E.C. BARNARD'S PHOTOGRAPHS OF THE MILKY WAY AND COMETS

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Edward Emerson Barnard (1857-1923) was one of the greatest observational astronomers of all time. Barnard obtained a series of epoch making astrophotographs of the Milky Way during the years 1892 to 1895 using Lick's observatory Crocker Astrograph. These photographs were only published in 1913[1]. His last legacy was the *Photographic Atlas of Selected regions of the Milky Way* edited by Edwin B. Frost (1866-1935) and Mary R. Calvert (1884-1974) published posthumously in 1927.

Barnard's first wide-field astrophotographs were made with a 1-inch Voigtländer lens (April 29, 1889). This lens was too small for Milky-Way photography and a larger and with a greater light grasp was used soon after. At the end of July 1889 Barnard was using a 6-inch lens built by Willard & Co., Wholesale Photographic and Optical Wharehouse. This lens was described by Barnard:

Willard, from all I can learn, was not the maker of the lenses, but simply a photographic stock dealer. I have been informed that the lenses bearing his name were made by Charles F. Us[e]ner in New York City, who, in the early days of photography, made portrait lenses for such stock dealers as Willard & Co. and Holmes, Booth & Hayden. These large lenses were used for making portrait"[2].

The advent of the Willard lens into astronomical work was due to the total eclipse of the Sun, which was visible in northern California on January 1, 1889. Through the influence of Professor Holden, a large number of amateurs photographers, especially those in San Francisco and neighbouring cities, became greatly interested in this eclipse. Under the general supervision of Mr. Charles Burckhalter of the Chabot Observatory, Oakland, California, these amateurs photographers, many of whom were very skilful, were assigned positions in the line of totality to secure, with crude appliances, the best results obtainable in the representation of the corona. Some of the photographs were excellent, especially those taken by Messrs Wm. Lowden, F.R. Ziel and Wm. Ireland. Mr. Ireland was especially fortunate in being able to use a large portrait lens of some 6 inces aperture and 31 inces focus, which he borrowed for the occasion from Wm. Shew, a photographer on Montgomery Street, San Francisco, who had used the lens, which had originally cost several hundred dollars, for making fashionable portraits (especially in the late sixties). Though Mr. Ireland had no equatorial mount for the lens, his photographs were very successful, particularly in showing the great extent of the coronal streamers. Impressed by the excellent results from this lens, Director Holden purchased it from Mr Shew for the Lick Observatory with funds provided for the purpose by Hon. C.F. Crocker [3].

Barnard mounted the Willard lens in a wooden box camera and used it with a 6 ½" equatorial which served has is guiding telescope. The equatorial mount was equipped with a clock drive but numerous manual adjustments had to be performed during the long exposures. Barnard explained his guiding methods:

There was no means of illuminating any spider threads. Fine wires were, therefore, inserted between the lenses of a negative eyepiece. These were coarse enough to be just visible, in black relief, on the dark sky. A star in focus would be hidden behind these wires. To render it visible, therefore, the image of the guiding star was thrown slightly out of focus. The intersection of the wires placed

[1] Barnard, E.E. (1913). Photographs of the Milky Way and of Comets. Publications of Lick Observatory, vol. 11. http://www.astrosurf.com/re/photographs_comets_milky_way_Barnard.pdf
[2] Barnard, E.E. (1913). Photographs of the Milky Way and of Comets. Publications of Lick Observatory, vol. 11. (page 12)
[3] Barnard, E.E. (1913). Photographs of the Milky Way and of Comets. Publications of Lick Observatory, vol. 11.

over this small luminous disc for guiding, produced four small segments of light. During the exposure the illuminated quadrants were kept perfectly equal – the slightest deviation from equality could be detected. This method permits great accuracy in guiding, even with a small telescope, but requires a brighter star to guide than usual.

The following measures were made of the lens by the writer soon after its purchase by Lick Observatory: Diameter of the front lens, 5.85 inches = 148.6 mm, Solar Focus 42.59 inches = 108.2 cm, Diameter of the back lens, 6.73 inches = 171.0 mm, Solar Focus, 70.2 inches = 178.3 cm [4].

Barnard's first long exposure photographs with the Willard lens were made on July 28, 1889. The exposure lasted for 1h 17 min in Scutum and it was cut short by clouds. On August 1 another long exposure in Sagittarius was made with better results (Figure 1).

Figure 1- Barnard's first long exposure photograph of the Milky-Way (August 1, 1889).

He wrote later:

"I specially selected as possessing the most intricate and complex structure of any portion of the Milky Way above the horizon[5]*"*

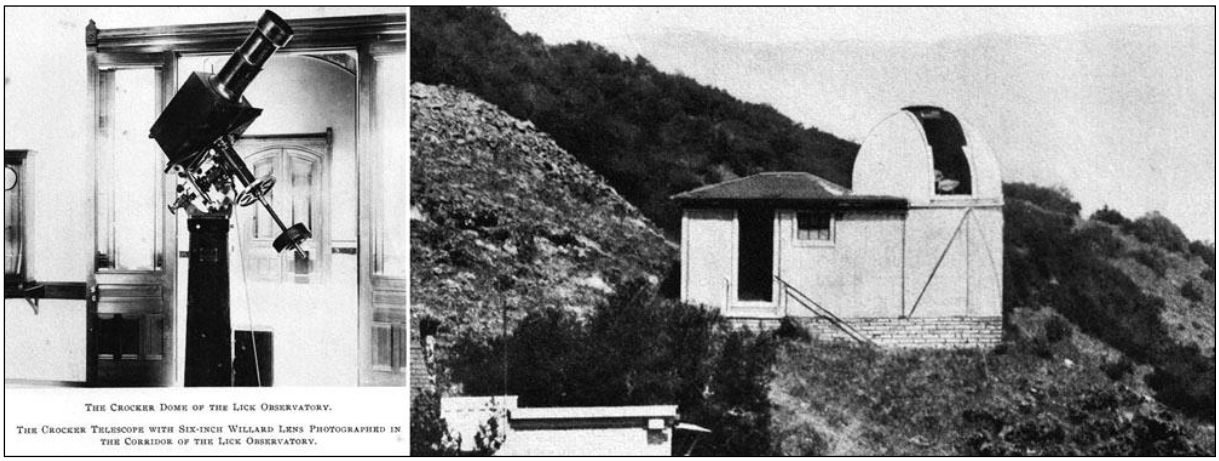
The total exposure time was 3h and 7 min. Barnard described this first plate:

[4] Barnard, E.E. (1913). Photographs of the Milky Way and of Comets. Publications of Lick Observatory, vol. 11.

[5] Barnard, E.E. (1890). On the Photographs of the Milky Way at the Lick Observatory in 1889. *PASP*, 2: 240-244

This remarkable picture shows the cloud-like forms like waves of spray. A curving lane of darkness runs from the lower left-hand portion of the picture and curves gracefully upwards to the place of Jupiter. It is singularly like the stem of a great leaf. At the middle of the picture it is seen to pass behind some of the clouds of stars and emerge beyond, showing us clearly which part of the Milky Way at that point is nearest to us… The black hole is seen to the left of centre, with the small cluster (NGC 6528) as a white spot close to the right of it [6]*".*

During August 1889 Barnard used the Willard lens to photograph M 11 (August 2), M 32 (August 21) and M 45 (August 23). In December of the same year the lens had become *"changed somehow, so that it gives a penumbra to stars*". The lens was sent to John Brashear's optical shop in Pittsburgh to be refigured. It was finally remounted on its own equatorial mount in its own dome (1892) (Figure 2).



THE CROCKER DOME OF THE LICK OBSERVATORY.

THE CROCKER TELESCOPE WITH SIX-INCH WILLARD LENS PHOTOGRAPHED IN THE CORRIDOR OF THE LICK OBSERVATORY.

Figure 2- Crocker Astrograph, Lick Observatory.

The work with this telescope was also described in detail by Barnard[7]:

On chilly and cold nights I wore an Eskimo coat made of reindeer skin, and heavy rubber overshoes. Frequently, on bringing the eye to the eye to the telescope on such night a spark would discharge with a light shock between the eye and the eyepiece. This was extremely annoying, and finally became so disagreeable that it was found convenient frequently to touch the metal if the instrument. Which would produce a discharge from the finger instead of from the eye. The probable explanation of this phenomenon is that it was due to the fur coat and the insulation of the rubber overshoes, the body becoming electrically charged like a Leyden jar. The approach of the eye to the eyepiece would discharge this electricity into the telescope from the eye. Neither telescope, at the time, had any electrical appliances. On one occasion, when going to bed in the early morning, the conditions were such that rubbing the hands over the sheets produced a perfect shower of sparks, apparently threatening to set the sheets in fire (Figure 3).

After beeing mounted it is own dome, the Crocker astrograph was mainly used to image the Milky Way from 1892 to 1895 using Collotype Photographic Plates were used with a scale of 1.81 degrees per inch. Barnard also used this instrument to photograph a number of bright comets, including Comet Brooks (1893), Gale (1894), Holmes (1892) and Swift (1892).

Barnard photographed in June 1892 the Sagittarius star cloud with an exposure of 4 h and 30 min. The "black holes"[8] were sharply defined in this image leading Barnard to remark that "*if drawn with a brush and India ink it could not be any more definite"*.

[6] Barnard, E.E. (1890). On some Celestial Photographs made with a large portrait Lens at the Lick Observatory. *MNRAS*, 50: 310-314.

[7] Barnard, E.E. (1913). Photographs of the Milky Way and of Comets. Publications of Lick Observatory, vol. 11.

In 1984 Barnard used another short-focus "magic lantern" lens to image the Milky Way. It was bought for only 7 US$. It was 1 ½" in diameter and 3 ½" focus. Using this lens attached to the Crocker telescope equatorial mount Barnard was able shoot wide-fields (20 to 25^{o} across). The entire constellation of Orion was photographed in October 1984 and the curved nebulosity we now call "Barnard's Loop" was imaged in great detail[9].

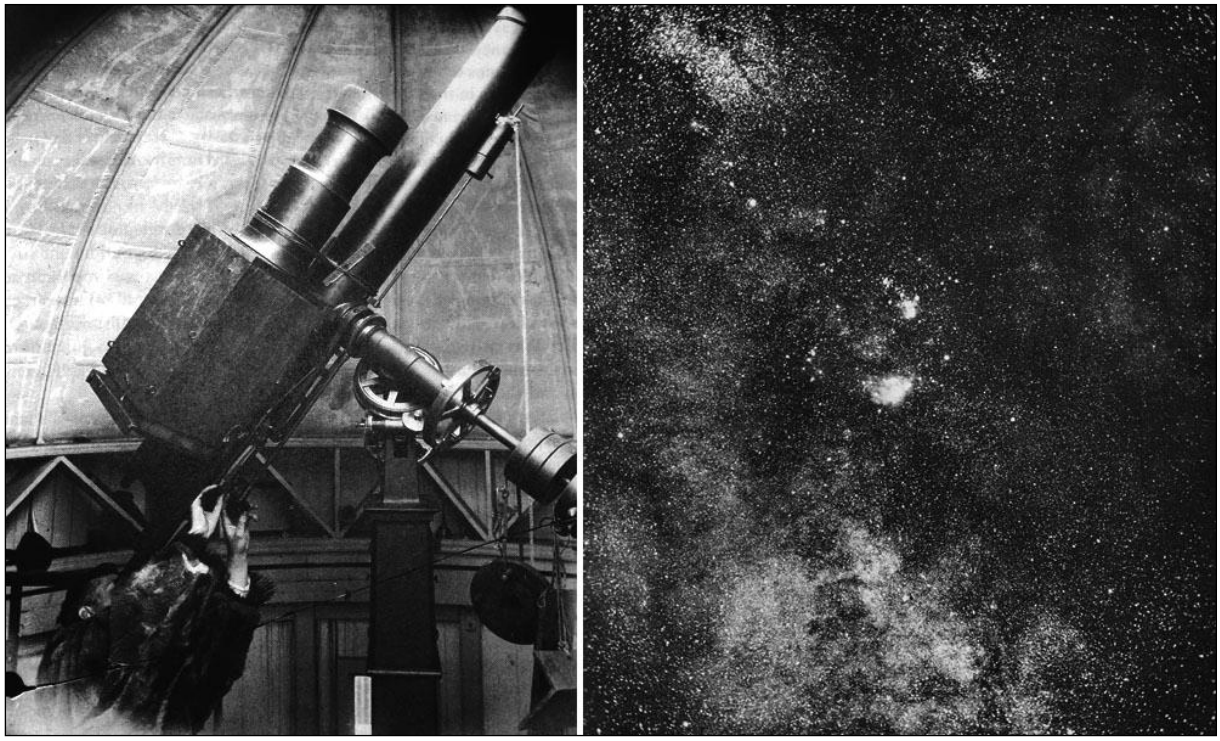


Figure 3- Crocker Astrograph and Barnard wearing a reindear coat (left). Plate 51 – Sagittarius (3 h exposure) Barnard, E.E. (1913). Photographs of the Milky Way and of Comets. Publications of Lick Observatory, vol. 11 (right).

A.A. Common two years later addressed the Royal Astronomical Society when Barnard received it's Gold Medal:

Professor Barnard has shown us with what modest means good results can be obtained, with only a small but a cheap lens, such as may be found in any magic lantern. No doubt his early experiences were valuable in giving him his this knowledge of what can be done with humble apparatus, but we must certainly admire, not merely his skill, but the courage of a man who could, under the very shadow of the great 36-inch refractor, demonstrate the merits if a lens which could be bought for a few shillings.

After a delay of more than twenty years *Photographs of the Milky Way and of Comets* was finally published. The work was only completed in 1913 and was published as part of the Publications of Lick Observatory (volume 11). Only a thousand copies were printed and Barnard sent copies to several astronomers and Institutions (including the Lisbon Observatory).

[8] Dark nebulas, a dense type of interstellar cloud that it obscures the light from the background emission, reflection nebula or background stars

[9] Barnard's Loop was discovered by W.H. Pickering in 1889.

Joel H. Metcalf reviewed Barnard's book in 1914[10]:

No publication of the Lick Observatory since Volume VIII, which contained reproductions of the photographs taken by Professor James Edward Keeler with the Crossley reflector has such general interest as Volume XI, which has just issued from the press. It contains reproductions of photographs of the Milky Way and of comets made with the 6-inch Willard lens and Crocker telescope during the years 1892 to 1895 by Professor E. E. Barnard at that time Astronomer in the Lick Observatory. As the Crossley telescope is 36 inches in aperture, one might think that the next photographs reproduced would be those taken with some larger instrument, say of 60 or 100 inches aperture; but, instead, these photographs, which were the first of the kind and most wonderful in their results, were made with an instrument nominally only six inches in aperture and really smaller. Professor Barnard has been a daring and a most successful astronomical discoverer, but never did he show such radicalism as when he, one of the keenest sighted and most experienced of observers, spent night after night in photographing the sky with so small an instrument and one that was not even made for the stars. It was originally a portrait lens, of the form adapted to the old "wet-plate" process of photography, and long ago discarded by photographers as a result of the invention of the "dry-plate" and the anastigmatic lens. The volume under review is a proof that the old scriptural saying may have a modern application, for in it the lens that the builders rejected is head of the corner. How the lens came to be used in astronomical work on Mount Hamilton is described by Professor Barnard in the introduction. The first experiments in astronomical work with an old fashioned portrait lens of the Petzval type were made by Dr. David Gill at the Cape of Good Hope on the great comet of 1882. In January, 1889, a 6-inch "Willard" lens was used by Wm. Ireland to photograph the total eclipse of the Sun, and its success then led to its purchase by Director Holden for the Lick Observatory, the funds being provided by the Hon. C. F. Crocker, Regent of the University of California. The information given shows that the lens was neither made by Willard nor is it six inches in aperture. Willard & Co., who have their name upon it, were stock dealers only. The lens was made by Charles F. Usner in New York City. His name should not be forgotten, for it is doubtful if lens-makers of to-day can turn out an instrument greatly its superior. It is true; however, that Brashear has refigured it, which doubtless adds much to the sharpness of its images. The chief limitation of the original lens must have been the fact that the optical and visual foci coincided, as was necessary for focusing in the old wet-plate process. A modern instrument made exclusively for astronomical photography would have a better colour correction and would give sharper images; otherwise it could not be greatly improved upon to-day. It is rather disconcerting that so little progress in the construction of astronomical lenses of large relative aperture has been made in the last fifty years. The only improvement, in the opinion of the writer, is the 10-inch Franklin-Adams lens made by Taylor of Cooke & Co., York, England, and it is practically impossible to get discs of the proper kind of glass for apertures larger than this. Returning to the Willard lens, it is interesting to know that the clear diameter of the front lens is only 5.85 inches and that this is still farther cut down by a diaphragm less than four inches in diameter, placed between the front lens and the back lens of the combination. But lenses, like wisdom, are justified of their children and Professor Barnard has shown what this lens can do in skilful hands. In the volume are 128 collotype plates, 89 of them of regions of the sky mostly along the Milky Way and the rest of comets. Professor Barnard's decision to use the collotype process seems especially fortunate. The reproduction of star pictures to retain the fainter stars without loss of the fainter detail in the nebulae is an art in itself, as difficult perhaps as making the original photographs. Mr. A. B. Brunk of the Chicago Photogravure Company has succeeded admirably and must have put much patience and many labours of love into this work. Not all the reproductions are equally good, but when Professor Barnard says, as he does often, "this is an excellent reproduction," there must have been very little in the original that does not show in the copy. Professor Barnard has given some very important technical hints in regard to the production of astronomical photographs in his Introduction. One might wish he had gone farther and told us about his enlargements of the original negatives — why he did not use contact reproductions and what was done to increase contrast in the tails of comets and the dark places and lanes in the Milky Way. In some of the pictures which have been several times enlarged the background shows a mottled appearance, doubtless due to the grain of the plate, but which some might take for a background of very faint stars. Just a few words in regard to the plates themselves. The large number is food for thought for those who live in the cloudy atmosphere of the effete East. What a wonderful climate has Mount Hamilton to make it possible to get such a large number of long exposure plates in three or four years! For one who has ever tried to take a long-exposure plate there is a deep appreciation of the long and wearisome hours spent by Professor Barnard, sitting

[10] Metcalf, J.H. (1914). Review of E.E. Barnards: "*Photographs of the Milky Way and of Comets*". PASP, 16:241-245.

with his eyes "glued" to the following telescope. Without counting the comet pictures and making no allowances for failures, which are very common with most observers, a rough estimate shows that he spent 286 hours with the shutter open taking the Milky Way pictures alone, and in the list many continuous runs of five hours, six hours, and even seven hours are found, and one of them (the picture that shows the nebulosities around the Pleiades) is of ten hours and fifteen minutes' exposure. The results of these indefatigable labours are a wonderful addition to our knowledge of the Milky Way and of comets. The human eye directly, no matter how great the power of the telescope, could never have seen the structure of the Galaxy or of comets' tails. The cumulative effect of light on a photographic plate and the fact that it does not require a magnification of four or five to each inch of aperture, as does the human eye, makes these wonderful pictures possible. There is one thing about these pictures, however, that it is well enuf to bear in mind. The relation between the brightness of the stars and the brilliance of the nebulosities is a purely artificial one. It would be possible to photograph every one of the stars upon these plates without showing a particle of nebulosity. It would also be possible to photograph the nebulosities and show scarcely any stars. A short-focus lens of great relative aperture "sees" the nebulosity rather than the stars and a long-focus lens of small aperture and great defining power would take the stars and not the nebulosity. I must not say anything about the pictures in detail. They speak for themselves, and added to that, Professor Barnard has for many of them pointed out features and made judgments which to the reviewer seem on the whole most just and conservative. Undoubtedly, however, there will be considerable difference of opinion as to how certain features should be explained. Some of the forms shown in the Milky Way must be due to chance, just as the "crouching beast" (Plate 45) is, and it would be folly to try to explain forms that have only accident for their cause. That remarkable line of stars on Plate 39 may be an example. If a person should splash ink in small spots on a wall, he would doubtless discover some interesting forms, but they would be as imaginary as the Castles or the Camels of the Clouds. There are other pictures, however, in which the streaming of stars in lines and net-work seems most real. The interpretation of the vacancies and the lanes is interesting. Professor Barnard thinks that in certain cases the absence of stars is due to an absorbing medium simply covering up the stars, and that the large telescopes to which he has had access show some of these to be slightly luminous. One could wish that he had correlated these observations with some of his more recent photographs of dark lanes, where, if the writer's memory serves, he took the point of view that the lanes were darker than the general background of the sky on his plates. It is possible that this difference might be reconciled, — perhaps by the difference in the instruments. Could an object be darker than the surrounding sky to a Petzval doublet and brighter to the human eye in a 40-inch refractor? Professor Barnard's comet pictures are most interesting. Brooks' Comet of 1893 must have been much like and perhaps more remarkable than the famous Morehouse Comet. It is a pity that other astronomers did not get a series of photographs of it, for it evidently would have given opportunity, even better than Morehouse's Comet, for measurements of regression of luminous matter in the tail. Professor Barnard's ingenious and successful combinations of photographs taken on different nights to show the freak motions and changes in the tail are also most interesting. That these changes cannot all be explained by eruptive disturbances and by varying speeds of repulsion of luminous particles from the head, without the necessity of assuming some kind of streaming in space, does not seem to me proved. The volume as a whole is a notable contribution to astronomy. It is a great credit to the Lick Observatory, to the people whose generous contributions made its publication possible, to the- Willard lens, and, most of all, to Professor Barnard. Winchester, Mass., November 4, 1914.

By the time *Photographs of the Milky Way and Comets* was finally published (September 1914) Barnard was already hard at work in reproducing the photographs obtained with the Bruce Telescope that became his last legacy, the *Atlas of Selected Regions of the Milky Way*[11].

[11] Ré, P. (2010). Barnard's Photographic Atlas of Selected Regions of the Milky Way. http://www.astrosurf.com/re/atlas_barnard_1927.pdf

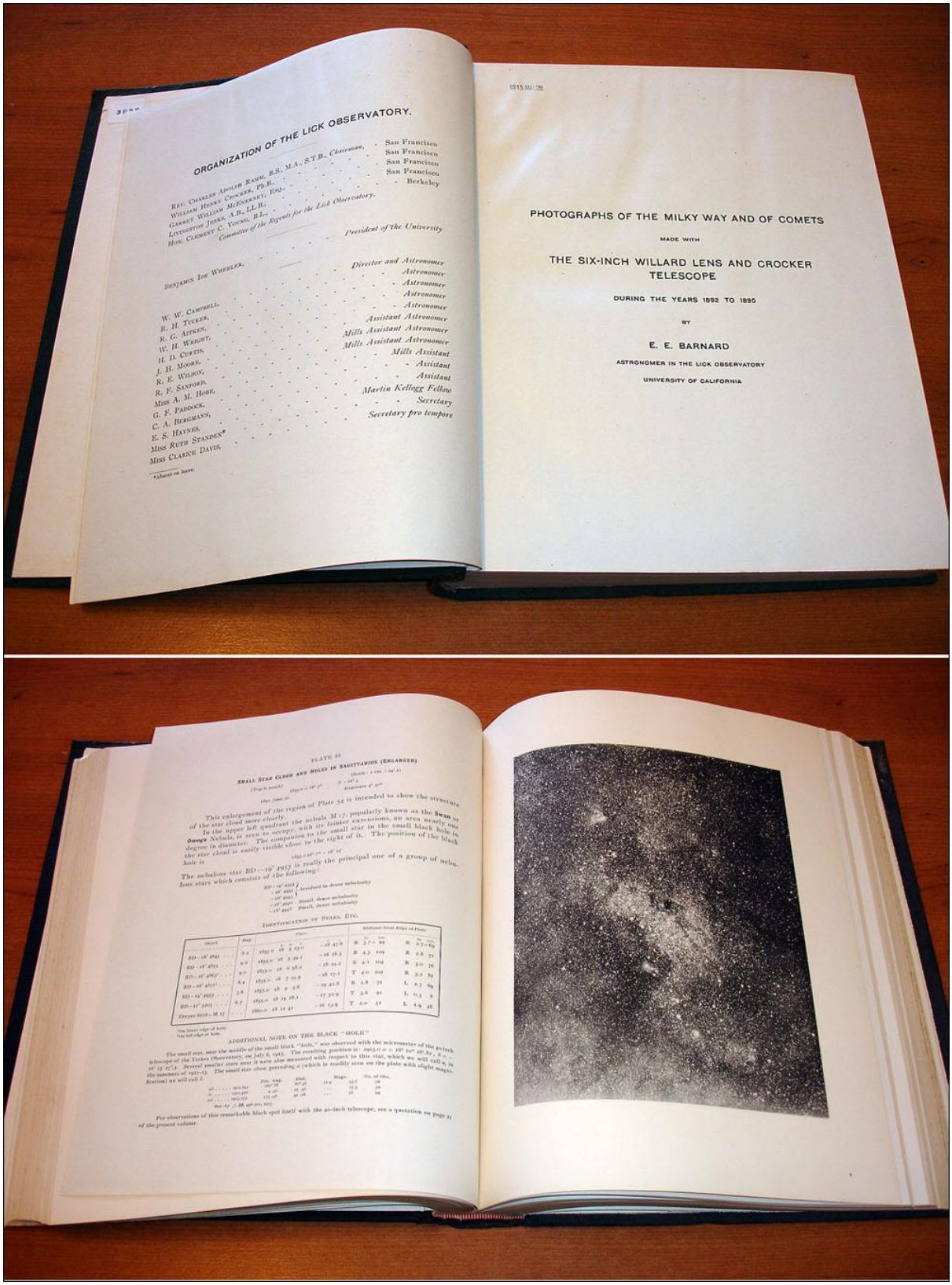


Figure 4- Barnard, E.E. (1913). *Photographs of the Milky Way and of Comets*. Publications of Lick Observatory, vol. 11. Library of the Lisbon Observatory.

Figure 5- Barnard, E.E. (1913). *Photographs of the Milky Way and of Comets*. Publications of Lick Observatory, vol. 11. Authour's personal copy.