> Occasionally the Smithsonian challenged all comers to a game of duplicate whist, but more often the group would gather around the fireplace for discussions of plans of work or of the state of the world in general. Hale's amazing breadth of interests, his great personal charm, and his stories of important figures in science and national and international affairs make these evenings stand out in memory.[53]

8

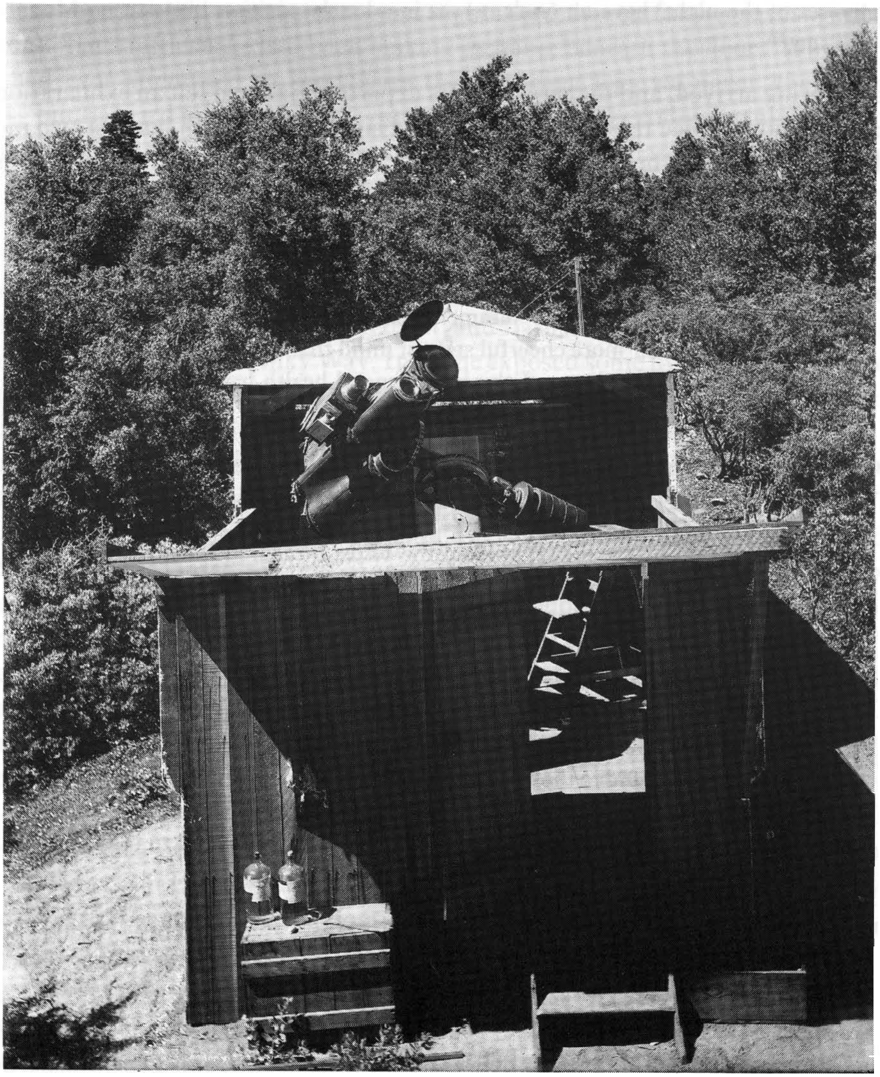
Barnard decided to erect the Bruce telescope on a small hillock on the trail midway between the Monastery and the observatory shop. By the end of his first month on Mt. Wilson, he had mounted together on the cement pier on this site four telescopes – the 10-inch and 6¼" photographic telescopes, and a 3½" doublet and a lantern lens.

Barnard made his first exposures on the night of January 27, and over the next seven months set himself a feverish pace of work. For many years he had been used to getting along with less than four hours of sleep a night. On Mt. Wilson he often gave up sleep altogether. As Adams later recalled:

> Barnard's hours of work would have horrified any medical man. Sleep he considered a sheer waste of time, and for long intervals would forget it altogether. After observing until midnight, he would drink a large quantity of coffee, work the remainder of the night, develop his photographs, and then join the solar observers at breakfast. The morning he would spend in washing his plates, which was done by successive changes of water, since running water was not yet available. On rare occasions he would take a nap in the afternoon, but usually he would spend the time around his telescope. He liked to sing, although far from gifted in the art, but reserved his singing for times when he was feeling particularly cheerful. Accordingly, when we at the Monastery heard various doleful sounds coming down the slope from the direction of the Bruce telescope, we knew that everything was going well and that the seeing was good.[54]

On first arriving on Mt. Wilson, when he was guiding the Bruce telescope alone in the darkness, Barnard sometimes experienced the terror that he had known at earlier times. The observatory was still in the construction stage, and sometimes he was the only one on the mountain. Moreover, he recalled, 'the Bruce Observatory was separated quite a little distance from the monastery, which was hidden by heavy foliaged spruce trees, so that while observing I was essentially isolated from the rest of the mountain':

> I must confess that at times, especially in the winter months, the loneliness of the night became oppressive, and the dead silence, broken only by the ghastly cry of some stray owl winging its way over the canyon, produced an uncanny terror in me, and I could not avoid the dread feeling that I might be prey any moment to a roving mountain lion. The sides of the observatory were about five feet high, so that it would have been an easy thing for a hungry mountain lion to jump over it and feed upon the astronomer. So lonely was I at first that when I entered the Bruce house



Bruce photographic telescope in its temporary shed on Mt. Wilson, August 1905. Archives of Mt. Wilson Observatory, Huntington Library

> and shoved the roof back I locked the door and did not open it again until I was forced to go out.[55]

Fortunately, with the coming of spring, the loneliness and oppressiveness that he experienced during the winter months began to lift. A good part of this had to do with the reawakening of insect life, which 'began its notes in the chaparral':

> the dread of the night soon passed away and the door was left open and it became a pleasure to sit and listen to the songs of nature while guiding the telescopes in long exposures, heedless of all beasts of prey. No one knows what a soothing effect these

> 'noises of the night' have on one's nerves in a lonely position like that on Mount Wilson.[56]

Once spring arrived, and the night terrors departed, Barnard felt an exhilaration that he had not known since the early days on Mt. Hamilton. Though his first two months had been hampered by heavy rains, by May he was getting beautiful photographs and was 'delighted with the conditions on the mountain.'[57] Hale wrote to Frost:

> [Barnard] is getting magnificent photographs that will be a great credit to the Hooker Expedition from the Y[erkes] O[bservatory]. I never saw him in such high spirits as at present, since the summer weather began. Even through the bad weather he was in a far more cheerful state of mind than he would have been under similar circumstances at home. I think his general health has improved considerably.[58]

Adams also noticed the improvement in Barnard's spirits. 'He at once fell in love with the mountain and everything connected with it,' Adams remembered afterwards.

> He was fascinated by the views, studied the birds, measured the growth of yucca stalks, and treasured the sight of a deer. I remember his excitement one winter morning when he came in to breakfast and announced that he had just seen a wildcat walking through the snow outside his bedroom window . . . Barnard's devotion to the mountain may be judged by the fact that during four months of his stay he made but one trip to the valley. This was to Sierra Madre to see a notary and to have his hair cut, after which he turned around and started back up the trail. His health was excellent at this time, and to those who knew him in later years it will be a surprise to learn that he once clambered down the steep walls of the ridge below the Monastery, crossed the deep canyon, and climbed the side of Mount Harvard to the toll road, perhaps as difficult a trip as any around the mountain top.[59]

Only Frost was worried that Barnard might overdo it, and wrote to him: 'It is a pleasure to know that you are having such fine weather for work, but I hope you will not overdo, and you will give up some clear nights when you need sleep.'[60] As usual, Barnard ignored this advice.

Since there was no running water on the summit, water, including that Barnard used for developing his plates, had to be packed up the mountain by burro from Strain's Camp, named after the first pioneer who had settled on the mountain. It was located on the north side of the mountain, where there were springs. The old burro which dutifully performed this laborious task was named Pinto. Barnard became especially fond of him when he discovered that his hair was much finer than a human's – thus exceptionally well suited for making crosswires for a guiding telescope.

Barnard's adventures on Mt. Wilson also included a rather close scrape with a rattlesnake. The floor of the small wooden building which housed the Bruce telescope was about three feet above the ground, and a trap door allowed access to the weights of the driving clock which were suspended by cable. When guiding the telescope, Barnard often opened the trap door and sat on the floor with his legs dangling through the opening. One summer morning at breakfast he casually mentioned that he had been hearing strange rustling sounds for several nights, and that on further investigation he had found that a rattlesnake had been making its home beneath the floor. 'Whether the snake had ever attempted to investigate the intruding legs we never knew,' wrote Adams, 'but Barnard took the episode quite calmly and on the following night [after the snake had been killed] the trap door was open as usual.'[61] Barnard later quipped that it must have been a friendly snake and was there for the purpose of warming the observer's feet.'[62]

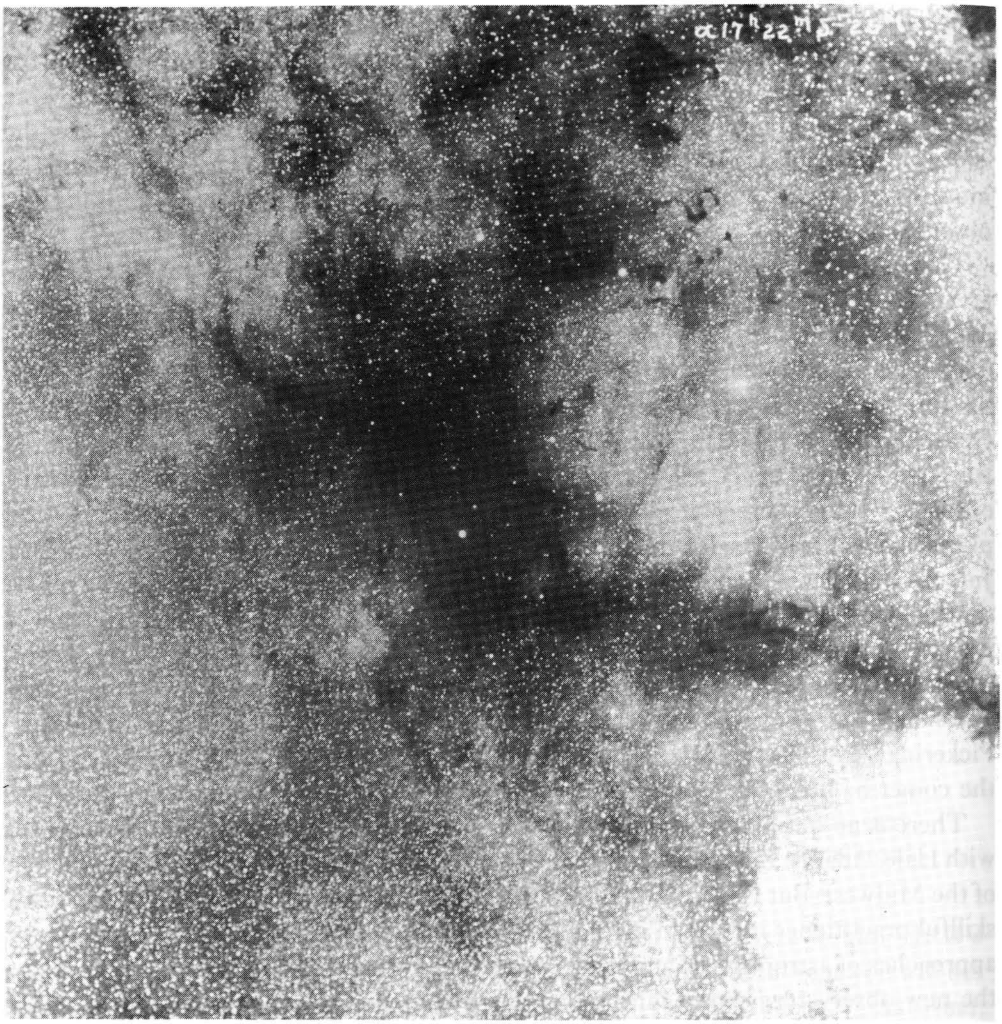
Generally, Barnard found the skies at Mt. Wilson much more transparent than those at Yerkes – after the drenching rains early in the season, the dust which had been a matter of concern had completely settled out, and Barnard was obtaining magnificently deep plates of the southern Milky Way. In all, he exposed some five hundred plates with his three telescopes and his lantern lens. He photographed the vacant regions of ρ Ophiuchi and θ Ophiuchi, which had been discovered with the Willard lens, on the larger scale of the Bruce telescope, and in the search for diffused nebulosities Barnard exposed a large number of plates on the upper part of the Scorpion.[63] Many of the plates, by chance, recorded the trails of faint asteroids, and on three plates exposed on July 22, 1905, he recorded the trail of an unknown comet. However, he did not notice the trail for over a year. 'The trail was rather conspicuous,' he then wrote, 'and how it was overlooked at Mount Wilson is a mystery, unless it was from the wearied condition of the observer at the time, for a sharp lookout was generally kept for just such objects.'[64] Unfortunately, he had not recorded it on any other plates; a search by E. C. Pickering's assistant, Henrietta Leavitt, of Harvard plates also failed to turn it up, and the comet had to be given up for lost.

There is no question that Barnard would have loved to have stayed on Mt. Wilson with Hale, Adams, Ellerman, and Ritchey, rather than return to the depressing winters of the Midwest. But Frost would never have agreed to give him up. Moreover, he was a skillful practitioner in the old methods of astronomy rather than a pioneer of the new approaches of astrophysics, and it was on the latter that Hale had staked the future of the new observatory. So in mid-september 1905, after a stay of only eight months, Barnard packed up the Bruce telescope and his precious plates and, escorted down the mountain early one morning by Adams, returned east.

9

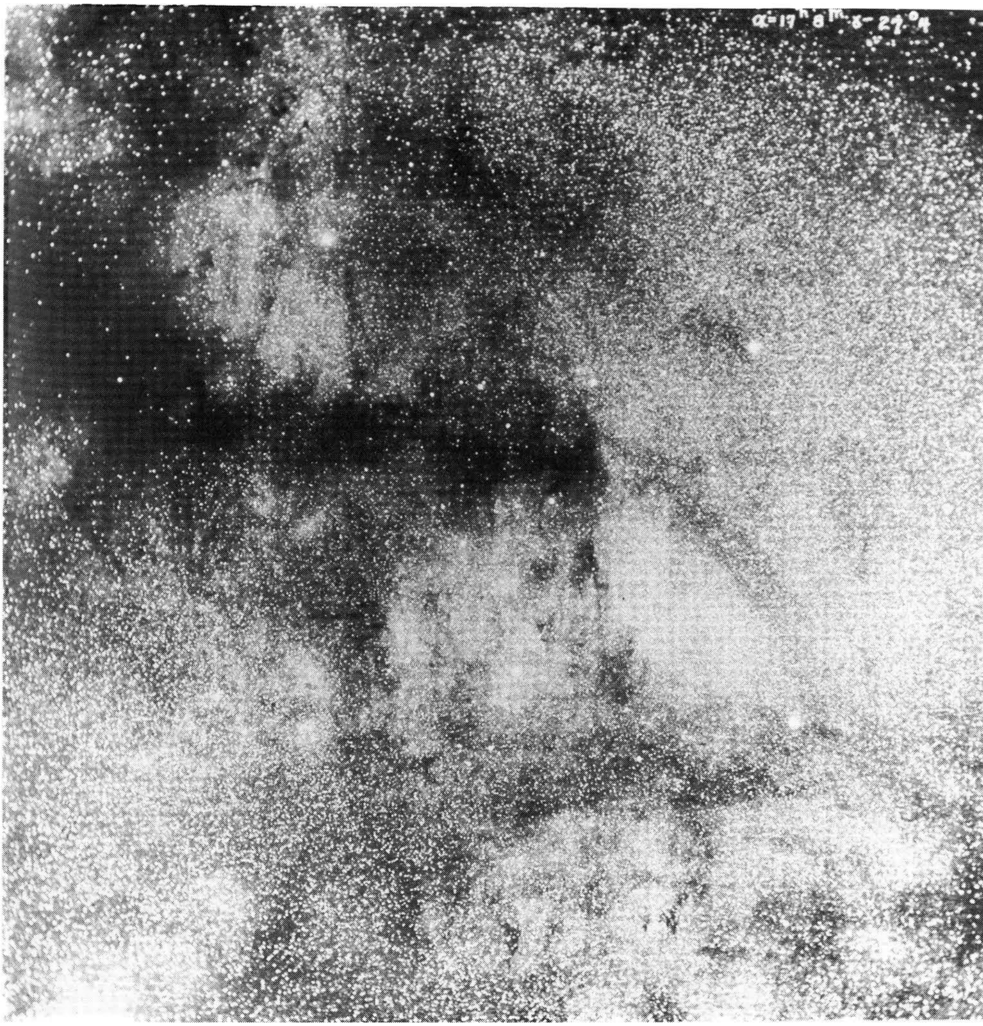
On returning to Yerkes, Barnard remounted the Bruce telescope in its small dome, where it remained until the telescope was moved and the dome torn down in the early 1960s.[65] He returned to Wisconsin in time for another miserable winter. 'This has been an awful bad winter for observing,' he summed up to Wesley in 1906; 'no clear weather at all hardly.'[66]

The oppression of that winter was lightened somewhat, however, by the arrival of his niece, Mary Rhoda Calvert (one of Ebenezer's daughters), who came from Nashville to join the Barnard household. A self-effacing woman, she devoted herself entirely to



Pipe Nebula, photographed with Bruce photographic telescope at Mt. Wilson; the plate above shows the region of **0** Ophiuchi and eastward, and is a 4 hr 45 min exposure taken on June 30, 1905; the plate opposite follows the stem of the 'pipe' through Ophiuchus into Scorpio and is a 4 hr 33 min exposure taken on June 28, 1905. Yerkes Observatory

Barnard and his work, helping him in the office with correspondence and computations, and after his death remaining at Yerkes where she served as chief computer and photographic technician for many years. She was one of the unsung women of astronomy during an era when discrimination against women was flagrant, as demonstrated by the following letter written by Frost to a woman applying for a computer position at the observatory: 'We give preference to men for this work, when we are able to get them, because they can assist in the observing with the telescope, which is too heavy for a woman.'[67]



After the weather began to improve in the spring of 1906, Barnard used the 40-inch for a series of visual observations of Phoebe, the ninth satellite of Saturn which had been discovered photographically by W.H. Pickering in 1898, and of the fifth and sixth satellites of Jupiter, the latter discovered by Perrine at Lick in 1905.

In the summer of 1907, Mars came to a good opposition, but because of its far southerly declination Barnard was unable to get satisfactory observations with the 40-inch. Typical notes from his observing books read: 'The outlines of the "seas" are strong and well defined. The air is like running water in front of the planet.' And: 'Have taken off the diaphragm. Full aperture now – though the image is not so well defined, I can once in a while really see it better than with 15 inches . . . The planet is very low and the air is moving across in waves.'[68]

On the other hand, his observations of the phenomena of Saturn's passages through

Region north of 0 Ophiuchi; a 3 hr 30 min exposure by Barnard with the Bruce photographic telescope at Mt. Wilson, May 8, 1905. The S-shaped marking north of 0 Ophiuchi is the 'snake nebula,' B72 in Barnard's catalog of these objects, shown also in the previous plate. Yerkes Observatory

the ring-plane that year are classic. There had not been an opportunity to make such observations since 1891, when Barnard had noted the disappearance of the rings with the 36-inch refractor on Mt. Hamilton. The first of three passages of the Earth through the ring-plane occurred in April 1907, but Saturn was then too close to the Sun to be visible. Between then and the end of July, the 'dark' side of the rings was on view from Earth. Barnard was prevented by unusually bad weather from observing with the 40-inch in the early summer, and when he finally got underway, on July 2, he noticed

Barnard, Rhoda, Mary R. Calvert and two of her sisters at Yerkes Observatory in 1909. Courtesy of Professor Robert T. Lagemann

that 'the entire surface of the ring was easily seen, though the Sun was not then shining on its visible surface. Where it was projected against the sky, the ring appeared as a greyish hazy or nebulous strip.' In addition he described two 'nebulous condensations' of greater brightness on the ring on each side of the planet, which were of a pale grey color.[69] Barnard deduced at once that what he was seeing was not the actual sunlit edge of the ring, but the oblique surface of the ring shining by sunlight 'percolating' through the particles making it up. The condensations, however, continued to perplex him for some time.

The Earth made its second passage through the ring-plane on October 4,1907. With precautions such as using a hexagonal diaphragm over the object glass to collect the stray light into six rays, leaving clearer sky in between, and an occulter in the eyepiece to block out the planet, he was able to make out 'very feeble traces of the ring.'[70] He continued to observe with the 40-inch refractor throughout the rest of the fall, keeping up observations on the nearly edgewise ring's aspect almost daily and from hour to hour. During this interval the appearance of the ring and the condensations remained more or less unchanged until December **25,** when Barnard noted that the thread-like ring appeared much thinner than it had looked two weeks earlier. By then southern Wisconsin was experiencing its usual harsh winter weather. Barnard, though he had 'not been well' for some time, as he told Wesley,[71] had not refrained from his usual demanding observing schedule, but now he became seriously ill just as these phenomena were passing through another critical phase – the Earth was due to make its final passage through the ring-plane on January 7,1908. On January 2, he got up from his sick bed long enough to note that the ring was still visible in the 40-inch telescope, though 'very thin' and with a satellite at each end. 'Without occultation it was almost impossible to see any trace of the ring on the sky,' he noted 'The condensations were feebly seen as slightly brighter parts of the ring.' On January 5, the ring was much fainter, and no trace of it could be seen without the occulter. On January 6, with poor seeing, it was completely invisible, and Barnard concluded that the Earth must have passed through the ring-plane that night.[72]

In sending these critical observations to T. Lewis of the Greenwich Observatory, Barnard wrote: 'I have been sick in bed . . . and am up for a bit to day to get this off but shall have to go back to bed. I managed to get the observations of Saturn by taking big risks and wrapping up good to go into [the] big dome.'[73]

Having obtained the observations he sought, Barnard now collapsed into his sick bed, though he continued to work, whenever he felt strong enough, on the report of his observations for the *Monthly Notices of the Royal Astronomical Society* (the archives of the RAS show that he sent constant revisions and corrections which must have come close to driving the poor secretary, W. H. Wesley, mad). Finally he was able to clear up the mystery of the so-called condensations.[74] On comparing their positions with his earlier measures of the ring system, he discovered that they lined up exactly with the crape ring and the Cassini division, from which he hazarded the guess – correct, as we now know – that the Cassini division is not entirely devoid of particles. 'If. . . the Cassini division were filled with particles as closely clustered as they are in the crape ring,' he suggested,

> a satisfactory explanation of the condensations would be that they were simply due to the sunlight shining through and illuminating the particles in the crape ring for the inner condensations, and a similar effect of the Sun shining through the Cassini division and illuminating the particles in it would produce the outer condensations. The fact that the inner and outer condensations were essentially of the same intensity would require that the particles should be as closely clustered in the Cassini division as in the crape ring.[75]

This was a marvelous deduction, and has now been completely verified by the Voyager spacecraft images.

1 E. E. Barnard, 'The Total Eclipse of the Sun in Sumatra,' *PA,* 9 (1901), **528-44:534-5**

2 J. M. Bacon, 'Wadesborough, North Carolina,' in E. Walter Maunder, ed., *The Total Solar Eclipse 1900: Report of the Expeditions Organized by the British Astronomical Association to Observe the Total Solar Eclipse of 1900, May 28,* (London, Knowledge Office, 1901), pp. 1617

3 R. H. Tucker to his mother, February 17, 1901; SLO

4 EEB to GD, March 26, 1900; BL
5 EEB, undated notes; VUA
6 ibid.
7 ibid.
8 ibid.
9 Barnard, 'The Total Eclipse,' p. 529
10 ibid., p. 543
11 EEB, Sumatra notebooks in possession of Robert Lagemann
12 ibid.
13 Barnard, 'The Total Eclipse,' p. 540
14 ibid.
15 ibid.
16 S. A. Mitchell, 'With Barnard at Yerkes Observatory and at the Sumatra Eclipse,' *JTAS*, 3:l (1928), 27
17 ibid., p. 26
18 ibid., p. 27
19 EEB to W. H. Wesley, July 29, 1901; RAS
20 EEB, unpublished lecture notes; VUA
21 E. E. Barnard, 'Peculiarity of Focal Observations of the Planetary Nebulae and Visual Observations of Nova Persei with the Forty-Inch Yerkes Telescope,' *Ap J*, 14 (1901), 151–7
22 The discovery was actually made by Antoniadi, who complained to Wesley of 'M. Flammarion wedding his name to mine . . . merely as Director of the Juvisy Observatory.' EMA to W. H. Wesley, November 15, 1901; RAS
23 See James E. Felten, 'Light Echoes of Nova Persei 1901,' *Sky and Telescope*, 81 (1991), 153–7
24 Isaac Roberts, 'Herschel's Nebulous Regions,' *Ap J*, 17 (1903), 72–6
25 ibid.; Roberts's description of Herschel's field no. 25
26 E. E. Barnard, 'Diffused Nebulosities in the Heavens,' *Ap J*, 17 (1903), 77-80:78
27 ibid., 78. For an insightful discussion of Roberts vs. Barnard on this question, see David Malin, 'In the Shadow of the Horsehead,' *Sky and Telescope*, 74 (1987), 253–7
28 GEH to WWC, April 1, 1903; SLO
29 EEB to WWC, April 15, 1903; SLO
30 ibid.
31 Quoted in Helen Wright, *Explorer of the Universe: A Biography of George Ellery Hale* (New York, E. P. Dutton & Co., 1966), p. 161
32 Quoted in ibid., p. 165
33 GEH to J. S. Billings, July 6, 1903; HHL
34 E. E. Barnard, 'White Spot on Saturn,' *AJ*, 23 (1903), 143-4:143
35 EEB to GEH, December 29, 1903; HHL
36 GEH to EEB, March 9, 1904; HHL
37 GEH to WSA, March 7, 1904; HHL
38 EEB to GEH, March 23, 1904; HHL
39 E. E. Barnard, 'The Bruce Photographic Telescope of the Yerkes Observatory,' *Ap J*, 21 (1905), 35-48: 45
40 EEB to GEH, March 24, 1904; HHL

41 EEB to WWC, June 4, 1904; SLO
42 ibid.
43 EBF to GEH, March 26, 1906; HHL
44 EEB to GEH, November 4, 1904; HHL
45 EEB to GEH, November 10, 1904; HHL
46 EEB to GEH, November 24, 1904; HHL
47 EEB to GEH, December 22, 1904; HHL
48 EEB to GEH, December 29, 1904; HHL
49 ibid.
50 EEB, observing notebook; YOA
51 Wright, *Explorer* p. 188
52 ibid., p. 123
53 W. S. Adams, 'Early Days at Mt. Wilson–11' *PA*, 58 (1950), 97-115: 99–100
54 ibid., pp. 97–8
55 EEB, unpublished MS draft; YOA
56 ibid.
57 GEH to WWC, May 15, 1905; SLO
58 GEH to EBF, May 16, 1905; HHL
59 Adams, 'Early Days,' p. 97
60 EBF to EEB, July 27, 1905; **VUA**
61 Adams, 'Early Days,' p. 98
62 Philip Fox, 'Edward Emerson Barnard,' PA, 31 (1923), 195-200:199
63 E. E. Barnard, *Atlas of Selected Regions of the Milky Way*, E. B. Frost and M. R. Calvert, eds. (Washington, DC, Carnegie Institution, 1927), vol. 1, p. 7
64 E. E. Barnard, 'Photographic observations of an unknown comet on 1905 July 22 (1905 f),' *AN*, 174 (1907), 3–8:4
65 The Bruce photographic telescope is now at the Athens Observatory in Greece.
66 EEB to W. H. Wesley, April 4, 1906; RAS
67 EBF to Mary Lilly, February 19, 1912; YOA
68 EEB, observing notebook; YOA
69 E. E. Barnard, 'Observations of Saturn's Ring at the time of its Disappearance in 1907, made with the 40-in. refractor of the Yerkes Observatory,' *MNRAS*, 68 (1908), 346–60:346–7
70 ibid., p. 350
71 EEB to W. H. Wesley, November 30, 1907; RAS
72 E. E. Barnard, 'Additional Observations of the Disappearances and Reappearances of the Rings of Saturn in 1907–08, made with the 40-in. refractor of the Yerkes Observatory,' *MNRAS*, 68 (1908), 360-6:363-4
73 EEB to T. Lewis, January 11, 1908; RAS
74 Earlier astronomers had noted them, but had given incorrect explanations. Thus William Cranch Bond of Harvard had surmised that they were the edges of rings A and B seen through the Cassini division. Others had supposed that they were clumps of material in the rings, but Barnard had disproved this on January 6 by showing that they disappeared when the ring was exactly edgewise.
75 Barnard, 'Additional Observations,' pp. 365–6

20

The comet and Milky Way photographs

After Keeler died in 1900, W. W. Campbell became director of the Lick Observatory. One of his first actions as director was to find out what progress Barnard had made toward the long dormant project of publishing his Milky Way and comet photographs which he had taken at Mt. Hamilton in the 1890s. Though Barnard was then busy preparing for the Sumatra expedition, he had Hale do some experiments for him back East, which he hoped would lead to adequate reproductions of his photographs.' On returning from Sumatra, he was at first too discouraged to do anything further about the project. Nevertheless, Campbell queried him again in July 1902:

> I am anxious to help you in every possible way in the publication of your excellent photographs. If your funds are insufficient. . . it will give me great pleasure to make efforts for the securing of the funds. I really am very anxious that your volume should be issued as soon as possible. The photographs, in my opinion, are extremely valuable; and, in justice to yourself and to the Lick Observatory, – and to the whole profession, – the issue should take place as promptly as possible. I hope you will feel that I am actuated only by the most appreciative feelings for your successful work on the photographs.[76]

This generous and diplomatically phrased offer of help succeeded in stirring Barnard back to action. Though Hale's experiments had come to naught, Barnard decided to put his negatives in the hands of a Chicago firm specializing in the halftone process.'' Briefly he was encouraged, and for a while in the winter of 1902–3 it looked as if the project would soon be moving forward again. Hale, too, was doing everything he could to encourage Barnard, and assured Campbell:

> I shall do all I can to induce Barnard to rush the reproduction of his Lick photographs. In fact, I have spoken to him periodically on this subject ever since he dropped the work after his exceedingly disappointing experience in Chicago. He now has strong hopes of successful results with the half tone process . . . I fully agree with you that further delay in publication would be extremely unfortunate.[78]

However, the perfectionist was almost impossible to satisfy. He decided that the halftone process would never do, and went back to the collotype and photogravure processes again. Still he was unable to get satisfactory results, and early in 1907, with the project continuing to be stalled after more than a decade of effort, he told Campbell:

> You have doubtless had experiences in trying to get work of this kind done in a satisfactory manner, and can in part understand the sad disappointments that come from such efforts. To me the whole thing has been a most bitter disappointment. It has caused many an illness from worry over it.[79]

He promised Campbell that he would either have the work completed 'before the end of the present year,' or 'every cent of the money, dollar for dollar . . . will be returned to California, and I shall once more be free from worry in that direction.'[80]

Campbell, whose own frustration with the endless delays was by now mounting, made every effort to shore up Barnard's flagging spirits: 'I am glad to have your statement of the condition of the reproductions and of further experiments that are in progress. It has always been a great personal pleasure, and at the same time I feel it to be my genuine duty as Director, to promote work on your volume in every possible manner . . . You will understand from my several letters that I have not meant to urge haste at the expense of quality.' Presumably to underscore the point about his patience, he quoted from his own letter of July 1902, 'I am anxious to help you in every possible way,' etc.[81] Barnard replied somewhat defensively: 'I fully appreciate the interest you have shown in the matter. While I clearly understand that one can not hope for perfection in these reproductions I was fully justified in stopping the work where I did because of the introduction of errors that would have made the work unreliable.'[82]

A few months later, no further ahead than he had been and his spirits drooping because of the illness which had afflicted him all fall and had worsened with the winter, Barnard worried that he might die without having the matter resolved. On the day after Christmas 1907 – as he was in the midst of his crucial series of observations of Saturn's edgewise rings – he wrote almost hysterically to Schaeberle, who in 1898 had left Mt. Hamilton in disappointment after being passed over for the directorship after Holden's departure and was now back at Ann Arbor. Schaeberle, of course, had been one of the earliest supporters of Barnard's plans to publish his Milky Way and comet photographs, and Barnard wanted to explain to his former colleague why the publication had not yet appeared. 'It has been a heart rending affair,' he wrote, 'and I have finally given it up. The pictures already made are many of them full of errors and I don't propose to do anything with them':

> Life is short and uncertain, and I cant stand the strain any longer, I had hoped this year to make another effort to get the work out but disappointment again came to me. I would rather die than to have a faulty work go out. I have therefore decided to give up any more efforts, and to put the money out of my hands, as I do not want to die with anything in my possession that does not belong to me . . .
>
> To get this dreadful responsibility off my hands, I have decided to place the entire sum $2225 that was given me, into the possession of the Lick Observatory as a fund for some purpose or other. I have already spent in the work, over one thousand dollars – this shall be my loss . . . The whole thing has been a very sad affair to me and has caused me many heart aches and I want to straighten it out before I die. I had set my heart on these pictures, but I would infinitely rather lose personally what I have spent on them than to have the work go out full of errors.[83]

Soon afterwards, Barnard sent Campbell a check payable to the Lick Observatory for $2225, which was the entire amount he had collected in 1895, together with the printed sheets of the Milky Way reproductions that were already completed. Barnard would have preferred to return the money directly to the contributors, but this was impossible since many of them were now dead. He wrote to Campbell a complete history of the sorry affair, and concluded:

> My sole desire in the matter has been to put in the hands of astronomers a trustworthy set of reproductions of these Milky Way and comet photographs. I have no desire to get out a volume simply for the sake of the volume. Recognizing at last the hopelessness of bringing out these pictures to my satisfaction, and feeling of late the uncertainty of life, I have finally decided, while it is within my power (but not without much pain and disappointment) to close up the matter and to abandon the work to its fate.[84]

Barnard also sent a set of his reproductions to Wesley at the Royal Astronomical Society, describing them bitterly as 'the wreck of the Milky Way and comet volume.'[85]

The subject was closed as far as Barnard was concerned. However, Campbell, who just then returned from an eclipse expedition to Flint Island in the central Pacific Ocean, had no intention of allowing the matter to drop. The Lick director pointedly asked Barnard to indicate which of the reproductions sent to him were not satisfactory.[86] He was aware that Barnard had been ill, but he was also suspicious that Barnard's lapse of interest was partly a result of his having received a grant from Carnegie to publish his photographs taken with the Bruce telescope at Mt. Wilson. As he confided to University of California president Benjamin Ide Wheeler:

> For many years following 1895, Mr. Barnard's ambition appears to have centered in securing a considerably larger photographic telescope than the one he used here, – a 10-inch, whereas ours is a 6-inch. With this instrument he obtained another series of Milky Way photographs on Mount Wilson, California . . . [and] the Carnegie Institution was considering the reproduction of this later series . . . Mr. Barnard has not offered further information as to a reproduction of his later series . . . I shall be surprised if my duty in this direction does not lead to bad feeling in certain quarters, but I shall get full information before expressing my sentiments and taking action.[87]

Barnard responded to Campbell's further queries with annoyance. 'I thought my letter indicated that the thing is closed for me. I am sick of it.'[88] However, he gave Campbell the information requested, and thus Campbell succeeded in keeping the project, however precariously, alive. Though in late February 1908 Barnard was complaining to Wesley that he still did not yet have his strength back, he was feeling somewhat better, and wrote optimistically, 'I suppose I will be all right by the beginning of the spring and summer.'[89] Indeed, he was feeling well enough to resume his work at the telescope, which he had given up ever since he had completed his observations of Saturn's edgewise rings in early January. Now he was no longer talking about dying, and he was again looking at the problem of the Milky Way and comet photographs 'in a more hopeful way.'[90] Campbell suggested that he ought to carefully consider the implications of 'the prior, or even simultaneous, reproduction of a later series of photographs,' and added that 'I do not agree that the returning of the money to the donors, even if this impossibility could be carried out, would be doing justice to the donors, to yourself, or to the Lick Observatory.'[91]

Barnard did reconsider. In another three months, he was proceeding with further experiments in reproducing his plates with a firm in Boston, and was negotiating once more with A. B. Brunk of the Chicago Photogravure Company, the same firm with which he had broken off the contract more than ten years before.[92] Eventually he decided that Brunk was the best man for the job after all, but still he continued to drag his feet, prompting another round of irritated letters from Campbell. 'It is somewhat over a year since you wrote me concerning the Chicago proofs of the Milky Way photographs that "they are quite as good as one can expect,"' Campbell scored him in August 1909. 'In this matter which concerns us it can scarcely be denied that I have been reasonably patient.'[93]

The work continued for another two years. Finally Barnard pronounced himself satisfied with the one hundred and nine plates to be included in the volume, and paid tribute to the efforts of Brunk and the Chicago Photogravure Company. '[They] have done everything in their power to get the best possible results,' he told Campbell. 'They have disregarded expense. The manager, Mr. A. B. Brunk, has given his personal attention and a remarkable devotion to the faithful reproduction of the pictures':

> I think you will be pleased with the results – especially with the Milky Way pictures. The comet pictures were more difficult. The scientific accuracy of these (comet plates) has, however, been retained at the expense of looks in some cases . . .[94]

On finally receiving the proofs, Campbell was as relieved as Barnard to see an end to the project, and explained the unprecedented delays in completing it to the Comptroller of the University of California:

> Astronomical subjects are extremely difficult to reproduce satisfactorily, and Barnard's temperament is such that discouragements led him to put the subject entirely aside for two or three years at a time. Shortly after I became Director I insisted that he go on with the work, partly because the photographs were the first great successes in their lines, and partly to show our good faith with private contributors. Barnard's entire freedom from business ability has made the administrative questions difficult, but the scientific merits of the subject have been sufficient to preserve my patience.[95]

Barnard also provided an introduction and descriptions to go along with the plates, to which Campbell suggested a few editorial changes. He felt that Barnard ought to say something about Holden's role in acquiring the telescope – 'I feel sure that you will want always to remember having done him full justice' – and he also thought that Barnard would want to give credit to Colonel Crocker who had paid for the lens and the equatorial mounting.[96] Barnard agreed to make these changes, and also, regretting that no reference had been made in the originally prepared text to the work done by him in the summer of 1889, when he obtained his first photographs of the Milky Way, added such a reference to the description of one of the plates. He explained to Campbell that 'I have avoided any reference to the cause of my not continuing the work with the lens when first started, but some reference to the fact that the lens then passed out of my hands for some time is necessary. It has been put, however, in a form that can reflect on no one.'[97] The long and bitter struggle with Holden was thus sanitized.

After a delay of nearly two decades, the book was finally ready for the press. In all, a thousand copies of volume 11 of the *Publications of the Lick Observatory*, 'Photographs of the Milky Way and Comets,' were printed (another two hundred copies of each plate were left over in California, which Barnard wanted sent to him by freight).[98] Among those to whom Barnard sent copies were many of the great astronomers and institutions of the day. In addition, as an afterthought, he sent one to his brother, Charles, with whom he had hardly had any communication since the early days in Nashville. Charles's reply is touching:

> Just received your Book all O.K. I think it is just fine and it is highlay apreciated by me and I thank you many times for it and Shall keep is a allwas as a Prize.[99]

Barnard, of course, was not finished with the Milky Way – by the time 'Photographs of the Milky Way and Comets' appeared, in September 1914, he was already working on reproducing the photographs taken with the Bruce telescope for what eventually became his *Atlas of Selected Regions of the Milky Way*. But his photographs with the Bruce, wonderful as they are, do not decrease the significance of those taken with the Willard lens, whose value, Campbell justly wrote, 'from my point of view, is immensely increased by the fact that they represent the first great pioneer successes.'[100]

1 WWC to EEB, February 1, 1901; EEB to WWC, February 6, 1901; SLO
2 WWC to EEB, July 10, 1902; SLO
3 EEB to WWC, February 26, 1903; SLO
4 GEH to WWC, April 15, 1903; SLO
5 EEB to WWC, January 8, 1907; SLO
6 ibid.
7 WWC to EEB, January 19, 1907; SLO
8 EEB to WWC, February 8, 1907; SLO
9 EEB to JMS, December 26, 1907; SLO
10 EEB to WWC January 27, 1908; SLO
11 EEB to W. H. Wesley, January 28, 1908; RAS
12 WWC to EEB, February 6, 1908; SLO
13 WWC to Benjamin Ide Wheeler, February 8, 1908; SLO
14 EEB to WWC, February 11, 1908; SLO
15 EEB to W. H. Wesley, February 25, 1908; RAS
16 EEB to WWC, March 1, 1908; WWC to EEB., March 6, 1908; SLO
17 WWC to EEB, March 6, 1908; SLO
18 EEB to WWC, June 3, 1908; SLO

19 WWC to EEB, August 19, 1909; SLO
20 EEB to WWC, May 15, 1911; SLO
21 WWC to Ralph P. Merritt, Comptroller of the University of California, July 26, 1912; SLO
22 WWC to EEB, March 18, 1913; SLO
23 EEB to WWC, February 7, 1914; SLO
24 EEB to RGA, September 1, 1914; SLO
25 C. H. Barnard to EEB, September 16, 1914; VUA
26 WWC to EEB, May 23, 1911; SLO

22

Observer of all that shines – or obscures

1

Apart from probing the nature of comets, the other scientific question that absorbed Barnard's closest attention during his later career was the nature of the dark markings of the Milky Way. Some of these dark markings he had recognized visually as early as the 1880s, when he was canvassing for comets with his 5-inch refractor, and ever since, he wrote, 'they have always appealed to me with an interest scarcely less than that of any other natural feature of the sky.'[1] Their proper study began only with Barnard's pioneering investigations with wideangle lenses – first with the Willard portrait lens, and later with the Bruce photographic telescope. His photographs showed that many of the large diffused nebulae were associated with vacant regions – the best example being the remarkable nebula of p Ophiuchi, situated 'in apparently a large hole in the Milky Way.'[2] This meant that the existence of the nebulae in these regions was in some way – though he was not yet sure in what way – the cause of the scarcity of stars.

He had made a beginning, but he still had a long way to go. Indeed, as late as December 1904, on the eve of departing with the Bruce telescope for Mt. Wilson, he was still espousing the view that these features were in most cases real vacancies among the stars. 'In reference to these dark lanes and holes,' he wrote,

> there seems to be a growing tendency to consider them dark masses nearer to us than the Milky Way and the nebulae that intercept the light from these objects. This idea was originally put forward by Mr. A. C. Ranyard. Though this may in a few cases be true – for some of them look very much that way – I think they can be more readily explained on the assumption that they are real vacancies. In most cases the evidence points palpably in this direction. In the few cases where the appearance would rather suggest the other idea – and this is mostly in reference to the nebulae – the evidence is still not very strong.[3]

Barnard obtained hundreds of plates of the Milky Way from Mt. Wilson, from which he later quarried most of the material used in his *Atlas of Selected Regions of the Milky Way*. But nothing in them caused him to change his mind about the dark markings. In a paper, 'On the Vacant Regions of the Sky,' read before the Astronomical and Physical Society in December 1905, only two months after his return, he repeated his still strong belief that 'most of these blank regions . . . impress one as being actual holes.'[4]

Region of the great nebula of ρ Ophiuchi, 4 hr 30 min exposure by Barnard with the Bruce photographic telescope at Mt. Wilson, April 5, 1905. Yerkes Observatory

Nevertheless, he had to admit that there were a few parts of the sky where this did not seem to be the correct explanation. In particular, he was deeply troubled by the peculiar features in Ophiuchus and Scorpio – what he called 'the most puzzling region that I know of in the sky.' 'Here occur vacancies within vacancies,' he wrote:

> [Tlhere are vast regions almost entirely free from stars, in a surrounding region thick with small stars. These regions seem veiled over with some sort of material in which occur blacker spaces, as if all this part of the sky were involved in a thin faint nebulous sub-stratum which partly veils the blackness of space beyond. In this, apparently, occur rifts and openings giving a clearer view of space.'

Here was the nearly starless chasm beginning near 0 Ophiuchi, which turned west in shattered form, then strengthened into a definite lane extending for another 15" and finally connecting with the 'remarkable vacancy in the dense sheeting of small near p Ophiuchi. These features were more complicated than the simple holes in sheets of stars that he thought he could discern so clearly elsewhere in the Milky Way:

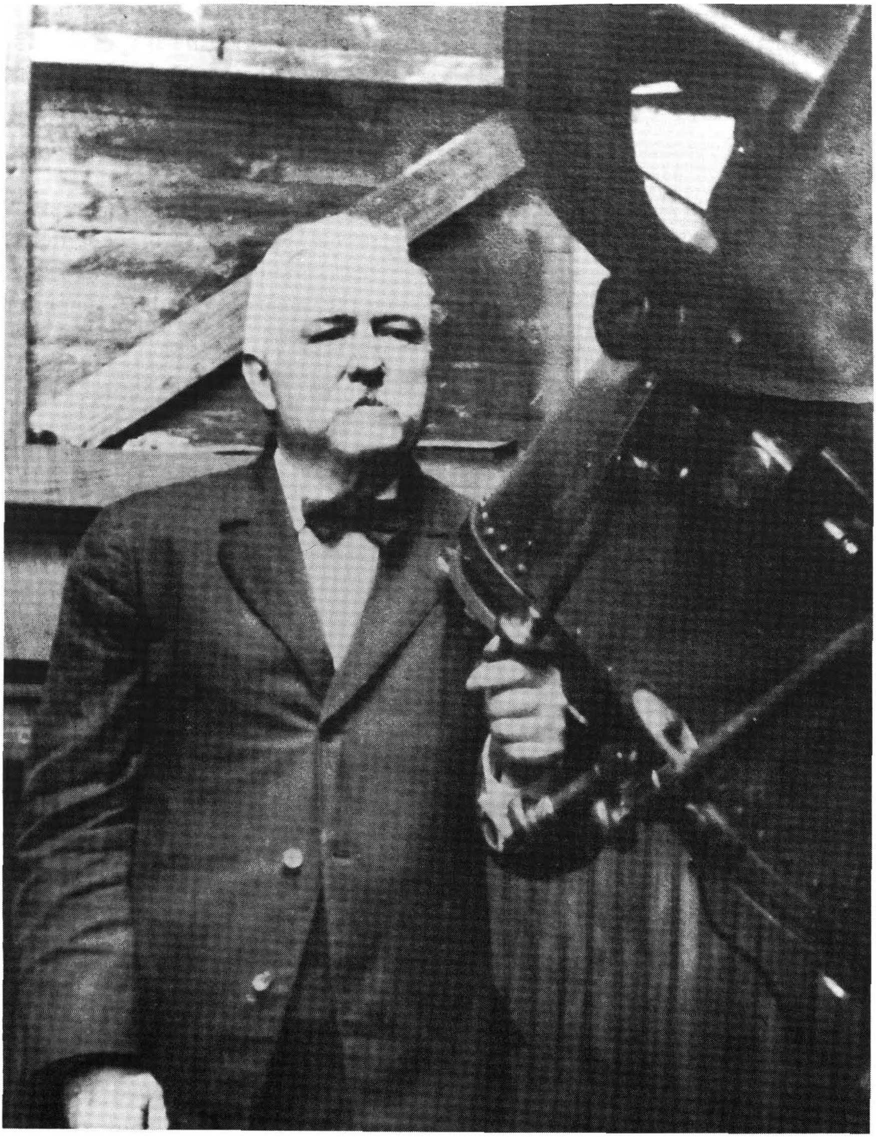
> The blending of this great nebula into the surrounding region, where it seems to mingle with the material of the vacancies, makes it hard to tell where the nebula leaves off . . . There is a slight suspicion that certain outlying whirls of the nebulosity have become dark and that they are the cause of the obliteration of the small stars near . . . [6]

No sooner had he put forward his 'slight suspicion' – that nebulae might fade out in parts, and eventually they become dark and obscure – than he felt the need to draw back:

> I think this is fanciful however, for the irregular vacancy in which it lies connects readily with the vacant lane running east to the region of 0 Ophiuchi. No one would suspect for a moment that this lane is anything but an actual vacancy among the stars.[7]

The only way to decide the whole question was to obtain more and better observations, so he returned to photographing the sky with the Bruce telescope. The question of the nebulous sub-stratum which seemed to exist in Ophiuchus and Scorpio nagged at him, but he also worried that the vacant lanes in the Milky Way might be entirely subjective – due to scarcity of stars alone – rather than 'channels in a bed-work ofnebulous substratum.' If the stars were removed, he asked, would the lanes still exist? Early in the frigid month of January 1907, he trained the Bruce telescope on the sky north and east of the Pleiades, where earlier photographs with the Willard lens had caught dim suggestions of dark lanes extending far to the east of the cluster. He exposed the plates for five and a half hours. When the plates emerged from the developing tray, the lanes showed up unmistakably. They were not only devoid of stars but darker than the surrounding sky, satisfying Barnard that they would still be visible even if the stars were all removed. In addition to the dark lanes, the plates showed a large nebula apparently in a hole almost devoid of stars, from which one of the lanes straggled away to the southeast for several degrees. He later described these remarkable features in his paper, 'On a Nebulous Groundwork in the Constellation Taurus' (1907):

> The pictures seem to show that the brighter part of this nebula is only a small portion of it, and that the nebula is feebly luminous over most of the vacancy . . . The feebler portions of the nebula would almost suggest the idea that a large nebula exists here, but that the major portion of it is dead or non-luminous, and that it actually causes the apparent vacancy by cutting out the light from the stars, while the few stars visible are perhaps on this side of the nebula. I give this simply as what the picture would suggest to one, and not as what may really be the truth.[8]



Barnard with Bruce photographic telescope. Yerkes Observatory

He had returned to the idea he had suggested then dropped a year earlier: why might not a luminous nebula – the cause of whose shining was not, admittedly, known – fade out and eventually die, just as the stars themselves did?

> The dying-out of nebulae . . . is a probability fully as warranted as the belief and certainty that the stars must die out. What would be the condition of a nebula that no longer emitted light[?] [I]t is likely that we should simply have a dark nebula which would not be visible in the blackness of space unless its presence were made known by its absorption of the light of the stars beyond it . . .[9]

Dark lanes in Taurus, 5 hr 29 min by Barnard with Bruce photographic telescope at Yerkes Observatory, January 9, 1907. **Barnard later wrote that this photograph was 'one of the most important of the collection, and bears the strongest proof of the existence of obscuring matter in space.' Yerkes Observatory**

At last Barnard was knocking at the very door of truth:

> This idea of the absorption of the light of the stars by **a** dead nebula or other absorbing matter has been used by some astronomers as an explanation of the dark or starless regions of the sky. Though this has not in general appealed to me as the true explanation – an apparently simpler one being that there are perhaps no stars at these places – there is yet considerable to commend it in some of the photographs . . . I have been slow in accepting the idea of an obscuring body to account for these vacancies; yet this particular case [that of the dark lanes in Taurus] almost forces the idea upon one as a fact.''

Even in 1907, he was not prepared to embrace the idea, however; once again he drew back. 'The idea of the dying-out of a nebula,' he suggested timidly,' . . . is not strengthened by the presence of the lanes, for we do not find in general any great streams of nebulosity extending away from the nebulae.'''

2

All this time, Barnard had been almost alone in struggling with the meaning of the dark markings revealed in his plates. Curiously, other astronomers seem to have taken scant interest. One exception was Max Wolf, who since the 1890s had been photographing the Milky Way from the Konigstuhl Observatory in Heidelberg. Wolf also noted the curious relationship which had impressed Barnard – the fact that extended nebulae were almost always situated within larger regions that contained only a very small number of faint stars. His North America nebula, for instance, was at the edge of a great, nearly starless region. Another astronomer who was working on the problem – though from an entirely different direction – was Jacobus Cornelis Kapteyn, of the Groningen Observatory, in the Netherlands. While a research associate at Mt. Wilson in 1909, Kapteyn published a paper in the Astrophysical Journa1, 'On the Absorption of Light in Space.' Kapteyn suggested that the 'enormous mass of meteoric matter' which filled space would undoubtedly intercept some part of the starlight; this, in turn, would produce a dimming of the stars as one looked farther into space and would cause astronomers to believe that the more remote stars were dimmer than they really were, thus leading to an exaggerated estimate of their distances.[12]

Barnard undoubtedly read Kapteyn's paper, and it is quite probable that it influenced his own choice of a title for his next important paper on the subject of the dark markings of the Milky Way, also published in the *AstrophysicalJournal* – 'On a Great Nebulous Region and on the Question of Absorbing Matter in Space and the Transparency of the Nebulae' (1910). Barnard concentrated on the large straggling nebula around ν Scorpii which he had first discovered with the small lantern lens in 1893 and whose extensions seemed to reach to, and in a feeble manner connect with, the great nebula of ρ Ophiuchi. 'The greatest interest in this nebula,' he wrote, 'lies in the fact that it seems to show a veiling of the stars in certain of its portions . . . The line of demarkation between the rich and poor portions of the sky here is too definitely and suddenly drawn by the edges of the nebula to assume the appearance due to an actual thinning out of stars':

> It looks, where this part of the nebula spreads out, as if the fainter stars were lost, and the brightness of the others reduced by at least a magnitude or more. . . In the region of ρ Ophiuchi there is every appearance of a blotting-out of the stars by the fainter portions of the nebula, but from its complicated and irregular form the hiding of the stars is not so clearly evident as is the case of the ν Scorpii nebula. At present we have no means of determining whether a nebula is transparent or not. The assumption has always been that they are transparent like the comets . . . I think in the present case . . . that the nebula of ν Scorpii is shown to be at least partially transparent, but the absorption of the light of the stars behind it must be

> considerable. The picture is quite conclusive evidence that the nebula is nearer to us than the general background of stars at this point.[13]

Though clearly on the threshold of accepting the view that the dark markings were opaque matter, he remained on the fence. 'If these dark spaces of the sky are due to absorbing matter between us and the stars – and I must confess that their looks tempt one to this belief – such matter must, in many cases, be perfectly opaque, for in certain parts of the sky the stars are apparently blotted out,' he wrote. But he added his customary disclaimer: 'It is hard to believe in the existence of such matter on such a tremendous scale as is implied by the photographs.'[14]

3

For some time Barnard had been edging closer and closer to accepting the opaque nebula idea, but he was at heart a conservative. He wanted to be certain before changing his mind. The decisive turning point for him finally came 'one beautiful transparent moonless night' in the summer of 1913. He was photographing the southern Milky Way with the Bruce telescope at Yerkes Observatory:

> I was struck with the presence of a group of tiny cumulous clouds scattered over the rich star-clouds of Sagittarius. They were remarkable for their smallness and definite outlines – some not being larger than the moon. Against the bright background they appeared as conspicuous and black as drops of ink. They were in every way like the black spots shown on photographs of the Milky Way, some of which I was at that moment photographing. The phenomenon was impressive and full of suggestion. One could not resist the impression that many of the small spots in the Milky Way are due to a cause similar to that of the small black clouds mentioned above – that is, to more or less opaque masses between us and the Milky Way. I have never seen this peculiarity so strongly marked from clouds at night, because the clouds have always been too large to produce the effect.[15]

In 1913 there were still few city lights, and Chicago light dome that now interferes with sensitive observations at Yerkes did not yet exist. Under these conditions, the clouds appeared perfectly black and darker than the background sky. Nowadays, they would appear brighter, due to reflection of artifical lights, and the effect that made such a strong impression on Barnard would be lost.

After his moment of revelation, Barnard began thinking back to earlier visual observations of some of the dark markings in the Milky Way. The most striking of these markings, because of their smallness and definite form, were in Sagittarius. One was the small object, 'like a drop of black ink on the background of the Milky Way,' which he had found with his 5-inch refractor in Nashville (it would be entered in his catalog of these objects as B86). With the 36-inch Lick refractor in 1895, it had nearly filled the field of view. The western half was well defined, the eastern half more diffused, and considerable nebulosity was associated with it.[16] The other, B92, was even more

Small star cloud in Sagittarius. The conspicuous dark spot in the upper part of the cloud is B92. Exposure of 4hr 30 min by Barnard with the Bruce photographic telescope at Mt. Wilson, July 31, 1905. Yerkes Observatory

striking. In previous observations with the Lick 36-inch and Yerkes 40-inch refractors, he had sometimes had the distinct suspicion that there 'was an actual object at this point,' but he had never been quite sure. On July 27, 1913, conditions were unusually favorable both for transparency and steadiness, and Barnard carefully examined this dark 'hole or spot' with the 40-inch refractor:

> With its following edge cutting across the middle of the field, which is some three times smaller than the spot, it was quite distinctly seen that the preceding half of the field, in which there were no stars, was very feebly luminous, while the following

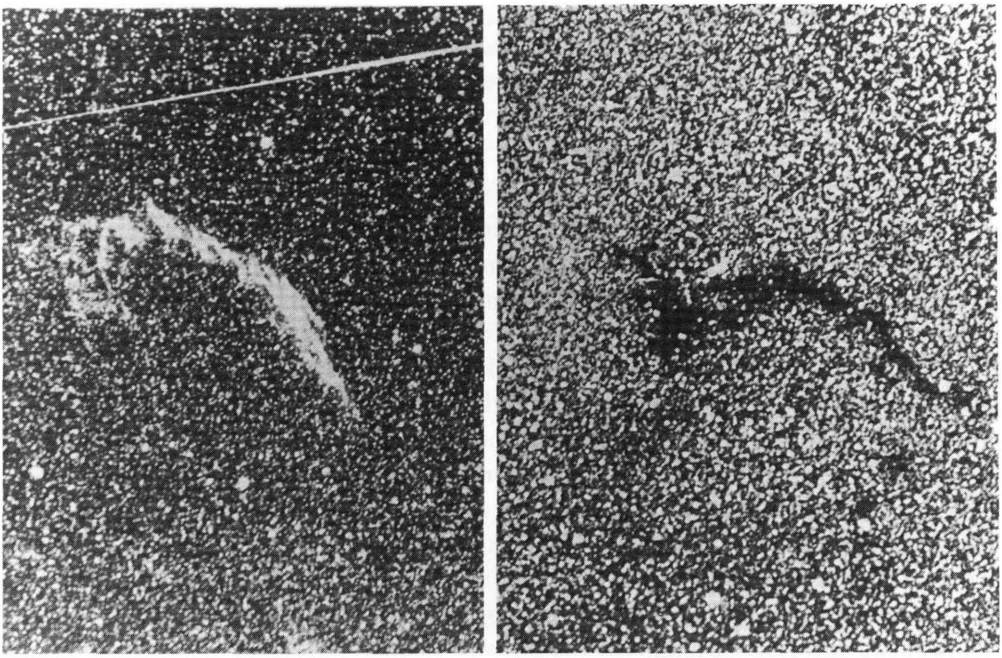
> side showed a rich, dark sky with the few small stars on it. From the view, one would not question for a moment that a real object – dusky looking, but very feebly brighter than the sky – occupies the place of the spot. It would appear, therefore, that the object may be not a vacancy among the stars, but a more or less opaque body.''

Though Barnard continued to caution against accepting all the dark regions as consisting of dark matter, insisting that some must be dark 'purely from the fact that there are no stars there,''' he never again doubted that this was the true explanation for most of them. However, he still fretted about how such objects – which in many cases appeared to be totally opaque – could be seen at all. They were silhouettes – but what was the nature of the luminous background against which they were silhouetted? 'If I have proved that there are dark objects in the heavens that are shown on photographs through being projected on a luminous ground,' he wrote, 'I have opened the way to prove something else. [The] very fact of there being a luminous background may prove of the greatest value to us in our solution of the problems of space, because one form of this background suggests a feeble luminosity through interstellar regions and perhaps beyond.'[19] We now know that the luminous background he was photographing consisted, in the Milky Way, merely of the innumerable faint background stars. In the Milky Way itself, Barnard himself guessed that this was the correct explanation, but in regions far away from the Milky Way he continued to believe in a 'widespread and undoubtedly universal (so far, at least, as our stellar universe is concerned) . . . feeble illumination of distant space.'[20] He did not know that here, too, there were faint galaxies in numbers beyond belief.

4

In his quest to demonstrate conclusively the obscuration of light in space, Barnard called attention to the spectacular object which carries the catalog designation B33 but is better known as the 'Horsehead Nebula,' near 6 Orionis. This object was discovered by Isaac Roberts on a photograph taken in 1900. Roberts himself described it as an 'embayment.' Barnard declared that 'This object has not received the attention it deserves. It seems to be looked upon as a rift or hole in the nebulosity, as implied . . . from Dr. Roberts' paper.' However, so too would Barnard have looked upon it, until now. Now that he had seen such dark objects in a new light, he had a different interpretation. His own photographs of it from February 1913 revealed 'instead of an indentation, the almost complete outline of a dark object . . . projected against the bright nebulosity,' leading Barnard to conclude that 'it is clearly a dark body projected against, and breaking the continuity of, the brighter nebulosity.''' On the night of November 4, 1913, he examined it visually with the 40-inch, using magnification of x 460:

> The outlines of the spot – so sharp and clear in photographs of this region – could not be made out with any definiteness. The view showed that the spot is certainly



Photographs published by Barnard in the ***Astrophysical Journal*** for January 1916, showing analogous shapes of bright and dark nebulae which he hoped would strengthen his case for the existence of dark nebulae. The bright nebula on the left is NGC 6995 in Cygnus, shown in this exposure of 5 hr 43 min taken by Barnard on July 15,1909; the dark nebula on the right is B150 in Cepheus, exposure 6 hr 2 min by Barnard on October 1, 1910. Barnard enhanced the weak image of the latter by making multiple printings with the position shifted slightly each time, which gives the illusion of a dense star field. Yerkes Observatory

> not clear sky, for the field was dull, apparently indicating the presence of some material substance at this point. To me the observation would confirm the supposition of an obscuring medium.[22]

Though now certain of their existence, Barnard was cautious in expressing any idea as to the nature of these opaque bodies. 'What their nature is we do not know,' he wrote in October 1915, 'and the spectroscope cannot help us because the objects are devoid of light, or nearly so. But there is strong evidence that they are of the nature of the nebulae – that is, that they are dark nebulae.'[23] He believed that they were nebulae that had lost their light, or had never been luminous – 'it is possible,' he suggested, 'that the original condition of a nebula is dark.'[24] Somehow he hoped to prove the connection, but there was no obvious way. 'Perhaps,' he suggested, 'if we show a close resemblance in form and size of one of these [dark opaque objects] to one of the well-known nebulae, it may aid us in connecting the two kinds of objects.'[25] He thus produced two photographs on the same scale, one showing part of his dark nebula in Cepheus and the other the luminous Veil nebula (NGC 6995) in Cygnus. The resemblance was striking and suggested analogy:

> There is a striking resemblance in the forms of these two objects; but one is a luminous nebula and the other a dark – what? One can readily see that if the nebula were to lose its light, it would, if dense enough, still be shown against the sky and would strongly resemble the dark object. For this and many other reasons I am constrained to believe that the dark object is really a non-luminous nebula seen against a luminous background.[26]

In fact, we now know that in this case Barnard was misled by the similarity in shapes. The Veil nebula has a gaseous spectrum, and represents the far-flung remnants of an exploded star – a supernova – that continues to be faintly luminous after having been violently hurled outward from the explosion. The dark nebula Barnard had photographed had no spectroscopic signature, but we now know that it is made up of a different kind of matter.

Indeed, only three years later, in his 1919 paper, 'On the Dark Markings of the Sky,' in which he published his famous catalog of 182 of these objects, Barnard retreated from the notion that they were dead nebulae. What influenced him to do so was the spectroscopic work of V. M. Slipher, Percival Lowell's assistant at Flagstaff, who had shown in 1912 that the nebulosity which surrounded Merope, in the Pleiades, had a star-like rather than a gaseous spectrum.[27] It was a reflection nebula, consisting of dust that reflected the light from the nearby star, and in 1914, Slipher obtained the same result for the **p** Ophiuchi nebula. Barnard was one of few astronomers who appreciated the significance of these results at the time. 'To me [there is] conclusive evidence that masses of obscuring matter exist in space and are readily shown on photographs with the ordinary portrait lens,' he wrote. 'What the nature of this matter may be is quite another thing. Slipher has shown spectroscopically that the great nebula about p Ophiuchi is probably not gaseous . . . The word "nebula," nevertheless, remains unchanged by this fact, so that we are free to speak of these objects as nebulae. For our purpose it is immaterial whether they are gaseous or non-gaseous, as we are dealing only with the question of obscuration.'[28]

5

As important as it was, Slipher's discovery of reflection nebulae was completely overshadowed by his far-reaching work on spiral nebulae. Directed to the problem by Lowell, who believed as most astronomers of the day had that the spiral nebulae were planetary systems in formation, Slipher had to overcome great difficulties in obtaining spectrograms of these faint objects. He began with the brightest spiral, M31 in Andromeda, but the spectrum was still so faint that in order to capture it with the means available at the time, he had to use very long exposures – one of his plates, obtained at the end of 1912, required exposures over three consecutive nights. The results were astonishing, to say the least. The spectral lines were abnormally shifted toward the violet end, indicating an unusual velocity of approach. The velocity worked out to 190 miles/sec, which was greater than had been measured for any other object up to that time. 'It looks as if you had made a great discovery,' Lowell told him. 'Try some more spiral nebulae for confirmation.'[29] This Slipher did, starting with NGC 4594, the spindle-shaped 'Sombrero Hat' nebula in Virgo, which showed an even greater displacement in its spectral lines – this time toward the red instead of the violet, from which he worked out a velocity of recession of 600 miles/sec. Over the next three years he obtained spectrograms of twenty-two more spirals, all shifted toward the red and all having velocities of recession of the same order. His work on NGC 4954 led, moreover, to another important discovery. On placing the slit of the spectroscope parallel to the long axis of this nebula, he found that the spectral lines were not only red-shifted but tilted, indicating a measurable rotation. A few months later he obtained similar evidence for the rotation of the Andromeda nebula.

Though Slipher himself did not at first grasp the full significance of what he had discovered – for a while he continued to believe that the spirals were planetary systems of some sort, 'composed of matter from dust-clouds to suns in size and development' – he later changed his mind, possibly owing to Lowell's influence, who in a November 1915 lecture cited Slipher's spectrograms as showing that 'the spiral nebulae are not the prototype of our system, but of something larger and quite different, other galaxies of stars.'[30] There was, by then, other evidence pointing in the same direction. From 1909 on, Heber D. Curtis took hundreds of direct photographs of spirals with the Crossley reflector. From these photographs, he estimated that the number of spirals within reach of this telescope was much greater than Keeler's estimate of 120 000, and more like 700 000 or even 1 000 000.[31] Moreover, in reaching his conclusion that these objects were 'inconceivably distant, galaxies of stars or separate stellar universes so remote that an entire galaxy becomes but an unresolved haze of light,'[32] Curtis referred not only to Slipher's spectrograms but also to the fact that some of the spirals which were seen edge-on, such as NGC 891 in Andromeda and NGC 4594 in Virgo, showed dark bands, which he believed must be due to 'occulting matter' similar to the 'dark nebulae' and 'coal sacks' which were already well known from Barnard's photographs of the Milky Way.[33] Barnard himself had written in 1915 of the grand edge-on spiral NGC 4565, in Coma Berenices:

> Another beautiful example of this kind is shown in photographs of [this] very elongated nebula, . . . which seems to be an object similar to the great nebula of Andromeda, with its edge toward us, where the darker outer periphery of the nebula is seen cutting across the brighter central region as a black irregular streak.[34]

However, he fell short of concluding, as Curtis did, that NGC 4565 and others like it were themselves galaxies seen edge-on, and that the dark nebulae he was photographing in the plane of our own Galaxy belonged to a similar ring of obscuring matter.[35]

Curtis had not yet published his ideas about the spiral nebulae when, in July 1917, George W. Ritchey, using the 60-inch reflector at Mt. Wilson, announced the discovery of a 14th magnitude nova in the spiral NGC 6946.[36] Soon other novae were located in plates of other spirals – they were ordinary novae, like those frequently observed in our own Milky Way, unlike the outburst in Andromeda in 1885, which had been an intrinsically much brighter object, what we now call a supernova. The apparent faintness of these ordinary novae showed, moreover, that the objects in which they were located must be at vast distances. Thus by 1917, the view that the spirals were other galaxies of stars was rapidly gaining ground, and Barnard, who followed Ritchey's nova visually with the 40-inch refractor between July 28 and August 28, wrote to Ritchey that he was now 'beginning to believe that the spirals really are outside universes.'[37]

6

Not everyone was willing to accept this conclusion. The leading skeptic was Harlow Shapley, a native Missourian, who had begun studying variable stars as a student of Henry Norris Russell at Princeton, and while there had become interested in one particular type of variable stars – Cepheids, known after the prototype δ Cephei, whose light variations had been discovered by John Goodricke in 1784. In 1912, Henrietta Leavitt of Harvard showed that if one plotted the periods of the Cepheids which she had identified in the Small Magellanic Cloud against their apparent brightnesses, the resulting graph was linear. Since the distances of these variables could, to a first approximation, be considered the same, their apparent brightnesses indicated their true luminosities. This meant, as the Danish astronomer Ejnar Hertzsprung realized the following year, that if only one could reliably measure the distance to one of them, the intrinsic brightness of all the other Cepheid variables could be worked out from the period alone, and one could use them as a powerful measuring stick across space. Hertzsprung mentioned his idea to Russell, who in turn mentioned it to Shapley, who was still Russell's doctoral student. Shapley went on to show that the Cepheid variables were large, intrinsically bright stars. Moreover, they were not binaries but true pulsating stars. After he left Princeton for Mt. Wilson in 1914, Shapley discovered Cepheid variables in the globular clusters, and using a calibration worked out from a handful of Cepheids in the Milky Way, tackled the problem of finding the distances to them. In 1918, he announced that the typical globular was on the order of 50 000 light years distant. Moreover, since most of the globulars were concentrated in the direction of Sagittarius, he assumed that the nucleus of the Galaxy was located in the center of this halo of globulars. Whereas the English astronomer Arthur S. Eddington had just a few years earlier estimated the extent of the Galaxy as on the order of only 15 000 light years, Shapley recalculated its breadth at 300 000 light years, and put the Sun in the remote outskirts far from the galactic center.[38] Because he failed to take into account dimming by obscuring matter, Shapley overestimated the distances to the Cepheids – the Galaxy is only about a third as large as he estimated, but his figure was certainly on the right order. It was so large that he could not bring himself to believe that the spirals could be outside it, and he was still troubled by the nova in the Andromeda nebula in 1885. In 1920, he and Curtis were invited to give lectures at the National Academy of Science in ,Washington, what later became known as the 'Great Debate.' Robert G. Aitken, the double star observer at Lick Observatory, wrote to Barnard at the time:

> I would like to hear the debate between Curtis and Shapley. I have read Curtis' paper – a very good one – and have had long talks with Shapley also, and each one has many very good arguments to present. For my own part, I am still 'on the fence' on the question. I very greatly doubt the visibility of half-a-million or more 'island universes' on the one hand, and, on the other, I am not ready to accept Shapley's conclusions on *the* basis of his measuring-rod. It seems to me that its value is not yet sufficiently demonstrated. I am open to conviction.[39]

Shapley talked about the scale of the universe, while Curtis, who did not accept Shapley's view of the scale of the Milky Way system, presented his arguments in favor of regarding the spirals as island universes. Both astronomers were partly right and partly wrong, though Curtis is generally regarded as having 'won.'[40] In any case, by early 1924 Edwin P. Hubble, who had been an assistant on the Yerkes staff in 1914 and came to Mt. Wilson just after the War, would use the 100-inch reflector on Mt. Wilson to identify a Cepheid variable in the Andromeda nebula – it proved to be excessively faint, and using Shapley's methods ('He never acknowledged my priority,' Shapley wrote ruefully long afterwards, 'but there are people like that'),[41] Hubble was able to work out the distance – well over 1 000 000 light years. Thus there could no longer be any doubt that the spiral nebulae were indeed vast star systems far beyond the confines of the Milky Way.

7

Shapley's globular cluster results came as no surprise to Barnard. He had himself been carefully measuring stars in some of them since 1898 – one of the most prodigious pieces of work he undertook with the 40-inch refractor. In M13 alone, he measured and remeasured no less than 247 individual stars; in all he obtained positions of 1363 individual stars in eighteen clusters. At first, as he later recalled, 'I had formed what I now believe was an entirely erroneous idea of their dimensions and of the sizes of the stars that compose them. They appeared to me as compressed groups of small suns that did not in any sense rank with the ordinary stars in the sky. Their distances from us, though great, were thought comparable with ordinary stellar distances. From these considerations I had reasonable hopes of detecting some relative motion of the individual stars in a few years' time from accurate micrometer measures.'[42] However, to his 'great regret and disappointment,' his measures repeated at ten years showed no changes. When, at twenty years, he continued to face the same negative results, he was finally ready to face the fact that these clusters 'were at vaster distances from us and on a more magnificent scale than their apparent insignificance might imply.'[43] His photographs of the Milky Way showed that some of them were superimposed on the great star clouds and therefore had to be nearer than the star clouds themselves.[44] Indirectly, his measures lent strong support to the very great distances which Shapley was claiming for these objects.

8

The heroic period between 1912, when Henrietta Leavitt identified the period-luminosity relationship of Cepheids in the Small Magellanic Cloud and V.M. Slipher began measuring the red shifts of spirals, and 1929, when Edwin P. Hubble plotted the distances of galaxies against their red shifts and discovered the expansion of the universe, was one of unprecedented change in astronomy; the classical methods gave way to those of astrophysics, and the modern view of the universe took shape. The globular clusters were identified as systems of stars on a vastly greater scale than had been hitherto supposed, forming a framework around the galactic nucleus which is itself situated far away in the direction of the constellation Sagittarius. The galactic nucleus is hidden from direct observation because, in silhouette between us and the galactic center, are clouds of obscuring matter, similar to the lanes of obscuration which were found in edge-on spirals. Barnard had photographed and struggled to understand these dark clouds over most of his scientific career, and though he eventually realized that they consisted of obscuring matter of some kind, he still had no real idea as to the nature of this matter. Just before Barnard's death, Henry Norris Russell proposed, though he could not yet prove, the correct idea – that this obscuring matter consisted of fine dust.[45] During the 1920s, this idea gained ground, and was finally proved by Robert J. Trumpler in his 1930 paper, 'Absorption of Light in the Galactic System.'[46] Interestingly, in this paper Trumpler took the existence of dark nebulae for granted. By 1930, writes Gerrit L. Verschuur, 'this was taken to be so obvious that no reference to any specific work was given, which paints Barnard's struggle in a sobering light.'[47] Thus do the great insights of one generation fade into the light of common day for the next and become accepted commonplaces.

Still later, in 1947, Bart J. Bok and Edith Reilly proposed that small dark clouds are sites of star formation (they are known today as 'Bok globules,' though Bok himself disliked the name. 'They should be called Barnard globules,' he protested; 'he discovered them').[48] Indeed, the dark nebulae that Barnard first photographed in Taurus and around Ophiuchi are now known to be teeming with young stars. Protostars form in the dense cores of these dark clouds, and when they begin to generate enough heat blow off their cocoons of interstellar dust. At that point they may become visible in optical telescopes as T Tauri stars (named after the prototypical star associated with Hind's variable nebula and located among the vast dark clouds in Taurus which Barnard first photographed in 1907). Though the details are complex, the broad outlines of the process of star formation are being worked out.[49] These clouds, whose ominous darkness fascinated Barnard, are not, as he once speculated, the remnants of dead nebulae, they are the birth places of suns.

1 E. E. Barnard, 'On the Vacant Regions of the Sky,' *PA*, **14** (1906), 579-83:579

2 E. E. Barnard, 'The Bruce Photographic Telescope of the Yerkes Observatory,' *Ap J*, 21 (1905)' 3548:46

3 ibid., pp. 46–7
4 Barnard, 'On the Vacant Regions of the Sky,' p. 582
5 ibid., pp. 58&1
6 ibid., p. 581
7 ibid., p. 581
8 E. E. Barnard, 'On a Nebulous Groundwork in the Constellation Taurus,' *Ap J*, **25** (1907), 218-25: 220
9 ibid., p. 219
10 ibid., p. 221
11 ibid., p. 222
12 J. C. Kapteyn, 'On the Absorption of Light in Space,' *Ap J*, **29** (1909), 46–54. Within a few years, Kapteyn had revised his thinking, concluding that the absorption of starlight was actually negligible. Thus he arrived at the erroneous belief that the Sun was near the center of the Milky Way.
13 E. E. Barnard, 'On a Great Nebulous Region and on the Question of Absorbing Matter in Space and the Transparency of the Nebulae,' *Ap J* **31** (1910), 8-14:8-9
14 ibid., p. 13
15 E. E. Barnard, 'Some of the Dark Markings on the Sky and What They Suggest,' *Ap J*, **43** (1916), 1–8: 4
16 He used a power of 350, which produced a field of view some 6' of arc across. EEB, observing notebook; LO
17 E. E. Barnard, 'Dark Regions in the Sky Suggesting an Obscuration of Light,' *Ap J*, **38** (1913), 496-501:497
18 EEB to Harlow Shapley, May 12, 1919; VUA
19 Barnard, 'Some of the Dark Markings,' p. 6
20 E. E. Barnard, 'On the Dark Markings of the Sky with a Catalogue of 182 such Objects,' Ap ***J*, 49** (1919), 1-23:4
21 Barnard, 'Dark Regions,' p. 500
22 ibid., p. 501
23 Barnard, 'Some of the Dark Markings,' p. 3
24 ibid., p. 4
25 ibid.
26 ibid.
27 V. M. Slipher, 'On the spectrum of the nebula in the Pleiades,' Lowell Observatory Bulletin, no. 55 (December 20, 1912)
28 Barnard, 'On the Dark Markings of the Sky,' p. 2
29 P. Lowell to V. M. Slipher, February 8, 1913; LOA
30 P. Lowell, 'Nebular Motion,' text dated November 23, 1915 of lecture to Boston's Melrose Club; LOA
31 Barnard was skeptical of these high numbers, telling J. L. E. Dreyer of the Armagh Observatory that even Keeler's more modest estimate was probably 'much exaggerated.' J. L. E. Dreyer to EEB, February 28, 1909; VUA
32 H. D. Curtis, 'Report 1913, July 1–1914, May 15,' draft; SLO.
33 H. D. Curtis, 'A Study of the Absorption Effects in the Spiral Nebulae,' PASP, **29** (1917), 145; 'A Study of Occulting Matter in the Spiral Nebulae,' PASP, 13 (1918), 45
34 Barnard, 'Dark Markings on the Sky,' pp. 6–7

35 As soon as he realized that the Milky Way had a ring of occulting matter, Curtis understood why the spirals were found exclusively outside the Milky Way's 'Zone of Avoidance' – they could not be seen there through the obscuration.

36 Curtis had already been on the same track. Already in March 1917, he had found a new star of 14th magnitude on a plate exposed two years earlier on the spiral NGC 4527. Finding that the star had since disappeared, he suspected that it might be a nova. He then compared other plates that he had taken in 1915 with earlier plates of another spiral, NGC 4321, and found two more new stars. However, he delayed publishing his results, wanting to be certain that these were not variable stars, and before he was finished, Ritchey had made his discovery.

37 EEB to G. W. Ritchey, December 6, 1917; HHL

38 Harlow Shapley, 'Globular Clusters and the Structure of the Galactic System,' *PASP*, 30 (1918), 50

39 RGA to EEB, April 27, 1920; YOA

40 For details, see Michael Hoskin, '"The Great Debate": What Really Happened,' *JHA*, 7 (1976), 169–82 and Robert W. Smith, *The Expanding Universe: Astronomy's 'Great Debate,' 1900-1931* (Cambridge, Cambridge University Press, 1982)

41 Harlow Shapley, *Through Rugged Ways to the Stars* (New York, Charles Scribner's Sons, 1969), p. 57

42 E. E. Barnard, 'Micrometric Measures of Star Clusters,' E. B. Frost, G. Van Biesbroeck, and M. R. Calvert, eds., *PYO*, 6 (1931), 3

43 ibid., p. 1

44 E. E. Barnard, 'On the Comparative Distances of Certain Globular Clusters and the Star Clouds of the Milky Way,' *AJ*, 33 (1920), 86

45 Henry Norris Russell, 'Dark Nebulae,' *Proceedings of the National Academy of Sciences*, 8 (1922), 115

46 R. J. Trumpler, 'Absorption of Light in the Galactic System,' *PASP*, 42 (1930), 214-27. There were several steps in Trumpler's reasoning. His main interest was in star clusters, specifically open clusters like the Pleiades. Most of them lie close to the galactic plane, and thus are called 'galactic clusters.' He obtained spectra and measured the apparent brightnesses of many of the individual stars in these clusters. From the Hertzsprung–Russell diagram that had recently been worked out by Henry Norris Russell and Ejnar Hertzsprung, which gives the relationship between spectral type and intrinsic luminosity of stars, he was able to determine the true brightnesses of these stars, and comparing this result with their apparent brightnesses was able to estimate their distances. His final step was to plot the apparent diameters of these clusters (their angular diameters in the sky) against their distances. When he did so he found that the sizes of the clusters showed a steady increase with their distance from the Sun. Since he could not accept that the Sun was at the center of the Galaxy, he reasoned that the more remote stars did not appear fainter due to distance alone – they were also being dimmed by some kind of intervening matter. When Trumpler carried out the same analysis of globular clusters, of which the most distant lie far from the galactic plane, he found that the absorbing effects were much less. Thus he was finally able to prove what had been strongly hinted at ever since Barnard began photographing the dark clouds of the Milky Way – the interstellar matter is concentrated mainly in the galactic plane.

47 Gerrit L. Verschuur, *Interstellar Matters* (New York, Springer-Verlag, 1989), p. 102

48 Bruce Medal acceptance speech, 1977; quoted in Joseph Tenn, 'E. E. Barnard: The Fourteenth Bruce Medalist,' *Mercury*, 21 (1992), 164-6:166.

49 For a brief popular account, see Charles Lada, 'Deciphering the Mysteries of Stellar Origins,' *Sky and Telescope*, 85 (1993), 18–24