is worth noting that these two curves approximate a Normal Error or Probability Curve, especially the Flagstaff curve.

CORRELATION OF SEEING WITH THE WEATHER

In the Southwest during winter, the best seeing, such as "6", "7", "8", and "9", comes in on a falling barometer.

It occurs between 24 and 48 hours before a snow storm breaks. The superb seeing seldom lasts longer than an hour or two. There is no seeing like it again for a week or more--until the next approaching snowstorm. The astronomers at Flagstaff have learned to watch the barograph. After some experience one can learn to recognize the "feel" of the air that accompanies such seeing. "Bitty" air and good seeing seldom go together. This state of affairs is fortunate for the comfort of the observer. Good seeing generally accompanies a southwest breeze or wind. The worst seeing accompanies a wind from the northeast. Observers in California report the same general thing.

In the summer season at Flagstaff, the best seeing following a good rain during the day. At Flagstaff, moderately good seeing (4, 5, 6) frequently occurs during late evening and early morning twilight, and lasts only an hour or less.

At Lawrence there is a good deal of wind from the north and northwest. No good seeing was ever observed here by the writer when a chilly wind was blowing from the north, or had been blowing from the north during the day.

VISUAL OBSERVATIONS WITH THE WILLIAM PITT 27-INCH TELESCOPE

EYEPIECES AND MAGNIFYING POWERS

A short study was made of eyepieces and magnifying powers used on the William Pitt 27-inch Telescope. The numerous lenses in the visual optical train made calculation of the equivalent focal length rather complicated. However, the equivalent focal length was obtained by simply comparing angular distances on the Moon with the 27-inch reflector and the 6-inch refractor, using the same eyepiece on both. The eyepiece marked "65" was used. On the 27-inch the rims of the craters, Kepler and Plato, facing each other, just fitted exactly in the field of view of the eyepiece. This corresponds to an angular field of view of very nearly 12 minutes of arc.

The same eyepiece on the 6-inch took in a span of lunar surface exactly 11/7 that with the 27-inch. The focal length of the 6-inch refractor is about 92 inches. Since the size of images in the focal planes is proportional to the focal lengths in telescopes, the equivalent focal length in the secondary focal plane of the 27-inch turns out to be 92 times 11/7, or about 145 inches. This happens to be very nearly equal to the primary focal length.

This #"65" eyepiece is a Huyghenion type, or negative, in which the focus lies at a point between the two lenses. The equivalent focal length of this eyepiece appears to be one inch, as determined by comparing scales with it on a short, hand telescope. Hence, it gives a magnifying power of 145 diameters on the 27-inch telescope. It gives a power of 92 on the 6-inch refractor.

Another eyepiece belonging to the 6-inch refractor, marked "135" has an equivalent focal length of $\frac{1}{2}$ inch (determined in the same way), and is also of the Huyghenian type. This one has an extraordinarily wide angle field and gives a very pleasing sensation of "spaciousness" on star-fields and on the Moon's surface. On the 27-inch, it gives a magnifying power of 290 diameters. On the 6-inch refractor it gives a power of about 185.

An adapter collar for the 27-inch was "turned" so as to accommodate the eyepieces belonging to the 6-inch refractor. Thus, these eyepieces are mutually interchangeable on the two telescopes. There are still higher-power eyepieces belonging to the 6-inch refractor but it will be only on rare occasions when such eyepieces can be used to advantage on the 27-inch reflector, because of prevailing atmospheric conditions at Lawrence.

LOSS OF LIGHT THROUGH THE VISUAL TRAIN

It is unfortunate that twelve optical surfaces lie within the beam of light between the 27-inch mirror and the eye in visual observations. However, most eyepieces have four surfaces, and an eyepiece must be used for visual observations in any telescope. Also, a right angled prism with two surfaces for light losses, or an additional mirror with an equivalent loss, must be used for visual observations in reflecting telescopes. So it is seen that the visual arrangement on the 27-inch embodies only six additional surfaces over the ordinary arrangement of a reflector.

Assuming that each surface reflects 5% of the incident light (a value customarily used), then from the six surfaces, we have: $0.95^6 = 73\%$ transmitted if there was no absorption. Making a reasonable allowance for absorption in the glass of the lenses, let us say that 60% of the light is transmitted and 40% is lost. This means a loss of one half a magnitude. Counting the light losses by occultation of the web, plate-holder box and attachments, as equal to the light furnished by a six-inch aperture, and subtracting that from the net aperture of the mirror (26.5 inches), makes the net light grasp equal to that of a mirror 25 1/3 inches in diameter. A 25-inch aperture is supposed to show stars, visually, down to the 16th magnitude.[1] Subtracting ½ a magnitude for light losses, reduces the limiting visual magnitude to 15½ with the present visual arrangement on the William Pitt Telescope. The total number of stars visible in the entire sky down to magnitude 15½ is 50 million.[2] It should be possible to see Pluto, which has a visual magnitude of about 14.8.

The above figures are theoretical. The writer has not had the time to actually test the telescope for its limiting visual magnitude. However, a visual observation of the faint stars in the globular star cluster (M13) in Hercules, indicates

1. Baker, Robert H., Astronomy 2nd edition. p. 362.
2. Ibid. p. 361.

that the theoretical figures are of the right order.

None of the lenses in the optical beam for visual observations can be eliminated without sacrificing the convenient change to the knife-edge test. For straight visual observations, the system of lenses could be simplified by replacing "B" and "C" together with a single achromatic, short-focus lens. (See Figure 5).

Compared to the visual arrangement, the photographic one is very efficient in light grasp. The light losses from 12 reflecting glass surfaces alone amounts to $100 - 0.95^{12} = 100 - 54 = 46\%$. Counting absorption losses in the glass of the lenses, runs up the total to about 60%, so that only 40% of the incident light from the 27-inch mirror is transmitted. This corresponds to one full magnitude. For photographic observations, the 27-inch is one magnitude ahead of the visual.

FIRST VISUAL OBSERVATIONS WITH THE 27-INCH

Rather pleasing and beautiful views have been obtained of the Moon, Mars, the globular star cluster in Hercules, the Orion Nebula, and Hassel's Comet.

The first good visual observations with the William Pitt 27-inch telescope were made on March 6, 1939. The objects viewed were Sirius, the Orion nebula, Procyon, and the Moon. A magnification of 145 diameters was used. The transparency of the sky was good, and the steadiness was "1, 2, 3, 4".

On March 12th, the spiral nebula, M98, was viewed.

On April 30th at 3:00 A.M. the first observation of Mars was made with the 27-inch. Seeing conditions were rather favorable at times, with good transparency and steadiness of 3,4,5,6, permitting the writer to see several markings on the planet. Such remarkable seeing at so low an altitude in the sky is rare. It was discovered while looking at the Moon that morning low in the western sky. The "Syrtis Major", "Dawes Forked Bay", "Margaritifer Sinus", "Sabaeus Sinus", and "Hellespontus" were recognized by the writer. Some of the more prominent "canals", like the double Gehon coming out from the Dawes Forked Bay, and the Nilosyrtis coming out from the tip of the Syrtis Major, were looked for; but no canals and no "oases" could be seen. The angle subtended by the disc of the planet was eleven seconds of arc.[3] The south polar cap of snow was observed to be moderately large. The reddish-ochre color of the Martian deserts came out well and was beautiful. On the other hand, the dark markings, mentioned specifically above, failed to show their usual color. They were mostly medium dark greys with a slight bluish cast.

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3. 1939 American Ephemeris and Nautical Almanac.

PHOTOGRAPHIC OBSERVATIONS WITH THE WILLIAM PITT 27-INCH TELESCOPE

PROCEDURE

Photographs are taken with the William Pitt 27-inch telescope by placing a sensitive photographic plate in the primary focal plane of the 27-inch mirror. Since the telescope is not of Newtonian form, the plate is suspended in the middle of the tube from a web at the upper end. The loaded plate-holder is slipped into the plate-holder box attached to the web. After the lights are turned out, the slide is removed from the plate-holder. The shutter is opened and the plate is then exposed to the rays of star-light. Any desired exposure between a few seconds and two hours of time may be given. Prolonging the exposure brings out fainter and fainter stars. After the plate is exposed, it is then developed, "fixed out", washed and set up to dry. After this, it may be examined, studied, or measured. A preliminary inspection of the plate may be made after it is fixed out and still wet.

In astronomical photography, plates are nearly always used for the original negatives because they maintain a rigid position for different tilting angles of the telescope. Plates are more convenient to handle on an examining rack or on a measuring engine. Also, any sagging of a film would be disasterous for work involving very accurate measurements of the positions of objects.

DIFFERENT KINDS OF PHOTOGRAPHIC PLATES

There are many different kinds of photographic plates, and several different brands. Each has its own spectral sensitivity and speed, and hence a type of work to which it is best adapted.

Very fine-grained plates, although slower, are more suitable in photographing the Moon and planets. Red, yellow, and blue sensitive plates are useful in recording the appearance of a planetary disc in different wave lengths of light.

High speed plates, even though they have coarser grain, are more satisfactory in photographing star-fields and nebulae. Generally, blue-sensitive plates are used; but for technical work, plates with other spectral characteristics are used in conjunction with the blue-sensitive ones.

In some kinds of spectrographic work, plates with spectral sensitivity over as wide a range as possible are desired.

Deep infra-red plates, and color films are coming into regular use.

The writer has used three kinds of plates so far with the William Pitt 27-inch telescope. Eastman fine grained lantern slide plates were used in photographing the partial eclipse of the Sun, and the Moon. These are very slow in speed, and are useful in controlling the exposure times for intensely bright objects. Both Eastman 33's and Wratten Panchromatic plates were used on star-fields and nebulae. Both kinds seem to have about the same speed. The sky-fog on the Wratten Panchromatic plates is much stronger than that on Eastman 33's with long exposures. This is probably due to the faint reddish illumination of the sky from the red neon lights of Lawrence. The eastern half of the sky seems to be worse than the western half. For this reason, the writer prefers to use Eastman 33 plates.

THE KNIFE-EDGE TEST

To focus the telescope has required slight changes in the focal setting on different nights. Whether this is entirely due to changes in the length of the tube with temperature, or whether part of it is due to real changes in the focal length of the mirror is not known. The necessary changes in the focal settings amount to a few hundredths of an inch. Hence, it is desirable to always test the position of focus by the knife-edge before beginning a photographic exposure. Otherwise, the images of stars may be found to be slightly out of focus.

The knife-edge test is accomplished quite simply by cutting the cone of light from a 1st or 2nd magnitude star by a very straight, even edge of a strip of metal. Hence, the name of "knife-edge". Either a piece of tin-foil, or a safety razor blade is fastened to a clear piece of glass, the same size and thickness as the photographic plate, by a strip of Scotch tape. This is placed in the regular plate-holder, which in turn, is inserted in the plate-holder box of the telescope. The knife-edge is in an identical position with the sensitive emulsion of the photographic plate.

The observer looks through the eyepiece (lettered "E" in Figure 5) with the lens "C" swung out of the beam. A large, circular portion of the 27-inch mirror is seen flooded with star light. By slightly moving the telescope in Right Ascension, the knife-edge cuts into the cone of light. If the knife-edge is exactly at the focus, the mirror darkens evenly all over, except for the wriggling effect of atmospheric disturbances and air currents. The observer will be quite unable to decide from which side the shadow enters or leaves the mirror. This test is a very delicate one, and only a very slight movement of the telescope will plunge the light-filled mirror into total darkness. The use of a little flexing or bending of the tube by slight pressure applied by one's hand, is very helpful in studying the appearance of the mirror at the critical point where the star image is just touching the knife-edge.

If the knife-edge is not exactly at the focus, the mirror will be noticed to darken from one particular side when the knife-edge cuts thecone of light. Depending on which side of the center the knife-edge is located, darkening of the mirror from one side may mean that the knife-edge is inside the focus, while darkening of the mirror from the other side would mean that the knife-edge was beyond the focus.

If the knife-edge is considerably out of focus (a few hundredths of an inch) the sharp, straight edge of the knife-edge shadow is distinctly seen on the mirror. At the half-way point the mirror looks like a half-moon or half circle of light.

To change the position of the knife-edge and attempt to set it in the focus, the two nuts on the large threaded bolt are loosened, then turned a fraction of a revolution and tightened. The knife-edge test is again performed. After a few trials, a very close focus can be obtained.

One night the focus was very carefully and accurately determined, and the focal setting dial was read to a thousandth of an inch. Then the nuts were turned, little by little, to see how much change would be required before the knife-edge was sensibly out of focus. The first indication that the knife-edge was out of focus occurred when the focal setting had been changed by 0.005 or 1/200th of an inch! The out-of-focus effect was easy to see with a change of 0.010 or 1/100th of an inch. Thus the knife-edge test is an excellent means of focussing the telescope accurately and quickly.

In all the knife-edging done so far, the writer has failed to see any certain distortions in the figure of the 27-inch mirror in the way of zonal aberrations. The plate-holder box has frequently been turned slightly so as to permit a view of an entire radius of the mirror, but no certain uneven darkening could be made out, apart from that caused by atmospheric disturbances. To make a crucial test, one should wait for a night of extraordinarily steady seeing.

OBJECTS PHOTOGRAPHED

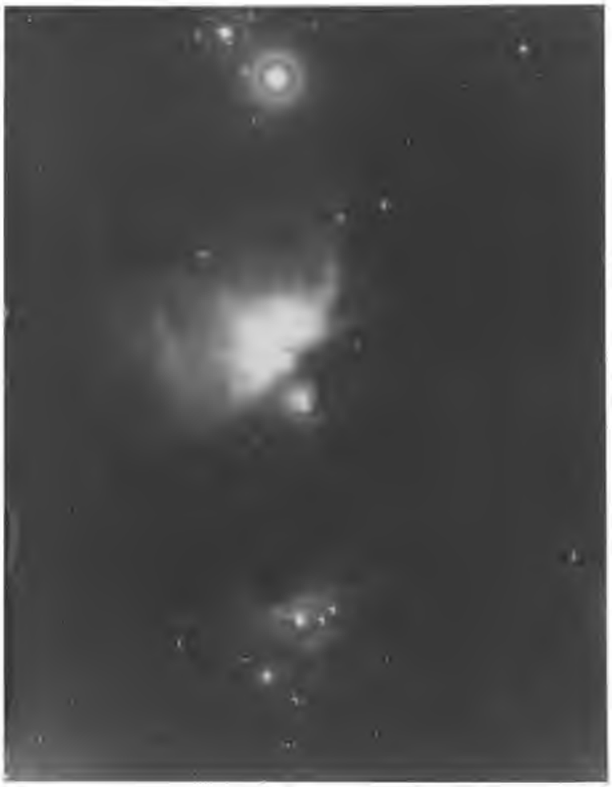
The following is a list of the photographs taken by the writer with the William Pitt 27-inch telescope during the school year.[4] Many of them were pure experiments and some might well be expected to be failures. So many things can happen to spoil an astronomical photograph. Constant vigilance is required to secure a goodly proportion of successful photographs, even after the apparatus has been tried and tested.

Plate no.	Object	Net Exposure Time	Date	Guided With	Remarks
23	Pleiades	10^m	Dec. 14	12"	Fair plate
24	Pleiades	30^m	Dec. 14	12"	Elongated images
25	Orion neb.	20^m	Feb. 6	27"	Very good images old plate (fogged) fair
27	Praesepe	20^m	Feb. 22	27"	Poor plate
28	Orion neb.	35^m	March 12	27"	Multiple star images
29	Spiral neb. M98	15^m	March 13	27"	Poor plate; driving bad
30	Orion neb.	40^m	March 15	27"	Fair plate; unsteady seeing
31	Spiral neb. M99	75^m	March 16	12"	Short trails; diff. flexure
32	Praesepe	50^m	March 16	12"	Short-curved star images

4. K. U. Observatory Record Book of Observations.

Plate no.	Object	Net Exposure Time	Date	Guided With	Remarks
33 1.	Orion nebula	60^m	March 19	27"	Fair plate; very close double images
34 2.	Spiral nebula M99	60^m	March 20	27"	Good plate; images slightly soft from seeing
35	Orion nebula	30^m	March 20	27"	Good images, not centered, fog streak at end
36 3.	Spiral N.G.C. 4565	35^m	March 21	27"	Good plate
37-47	Arcturus	$< 1^m$ each	April 7,8	none	Several Hartmann plates
48 4.	Hassel's Comet	5^m	April 29	none	Fair, plate a little out of focus
49	Hercules Cluster M13	12^m	April 30	none	Double images, driving bad
52	Mt.Wilson Area 9^h27^m $+29^\circ 50'$	10^m	May 9	none	Double images, driving changed Equivalent 3 and 7^m exposures
54	Moon	1/4s	May 27	none	Good detail
5. 55	"	"	"	"	Superb detail

A few prints of verious objects from some of the better photographs are shown on the following pages.



1.

THE ORION NEBULA (Same scale as negative)

The Orion Nebula is a great field of glowing gas 600 light years distant.[5] On the original negative, the star images are very closely double, probably due to some flexing of the 27-inch guiding eyepiece. Nevertheless, this is a fairly good photograph. A little over one square degree of sky is shown on the print. The rings of light around the bright stars are merely a halation effect and are spurious. South is at the top. (From negative # 33) Exposure : 60 minutes on Eastman 33 plate.

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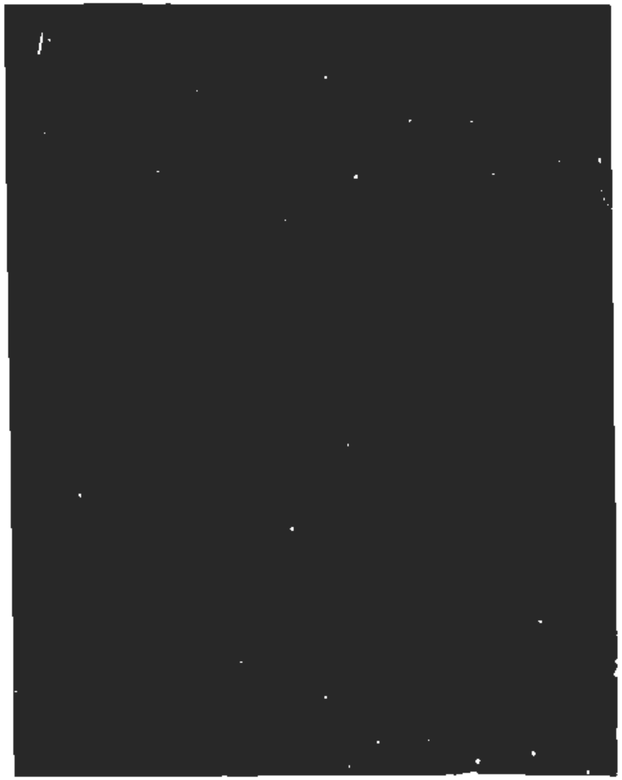
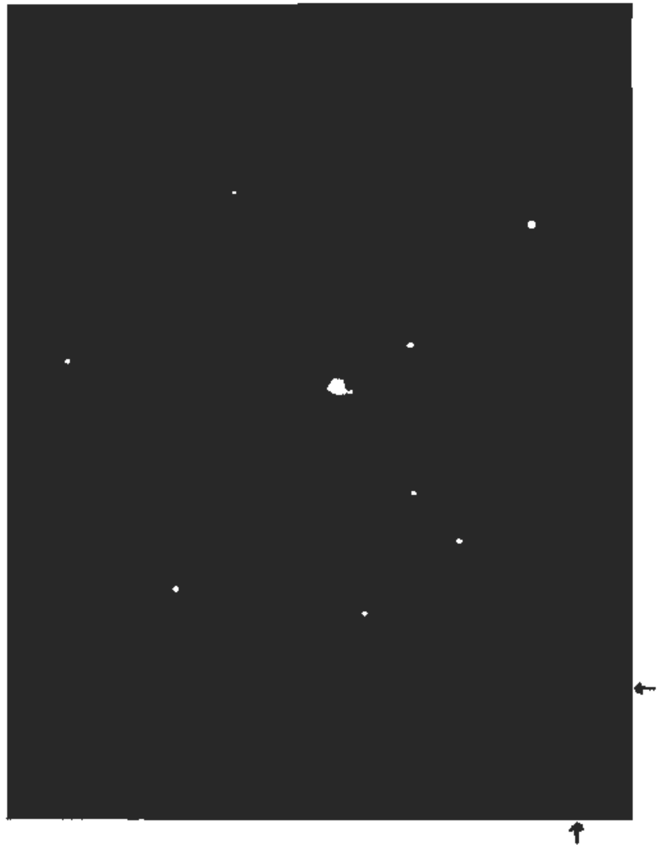
5. Hale, George Ellery, <u>The Depths of the Universe</u> p. 60.



Same Scale as Negative



Enlarged 5 Diameters

THE SPIRAL NEBULA "M99"

The spiral nebula, M 99, is another galaxy of stars similar to our Milky Way System, and so distant that it requires 7 million years for its light to reach us.[6] It is a member of the Coma-Virgo group of extra-galactic nebulae. This object is ten times more remote than the two nearest known spiral nebulae, and yet much detailed structure can be seen on the photograph. The hazy-looking knots showing in the spiral arms probably correspond to some of the rich, individual star-clouds in the Milky Way. The angle in the sky subtended by this spiral nebula is five minutes of arc.

To the lower right on the enlarged print, the arrows point to a very faint, small nebula, yet large enough to be distinguished from a faint star image. Spiral nebulae are known not to vary greatly in absolute size and luminosity, generally. If this faint galaxy is of average size, then its apparent, faint magnitude and small size would correspond to a distance of 75 million light years _ ten times more remote than the large spiral shown in the picture. This faint object is typical of the smallest and faintest nebulae distinguishable on the plates.

The magnitude of the faintest stars showing on this photograph is about 18 1/2, which is equivalent to the light of a standard candle placed at a distance of 2,080 miles !

The large spiral shown is a typical example of one that is oriented broad-side to our view.

Exposure : 60 minutes on Wratten Panchromatic plate.

Two other spiral nebulae may be seen in the lower right.

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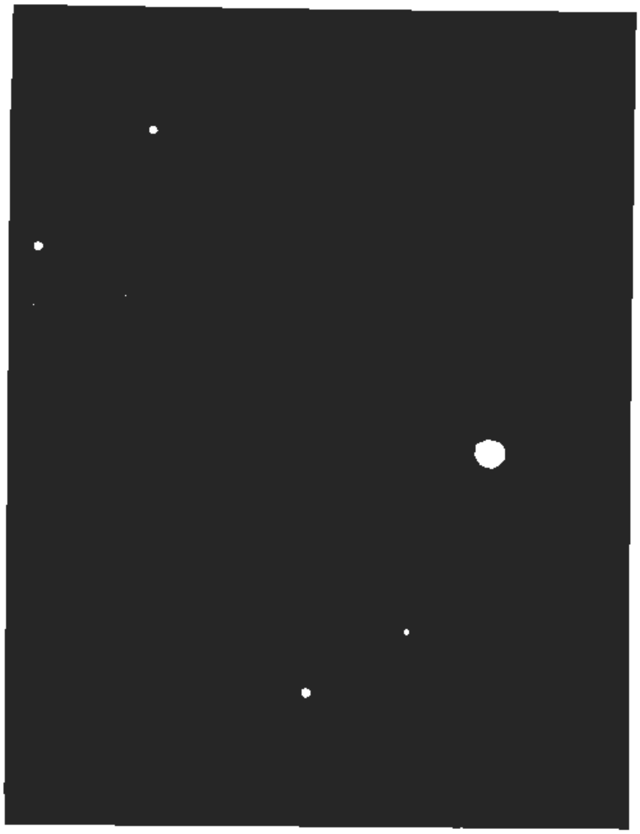
6. Hubble, Edwin, The Realm of the Nebulae p. 163.

3.

THE SPIRAL NEBULA, N.G.C. 4565

The spiral nebula, N.G.C. 4565 is a typical example of one oriented edgewise to our view. This object is also a member of the Coma-Virgo group of nebulae and is situated at a distance of 7 million light years. Obscuring matter in the equatorial plane, a frequent characteristic of extra-galactic nebulae oriented edgewise, is plainly seen in the photograph. This print was enlarged five diameters from the original negative.

Exposure : 35 minutes on Wratten Panchromatic plate.



4.

HASSEL'S COMET April 29, 1939

Hassel's Comet was in view in the low western sky in latter April and early May. Its stellar magnitude was about 4 at the time this photograph was taken. The exposure was only 5 minutes long. Even then the nucleus shows elongation, due to the rapid motion of the comet thru the star-field. At present the telescope is not equipped to follow objects moving thru the star-field, as would be required for longer exposures. A faint, slender tail may be seen extending to the left of the nucleus.

5.

THE MOON

Taken May 27, 1939. Enlarged 6 diameters.

SIZE OF THE PHOTOGRAPHIC IMAGES OF FAINT STARS

It is a matter of considerable interest and value to know the size of the smallest photographic star images that a telescope will give under moderately good working conditions. Accordingly, two plates were selected for study.

Plate # 34 is a one-hour exposure containing the spiral nebula M 99. Several faint star images were measured under the microscope of the measuring-engine. The average diameter was 0.070 millimeter (mm.), which on the scale of the 27-inch telescope plates corresponds to an angular diameter of 3.8 seconds of arc. (1" = 0.0183 mm.). The smallest star image measured had a diameter of 0.054 mm. The diameter of the faint nebula, position indicated by arrows on page 62, measured 0.227 mm., subtending 12". Judging from its appearance, the writer is confident that nebulae one half this width could be distinguished from stars.

On plate # 52, the average of two measures of the star listed at magnitude 16.60 gave a diameter of 0.081 mm. The average of four measures on the companion image of the star, magnitude 14.45, gave a diameter of 0.059 mm., corresponding to 3.2 seconds of arc. It is significant that this companion image was fully 1 1/2 magnitudes brighter than the limiting magnitude of the plate.

The results of these measures indicate that the resolving power on photographic plates taken in the primary focal plane of the 27-inch telescope is almost exactly one thousandth of one degree, or 3 1/2 seconds of arc. Under choice observing conditions the 100-inch reflecting telescope in

California gives images which are one second of arc in width, but its focal length is just 3 1/2 times longer and should give correspondingly smaller angular diameters.

The plates, Nos. 34 and 52, were made under only average seeing conditions, steadiness "2-3". Also, they are coarse-grained emulsions. From the appearance of a superb photograph of the Moon on a fine-grained Eastman Lantern Slide plate and seeing "3-4", the resolving power is better still. Small craters only 2 1/2 miles across, subtending angles slightly more than two seconds of arc, were identified on the plate. This is excellent performance. Thus, the William Pitt 27-inch Telescope is capable of yielding photographic star images as small, linearly, as other Reflectors.

LIMITING MAGNITUDES

On May 9, a ten-minute exposure was made of the Mount Wilson Selected Area, 53, centered at: R.A. $= 9^h\ 25^m$, DECL $= +30^\circ 00'$ (Epoch 1900). This area is one of a number in which over a hundred stars of various magnitudes have had their magnitudes determined very accurately at the Mount Wilson Observatory.

No attempt was made to find a guide star for so short an exposure; but, unfortunately the electric power fluctuated too greatly for the "Relays" to handle, and the telescope skipped an interval--resulting in double images. However, an inspection of the two images shows that the exposure times for the two images are of the order of 3 and 7 minutes respectively.

A plot was made of the stars listed in this Selected Area and many of the fainter stars were identified on the plate. Considering only the 7-minute exposure images: stars of magnitudes 16.60, 16.69, and 16.72 were easily seen on the plate. Stars of magnitudes 17.11, 17.18, and 17.31 were seen with difficulty, but exactly in the positions indicated on the plot. However, a star on the plot marked as magnitude 17.25 could not be seen, and thus casts some doubt on the genuineness of the star image in the position of the one marked 17.31.

Therefore, it seems safe to say that the William Pitt 27-inch telescope reaches stars fully to the 17th magnitude in 7 minutes of exposure with Eastman 33 plates. This is marvellous efficiency in light-grasp. Of course, the absence of a ten per cent light loss in a second reflection from a diagonal mirror is an advantage.

Extrapolating for a one-hour exposure, assuming that a magnitude is gained by tripling the exposure (a recognized general rule) it follows that stars to the 19th magnitude would be recorded with the William Pitt 27-inch telescope. This is within only two magnitudes of one-hour exposures with the 100-inch telescope in California. The writer regrets that he did not have the opportunity to make some long exposures on this region. The photographic arrangement on the William Pitt 27-inch Telescope is as efficient in light gathering power as it is possible to attain in any telescope.

SPACE PENETRATING POWER

From known absolute magnitudes of various types of stars, it is of interest to calculate to what distances various types of stars are visible on one-hour exposure photographs taken with the William Pitt 27-inch Telescope.[7] Neglecting interstellar space absorption within our Galaxy (which, according to Trumpler is equal to 2/3rds of a magnitude per 1,000 parsecs)[8], we have: (19 th mag. limit)

Object	Absolute Magnitude.	To a Distance of
Stars like our Sun	+ 5	20,000 light years
Bright Cepheids (long period) Hence would just be visible in the two nearest spiral nebulae, or neighboring galaxies.	– 3	800,000 " "
Faint Cepheids (short period) All Cepheids in the Milky Way would be visible	0	200,000 light years
Average Galactic Nova	– 6	3,200,000 light years
Average Globular[9] Extra-Galactic Nebula	– 15.3	about 230,000,000 light years
Average Globular Extra-Galactic Nebula--distinguishable from stars	– 15.3	about 150,000,000 light years

7. Baker, Robert H., Astronomy. pp. 371, 378, 387.

9. Hubble, Edwin, Realm of the Nebula. p. 176.

8. Lick Observatory Bulletin No. 420 p. 168. (1930).

UNFAVORABLE LOCATION OF THE TELESCOPE

A very discouraging feature about the William Pitt 27-inch Telescope is its location. The observatory is situated on a corner at the intersection of four roads, which carry considerable traffic. At night brilliant car lights flash into the dome through the slit from one or two roads at a time, and there is no quarter of the sky that is exempt from them. The southeast quadrant of the sky is more shielded than the others, but this one is frequently spoiled by cars driving in behind Marvin Hall and turning around.

Lights, of course, fog sensitive photographic plates. Even if the lights do not shine directly on the plate, the illumination of the interior of the dome is sufficient to cause an appreciable blackening of the plate when several cars pass by. The observer has some means of protecting the plate by quickly closing the shutter on the plate-holder box. But frequent closing of the shutter is a nuisance, and many interruptions make the net exposure times uncertain.

On nights of public gatherings at Hoch Auditorium the flood lights on the north side of the Engineering Laboratory are turned on, and these together with the numerous car lights make it quite impossible to take photographs with the telescope. Then too, the bright street lights on the north practically prohibit photographing of the northern half of the sky.

Another discouraging feature is the immense amount of dust stirred up by passing cars on the south road and the drive behind Marvin Hall. The fine dust floats in the air for some time and this, in turn, is illuminated by car lights--causing a diffused light. Dust floats in the dome on to the telescope and observing platform in considerable quantities. This makes it necessary to clean the mirror oftener than is desirable. Within a few days after cleaning the observing platform, it becomes so filthy again that it is highly undesirable to observe in one's good clothes.

CONCLUSION

Getting the William Pitt 27-inch Telescope ready for photographic observations is a lengthy and somewhat complicated procedure. It usually takes twenty minutes or more before one is ready to begin exposing the plate to a star field. It is often difficult to find a suitable guide star, and this act generally consumes several minutes of time.

The electric power supplied in the winter season was found to be quite constant. From his experience, the writer is inclined to believe that no guiding is needed for 15-minute exposures or less on objects near the meridian. Once the Relays are carefully adjusted, all that is needed is to set the telescope on the field and let it "run". However, the writer has the feeling that the drive-control has not worked as satisfactorily during the latter part of April and May, 1939. This may be due to fluctuations in the voltage in the power line, which in summer is supplied from the city lines.

Preliminary Hartmann tests by Dr. Storer and the writer, independently, indicate that the William Pitt 27-inch mirror possesses a good figure, which is essential in getting small, sharp star images. Combination of the good figure and the photographic arrangement make the telescope a very efficient instrument in light-gathering power.

The seeing at Lawrence is good enough a fair proportion of the time to secure sharp images and reach faint stellar magnitudes. The 27-inch is probably as large as general seeing conditions would justify, however. The frequent and prolonged spells of cloudiness at Lawrence is a serious hindrance for various kinds of work requiring frequent and regular observation. Not much useful research can be accomplished in double star and planetary detail studies because of the lack of high quality steadiness in seeing.

Exposure times longer than an hour are not very practical because of various sources of extraneous light--tending to fog the photographic plates. Exposures of ½ hour or less are preferred, which is too short for nebulae, but is suitable for a study of star clusters and star fields. With the exception of the last mentioned program of work, the writer sees little hope of much useful research being accomplished until the telescope is moved to a more favorable location which would be free of obnoxious lights and dust.

It is desirable to locate an observatory on a hill to improve the steadiness of the air and escape the valley mists. The writer things that a hill-top about a mile or so southwest of the present location would be a decided improvement.