11 The Milky Way as Optical Phenomenon

Perception and Photography in the Drawings of Anton Pannekoek

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Abstract

One of Anton Pannekoek's main scientific projects was to provide a representation of the appearance of the Milky Way – an object he believed to be an optical illusion. This paper elucidates how Pannekoek thought the Milky Way appearance was formed by a combination of human psychology and physiology, and why he attributed such significance to it. In doing so, it explores the connections between Pannekoek's scientific methodology and his socialist epistemology. The paper also outlines the various techniques Pannekoek employed in his research. To observe the Milky Way, he used both extrafocal photography and visual observations by himself and others. To represent the results, he combined naturalistic drawings with verbal descriptions, numerical tables, and isophotic diagrams.

Keywords: Anton Pannekoek, Milky Way, Marxism, astronomical drawing, perception, photography

Ever since they were first published in the 1920s, the Milky Way images created by Anton Pannekoek have captured the imagination of astronomers

* This research has been funded by the Institute of Physics and the Anton Pannekoek Institute for Astronomy, University of Amsterdam, the Descartes Centre, Utrecht University, and Stichting Pieter Zeeman Fonds. I would like to thank Omar W. Nasim for our conversations on astrophotography, which helped me to further develop and clarify many of the ideas present in the paper, and Emma Mojet, Sjang ten Hagen, Robert W. Smith, Bart van der Steen, and Jeroen van Dongen for their valuable comments on earlier drafts of this paper.

Tai, Chaokang, Bart van der Steen, and Jeroen van Dongen (eds), *Anton Pannekoek: Ways of Viewing Science and Society*. Amsterdam, Amsterdam University Press 2019
DOI: 10.5117/9789462984349_CH11

and the public alike. Astronomers have used them as a definitive source for the distribution of galactic light, while the public got to know them through their inclusion in Zeiss planetaria and the Lund Panorama of the Milky Way.[1] More recently, they inspired visual artist Jeronimo Voss in the creation of his exhibition 'Inverted Night Sky', which was displayed at the Stedelijk Museum Bureau Amsterdam.[2] Joseph Ashbrook, editor of *Sky and Telescope*, even considered Pannekoek to be the '[g]reatest of all naked-eye observers of the galaxy'.[3] A striking feature of Pannekoek's Milky Way research was that he used both visual observations and photographical methods to determine the distribution of galactic light, which he then represented using many different techniques, including naturalist drawings, verbal descriptions, isophotic diagrams, and numerical tables. In this chapter, I focus on how these various representations were made and why they were made in the first place. Revealing how and why Pannekoek employed such wide-ranging methods for observing and representing the visual aspect of the Milky Way provides crucial insight into the development of early twentieth-century astronomy. It illustrates the complex relation between naked-eye observations and photography during this period, reveals how astronomers coped with the characteristics of human psychology and physiology, and deepens our understanding of the connections between political philosophy and scientific epistemology.[4]

To explain the coexistence of various representational methods in Pannekoek's research, we must first examine the role he attributed to astronomers in observing the Milky Way. In particular, how he thought certain characteristics and limitations of human physiology and psychology combined to create the image of the Milky Way. On this issue, it is informative to draw a parallel with late-nineteenth-century epistemic debates concerning the inherent differences between astronomical observers. Following the realization that well-skilled observers recorded different coordinates for the same star even when using the same instruments and diligently abiding to the same methods, astronomers had to reconsider the role of human perception in visual observation and develop strategies to either minimalize or stabilize these differences.[5] This reflexive inward look of astronomers was part of a greater 'reflexive turn' in

1 For the Zeiss Planetarium, see King 1958; for the Lund Panorama, see Lundmark 1957.

2 See SMBA 2016; Alena J. Williams, 'A Galaxy of Appearances', in this volume, 305-318; and Johan Hartle and Jeronimo Voss, 'Cross-Fading the Milky Way', in this volume, 285-303.

3 Ashbrook 1984, 375.

4 This chapter expands on earlier research presented in Tai 2017, 218-230.

5 See Schaffer 1988; Canales 2001; Hoffmann 2007. As Hoffmann indicates, the term 'constant differences' was used in the early nineteenth century before the concept of a personal equation

observational science during the mid-nineteenth century and it caused several astronomers to venture beyond their own field and participate in a cross-disciplinary exchange of ideas.[6] More than half a century later, Pannekoek too was deeply concerned with the anatomy of the human eye and the psychology of the human brain when developing his method for visual photometry of the Milky Way. He too ventured beyond astronomy to develop his ideas. In his case, however, it was not experimental psychology, but Marxism he turned to.

There are clear advantages to actively considering Pannekoek's Marxism when discussing his scientific methodology, even if he himself tried to keep his socialist and astronomical careers separate from one another. It is in his Marxist writings that Pannekoek developed his philosophy of the human mind: that humans have an innate ability to analyse and synthesize sense perceptions, but that this ability is implicitly influenced by prior experience. Historians of science Lorraine Daston and Peter Galison have argued that scientific epistemology is inextricably linked to conceptions of the self, as scientists seek to counteract the weaknesses of the self while emphasizing its strengths.[7] In Pannekoek's Milky Way research we find that he wanted to utilize the intuitive analytical character of the human mind while eliminating the effects of implicit bias.[8] In doing so, he concurred with contemporary ideas on scientific collaboration. The late nineteenth century saw the emergence of large-scale scientific collaborations taking on grand transnational projects. The organizers of these projects considered it vital for participants to show self-restraint and follow predetermined methods; for contributions to be mutually compatible, individual discrepancies had to be minimalized.[9] Although Pannekoek's Milky Way research was conceived on a much smaller scale, he advocated a similar ethos in the hope of eliminating individual subjectivity while preserving collective subjectivity.

The question of how to observe and represent the Milky Way inevitably leads to a discussion on the role of photography in early twentieth-century astronomy. When discussing the development of astrophotography, it is tempting to list vivid and increasingly more detailed photographic images of visually striking astronomical objects, like nebulae, clusters, or the moon,

that was tied with individual physiology and psychology emerged in Greenwich in the second half of the nineteenth century.

6 Canales 2001; for a similar reflexive turn in microscopy, see Schickore 2007.

7 Daston and Galison 2007; Galison 2004. See Daston 2008 for the importance of the visual in bridging psychology and epistemology.

8 For a detailed discussion on Pannekoek's epistemic virtues in astronomy and socialism, see Tai and van Dongen 2016; and Tai 2017.

9 Galison and Daston 2008.

being produced by the latest technological innovations. Such a listing, however, ignores the fact that the acceptance of photography in astronomy was far from straightforward: it was accompanied by genuine epistemic concerns about the usefulness and trustworthiness of photography.[10] Historical research on this topic has mostly focused on the second half of the nineteenth century, but these concerns persisted well into the twentieth century. When we look at Pannekoek's Milky Way research, we find that drawing and visual observation still played a prominent role in his work precisely because he believed contemporary photographic images of the Milky Way were inadequate for his purposes. Moreover, it was rare for photographs depicting astronomical objects to find their way into professional publications at all. Rather, photography was used as a tool for gathering, storing, sharing, and measuring large amounts of observations without needing constant access to a telescope and clear skies.[11] The information they contained was then usually presented in the form of large tables of numbers. Pannekoek's use of astrophotography fits in this profile. He was not interested in the way the Milky Way was depicted by photographic images, but in the measurement of its light intensity on photographic plates.

This chapter will begin by investigating Pannekoek's ideas on what the Milky Way actually was; how, as a phenomenon, it was related to human physiology; and how astronomers could best take advantage of this physiology while counteracting its flaws. In doing so, it is vital to look beyond his scientific writings and consider his Marxist philosophy. The next section will illustrate how these epistemic concerns were then translated into astronomical practice. It explores Pannekoek's method of photometry through visual observations, how he combined observation from various observers, and the various ways in which he represented the final results. The final section will discuss his method of photographic photometry as a way of replacing visual observations and address the striking continuity between his visual and photographic programme.

The Milky Way as Optical Phenomenon

To understand what Pannekoek wanted to achieve by researching and representing the Milky Way, it is necessary to first establish what he

10 See, e.g. Lankford 1987; Rothermel 1993; Pang 1997; 2002; Canales 2002; Tucker 2005, chapter 5; Nasim 2018.

11 See, e.g. Bigg 2000; Ratcliff 2008, 60-74; Wilder 2009a, 34-38; Hoel 2016; Daston 2017.

believed the Milky Way was. In the introduction to his 1920 publication on the northern Milky Way, Pannekoek goes into this explicitly: 'The Milky Way image that we observe is an optical phenomenon on whose creation various optical, physiological and psychological conditions work together. [Cornelis] Easton once referred to the Milky Way as an optical illusion; this expression may be even more true than the author himself had intended'.[12] The Milky Way, according to Pannekoek, was not a real entity that existed in the external world; it was the result of the combined light of countless faint stars, as processed by the human eyes and brain. Even so, he still believed it was valuable to investigate and represent this optical illusion. To understand why, we must turn to his Marxist philosophy, where he examined both the essence of scientific laws and the nature of the human mind.

According to Pannekoek, the task of the human mind was to analyse and abstract the information it received from the sense organs. This intuitive abstraction was required to make sense of the external world, which was a constant flow of infinitely varied and ever-changing phenomena. The mind turned these phenomena into stable objects and causal effects that we could understand. In his own words: 'The mind is the faculty of generalization. It forms out of concrete realities, which are a continuous and unbounded stream in perpetual motion, abstract conceptions that are essentially rigid, bounded, stable, and unchangeable'.[13] For Pannekoek, this reasoning extended to natural laws uncovered by science. These had no existence outside of the human mind, but were, in their essence, abstract rules extracted from our sense perceptions, formulated to bring structure and understanding to our observation of the external world of appearances. The aim of scientific research then should not be to search for the true structure of reality, but to summarize knowledge and provide economy of thought. By organizing and systematizing natural phenomena into laws and models, it became possible to comprehend them.[14] In light of this conceptualization of natural law, one can begin to understand why Pannekoek thought it worthwhile to investigate and represent the Milky Way. Even if it was not a real physical object, it was still valuable as a *scientific* object. As an intuitively created abstraction of the distribution of stars in the galaxy, it allowed astronomers to use it as a comparison for statistical astronomy and to track changes in the general distribution of stars.

12 Pannekoek 1920, 14.

13 Pannekoek 1906.

14 Pannekoek 1917; 1932.

What makes the Milky Way phenomenon especially interesting in the context of Pannekoek's philosophy of science, is that he explicitly discussed the various conditions that played a role in transforming the light of countless faint stars into the Milky Way as perceived by our eyes. He divided these conditions into three classes: the optical-anatomical, the psychological-physiological, and the purely psychological. Optical-anatomical conditions referred to such properties as the size and number of photosensitive nerves on the retina. The limited number of these retinal elements meant that the light of multiple stars, which otherwise would have been too faint to be detected individually, combined onto a single nerve. At the same time, the light of each star was not detected by just one nerve but was spread out over multiple. The combination of these two effects obscured the individuality of stars in rich agglomerations and made their light appear to human eyes as a flat image of gradually changing surface brightness. This flat image, Pannekoek identified as 'the theoretical Milky Way'.[15]

The theoretical Milky Way was not how one actually perceived the Milky Way, however, as this image was further altered by psychological-physiological conditions. An example of such a condition was the visual stimulus threshold, which was a function of both the size and brightness of an observed object. The smaller the object, the brighter they had to be to still be detectable.[16] Additionally, small bright features were also blurred over a larger area, making them appear less distinct. Crucially, both optical-anatomical and physiological-psychological conditions were tied to individual personal properties – like the number of retinal elements, visual acuity, or sensitivity to faint light – which meant that the Milky Way appeared differently to each observer.[17]

It was impossible to discern the extent to which personal differences in physiology and anatomy affected the appearance of the Milky Way, however, as the effect was drowned out by a much more significant effect. As Pannekoek explained it: 'The personal Milky Way image is not objectively determined by the earlier mentioned conditions, but is subject to still other influences, which can best be described as purely psychological'.[18] Due to the elusive faintness of the Milky Way light, the brain inevitably created patterns where there were none. Unlike the other two classes of conditions, purely

15 Pannekoek 1920, 15.

16 Here, Pannekoek explicitly referred to the work of physiologist Hans Edmund Piper, which later became known as Piper's law. Pannekoek 1920, 15, n. 1.

17 Pannekoek 1920, 14-16.

18 Pannekoek 1920, 16.

psychological conditions were largely random and not necessarily connected to the actual distribution of stars. Furthermore, because pattern creation was influenced by the observer's prior investigations of the Milky Way, an effect that could not be lessened by further observations: 'No repetition of the work, no matter how often, can help there; personal style will not be reduced, but will only impress itself stronger and clearer.'[19]

Pannekoek's views on human psychology and the role of prior knowledge in the creation of the Milky Way phenomenon resonated with his particular Marxist philosophy. The foundational principle of Marxist philosophy is that human consciousness is ultimately determined by external material factors. What exactly encompassed these material factors, however, remained a point of contention among Marxists. Pannekoek's interpretation was remarkably broad: for him, everything that was objectively observable was material, including ideas, thoughts, and theories. These were observed through conversations or texts and could have a notable influence on the further development of thoughts and ideas.[20] In the case of the Milky Way, this meant that any knowledge of earlier observations, either through memory or by looking at drawings, would inevitably influence the perceived structure. The resulting image of the Milky Way would then mimic preconceived notions of how it should look. Escaping this influence of earlier knowledge was impossible and so observations of the Milky Way were always altered by purely psychological conditions.[21]

Although Pannekoek did not appear to be too concerned about personal differences due to optical-anatomical or physiological-psychological conditions, differences caused by purely psychological conditions were a problem to him, precisely because they were both substantial and random. In 1897, he discussed various recently published Milky Way drawings and drew attention to the fact that, despite remarkable agreement on certain features, there were also great discrepancies in the structures they depicted. At times it was even hard to recognize that they were meant to represent the same object at all as a result of differences in the way observers recognized and recorded features, and differences in style and method of drawing.[22] Pannekoek was not alone in noticing the discrepancies among Milky Way drawings. A few years earlier, for example, Edward Emerson Barnard, a pioneer in Milky Way photography, argued: 'Eyes differ so much, and astronomers, as a rule, are such poor artists,

19 Pannekoek 1920, 16.
20 Pannekoek 1937, 451.
21 Pannekoek 1920, 16.
22 Pannekoek 1897a, 40-41.

that we may never expect to get anything like a fair delineation of the Milky Way by the human hand alone'.[23] Pannekoek disagreed with this sentiment, however. As we have seen, he considered it valuable to create a representation of the Milky Way based on visual observations. Such a representation, he believed, could be constructed by combining the work of many different independent astronomers in such a way that eliminated personal biases while preserving the inherent advantages of human perception.[24]

This section has revealed some striking interrelations between Pannekoek's scientific research and Marxist epistemology. By considering the latter, we can better understand methodological and epistemic choices he made in the former. It elucidates why Pannekoek believed it was important to capture the Milky Way as it was observed by the human eye, despite the fact that it was an optical illusion, and despite the considerable discrepancies among different observers. Intuitive abstraction was, after all, an inherent virtue of being human, and if the Milky Way aspect proved to be valuable for the investigation of the general structure of the distribution of stars, then it was worthy of scientific research. It also reveals why Pannekoek thought it was impossible to eliminate personal interpretation from visual observations. Since, as he explained in his Marxist writings, ideas and memories are material factors that determine human thought, subsequent observations of the Milky Way would only reinforce this interpretation, as they were unavoidably influenced by earlier impressions. It should be stressed, though, that neither belief was unique to Marxism and that Pannekoek had already begun to develop his ideas on the Milky Way before he had turned to Marxism. What the interrelations indicate, however, is that Pannekoek had a coherent epistemology that connected the practice of science with political and ethical philosophy.

At the same time, we can relate Pannekoek's extensive description of the various anatomical, physiological, and psychological circumstances that create the Milky Way phenomenon to how astronomers reflected on their own role in astronomical observations from the mid-nineteenth century onwards. By this time, due to the increasing precision of astronomical observations, astronomers began to notice that different observers recorded different stellar coordinates when using the trusted eye-and-ear method in transit observations.[25] These

23 Barnard 1890, 312; also quoted in Pannekoek 1897a, 41.

24 Pannekoek 1897a, 42.

25 The ear-and-eye method is a method of measuring the right ascension of a star by following its movement across reticles in the telescope while listening to a ticking clock.

so-called 'constant differences' forced astronomers to acknowledge that even among the most skilled and educated observers, inherent differences could occur. Astronomers started to reflect on themselves as an intricate part of their astronomical instrumentation. They each had their own characteristics and variations that could be measured and had to be corrected for, as in the case of any systematic instrumental error. Crucially, different beliefs on what caused constant differences led to different strategies to eliminate them. When it was believed that the effect was caused by psychological factors, the proposed solution was to minimize it by emphasizing discipline, skill, and education. When the effect was believed to be due to physiological factors, on the other hand, it became an inherent characteristic of the observer that could not be eliminated. It could, however, be standardized and accounted for by introducing mechanical methods and keeping track of who made each measurement. This ultimately led to the measurement of each observer's characteristics in order to calculate their so-called 'personal equation'.[26] According to Pannekoek, both psychology and physiology played a substantial role in creating the appearance of the Milky Way. Accordingly, we will see combinations of both strategies in his research. Psychological conditions could be reduced through proper methods and collaboration. Physiological conditions, on the other hand, could only be eliminated through photography.

How to Represent the Milky Way

Pannekoek's solution to the problem of providing a visual representation of the Milky Way that everyone could agree upon, was to make use of collaborative effort. By combining various independent drawings and descriptions of the Milky Way, it would be possible to filter out random personal patterns, which were restricted to a single observer, while preserving those features that were present in the work of multiple observers. The resulting image, Pannekoek argued, would then be far more objective than any individual image.

> Here, the importance of many independent works becomes apparent. Their differences give an impression of the objective uncertainties of faint particulars, which far exceeds the limits of subjective certainty. On the other hand, their agreement can secure faint details that each observer individually would be inclined to consider doubtful. In the

26 Hoffmann 2007. For more on the personal equation, see Schaffer 1988; Canales 2001.

> average of various representations, the accidental-subjective, the style of each observer, disappears to a large extent. What is retained, is not an objective image of the Milky Way, but that which one could call the mean-subjective image [*durchschnittlich-subjektive Bild*], the objective image as it is altered by the general physiological-psychological observation conditions. The connection with an objective Milky Way image is then at least significantly easier to find.[27]

The method of combining the observations of multiple observers to create a single composite image was common in late-nineteenth-century astronomy. Similar projects had been undertaken, for example, by William Parsons, the third Lord Rosse, in his drawings of nebulae, and by Arthur Ranyard and William Wesley in their depictions of the solar corona.[28] In both these cases, the final image was extracted by a single astronomer whose task it was to determine the true shape of the astronomical object based in their careful visual inspection of the various observations. Pannekoek, as we will see, took a far more mechanical approach in his pursuit for the mean subjective image; an approach that was closely connected to his ideas of how the Milky Way should be represented in the first place.

A requirement for constructing a collaborative representation of the Milky Way was that there were observations by other astronomers in the first place. In 1897, when he was still a student in Leiden, Pannekoek published a series of articles in popular astronomy journals that encouraged amateur astronomers to record their observations of the Milky Way and outlined a method that they should follow while doing so. Prior to observing, Pannekoek asserted, observers had to take proper precautions. They had to ensure that there was no artificial illumination nearby and that the sky was clear and cloudless, but more importantly, they also had to avoid learning about any previous research: 'For [the Milky Way's] great faintness makes it very easy to see what we expect to see, and preconceived ideas will soon vitiate the results'.[29] This is a clear example of how Pannekoek believed thoughts and ideas could have a real influence on scientific research. It should be noted, however, that this epistemic fear of prior knowledge altering what was seen was quite common among astronomers of his time. Milky Way researcher Otto Boeddicker, for example, wanted to exclude the influence of prior knowledge to the point that he avoided looking at

27 Pannekoek 1920, 16-17.

28 For nebula drawings, see Nasim 2013, 38-65; for the solar corona, see Pang 2002, 96-105.

29 Pannekoek 1897b, 77.

any earlier drawing of the Milky Way, including his own, so that he could 'remain as long as possible in ignorance of [the Milky Way's] appearance *as a whole*'.[30]

To record observations of the Milky Way, Pannekoek proposed a dual method that combined verbal descriptions with visual diagrams. To record particular features, it was important to investigate only small parts of the Milky Way at a time, and describe in detail, the position, boundaries, and interconnections of each Milky Way stream and cloud. Often, it was advantageous not to look at a bright spot directly but slightly next to it, as indirect vision could reveal details that were not seen by direct vision. Recording these details could best be done by written descriptions, as Pannekoek considered these to be much more intelligible and certain than drawings, for which it was never clear whether particular features were actually seen by the observer or the result of an inaccurate rendering by the draughtsman.[31] To record the general distribution of brightness in the Milky Way, Pannekoek recommended the use of isophotes – lines of equal brightness – which could be produced as follows: 'After having examined the region thoroughly, a boundary line is picked out, and its course is followed along the Milky Way, everywhere tracing the places of equal brightness. After having finished such a line, and after having marked its course upon the chart, another is chosen, shaping its course along a track of greater or lesser brightness'.[32] The number of isophotes should be limited to only a few in order to avoid confusion. They also should be supplemented with systematic photometric estimates that had to be made by repeatedly comparing distant sections of the Milky Way to each other. The dual method had the advantage of catering to both astronomers who wanted to track changes in the visual appearance of the Milky Way, where minute details were important, as well as those who wanted to use the Milky Way as a guide for researching the overall structure of the galactic system, for which the general distribution of light was more useful.

Pannekoek abandoned his own research on the appearance of the Milky Way in 1899, when he was hired as observer at the Leiden Observatory. When he picked up the subject again in 1910, he noticed that he had failed to cover the whole of the northern Milky Way in his observations, which he attributed to the fact that he had deliberately avoided looking back at his earlier observations during this research. From 1910 to 1913, he worked

30 Boeddicker 1889, 13; emphasis in the original.

31 Pannekoek 1897b, 78-79.

32 Pannekoek 1897b, 79.

Figure 11.1 Naturalistic drawing of a section of the Milky Way by Pannekoek

Source: Anton Pannekoek, *Die nördliche Milchstrasse*, Annalen van de Sterrewacht te Leiden, 11:3 (Haarlem: Joh. Enschedé en Zonen, 1920)

on the missing areas until he finally covered the Northern Milky Way in its entirety. The results of his observations were only published in 1920. Throughout this period, Pannekoek's ideas on how to represent the Milky Way continued to develop. He concluded that the dual method of verbal descriptions and isophotic diagrams was insufficient; they had to be supplemented with naturalistic white-on-black drawings that showed the Milky Way 'as it appeared to [Pannekoek's own] eyes' (Figure 11.1).[33] This inclusion is significant as these naturalistic drawings would have been by far the most difficult and expensive to reproduce, while serving no immediate scientific purpose like the isophotic diagrams and verbal descriptions did. Isophotic diagrams could be used in comparison with statistical star counts in order to probe the three-dimensional structure of the star system, while verbal descriptions could be recorded over a prolonged period of time in order to track minute changes in particular features of the Milky

33 Pannekoek 1920, 11.

Way.[34] Instead, the naturalistic drawings were included because they had aesthetic value. Conveying this aesthetic value was important, according to Pannekoek, because it was what often stimulated interest in astronomy in the first place: 'For modern man [...] the aesthetic element undeniably helps to arouse love for the night sky, all the more because the pleasure that direct observation provides us, [...] is further validated and enriched by knowledge'.[35]

Pannekoek's observations of the northern Milky Way prompted German astronomer Josef Hopmann to observe the southern Milky Way as part of his 1922 solar eclipse expedition to Christmas Island.[36] Hopmann explicitly followed Pannekoek's method in making and recording his observations. He also presented his results in the form of an isophotic diagram, which he later supplemented with numerical values for the surface brightness.[37] Pannekoek, however, was sceptical of Hopmann's results. The latter's photometric values for those areas that overlapped with the northern Milky Way were not consistent with the values that Pannekoek had found. Furthermore, Pannekoek doubted the truthfulness of the incredibly rich and detailed structure displayed in Hopmann's southern Milky Way.[38] When the Dutch Royal Academy of Sciences organized an expedition to Palembang in the Dutch East Indies for the 1925 solar eclipse, Pannekoek saw it as an ideal opportunity to observe the southern Milky Way himself.

Prior to his expedition to the Dutch East Indies, Pannekoek had never been able to follow his own instructions in earnest as he had been well acquainted with the appearance of the northern Milky Way prior to his first recorded observations. Now, with the southern Milky Way, he could truly start with a blank canvas. He soon discovered that there were practical problems to being unfamiliar with the area under investigation. It took him several days to get familiar enough with the stars of the southern hemisphere to be able to observe the southern Milky Way without constantly having to reorient himself. Moreover, he realized that even when looking at a completely unfamiliar sky, there were still ways in which implicit bias altered his observations. Increased knowledge of the importance of absorbing nebulae, for example, made him more inclined to mark dark features as real resolved objects. Nevertheless, he was satisfied with his method as it

34 Pannekoek 1897b, 79-80; for an analysis of how Pannekoek used the appearance of the Milky Way for his research on the statistical distribution of stars, see Tai 2017, 230-240.

35 Pannekoek 1916, 3.

36 Ferrari d'Occhieppo 1977.

37 Hopmann 1923; 1924.

38 Pannekoek 1925.

provided him with a systematic method of handling observational data, which in turn led to a more successful representation of the Milky Way. He also mentioned the valuable contribution of his wife, Anna Pannekoek-Nassau Noordewier, who acted as an observational assistant and penned down the verbal descriptions he dictated.[39] Significantly, one of the main conclusions of his research was that the richness of the southern Milky Way, which Pannekoek had dismissed in the work of Hopmann was indeed accurate. In a letter to Easton, he described how he had been stunned by the beauty of the southern Milky Way, further reinforcing the continued presence of aesthetics in Pannekoek's Milky Way research.[40]

Of course, presenting his own Milky Way observations was only the first step of the process for Pannekoek. His ultimate goal was to produce the collaborative mean subjective image. In 1920, Pannekoek did exactly that for the northern Milky Way, making use of the earlier observations of multiple independent observers, most prominently those by Otto Boeddicker, Cornelis Easton, and J.F. Julius Schmidt.[41] Pannekoek had initially intended to present the mean subjective image in the form of separate reproductions of each individual drawing from which the readers could draw their own conclusions about the structure of the Milky Way by comparison.[42] By 1920, however, Pannekoek had grown more ambitious in his plans for the mean subjective image. His new strategy was to make use of the numerical properties of isophotic drawings. He wanted to mimic the image that would emerge if these drawings had been made on translucent paper, placed on top of each other. He believed he could simulate this effect numerically by measuring isophotic diagrams of the drawings and calculating the arithmetic mean.[43]

For his own observations and those of Easton, isophotic diagrams were already available, but those of Schmidt and Boeddicker had to be specially created from the original drawings.[44] When these were done, however, Pannekoek realized that the brightness estimates in the drawings of Boeddicker and Schmidt were far from systematic, making their absolute values

39 Pannekoek 1928, 6. I have not found any other instance where Anna Pannekoek-Nassau Noordewier assisted Anton Pannekoek in his astronomical research.

40 Pannekoek to Easton, 19 April 1926, CE.

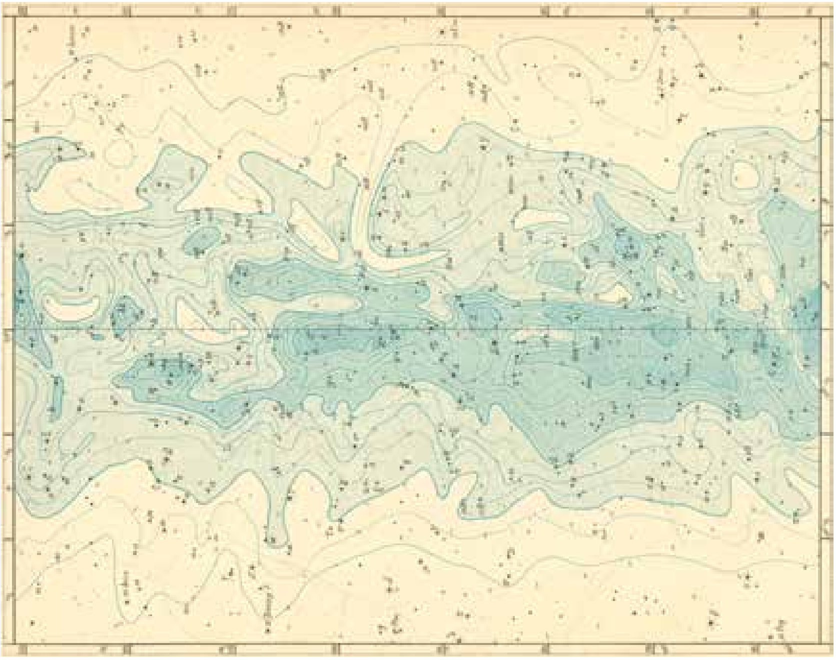
41 The drawings of Boeddicker and Easton had been published in 1892 and 1893 respectively. The drawings of Schmidt were unpublished in 1920. Pannekoek and De Sitter eventually managed to get them published as: Schmidt 1923.

42 This strategy was later used by Fritz Goos, see Goos 1921.

43 Pannekoek to Willem de Sitter, 11 August 1920, WdS 45.1, 80-82.

44 Pannekoek to Willem de Sitter, 21 July 1919, WdS 45.1, 57-59; Pannekoek to Willem de Sitter, 24 January 1920, WdS 45.1, 67-70.

Figure 11.2 Isophotic diagram of the mean subjective image



Source: Anton Pannekoek, *Die nördliche Milchstrasse*, Annalen van de Sterrewacht te Leiden 11:3 (Haarlem: Joh. Enschedé en Zonen, 1920)

unreliable. Yet, at the same time, their drawings were often richer and better in their finer structures than those of Easton and Pannekoek. To make the most of the benefits of each drawing, Pannekoek ignored the work of Boeddicker and Schmidt for the general structure of the Milky Way, while attributing greater weight to them in the case of particular feature rich areas – a striking example of how he relied heavily on his own judgement in creating the mean subjective image.[45] Pannekoek was very pleased with the end result, which he believed rose far above that of any one observer in depicting the Milky Way structure, making it ideal for comparison with photographic results.[46] The calculated mean subjective image was presented both in the form of an isophotic diagram (Figure 11.2) and as a numerical table. Additionally, for each section of the Milky Way, verbal descriptions by multiple observers were placed side by side.

45 Pannekoek 1920, 90.
46 Pannekoek to Willem de Sitter, 20 September 1920, WdS 45.1, 83-84.

Pannekoek's strategy for constructing the mean subjective image from existing depictions of the Milky Way elucidates his views on the ethos of scientific investigation and collaboration. According to Pannekoek, the most important quality for Milky Way astronomers was not their excellent vision or innate genius. Indeed, such individual qualities were exactly what Pannekoek sought to eliminate in his creation of the mean subjective image. Instead, he implored astronomers to show self-restraint and follow the proper method in describing the Milky Way. Doing so would make their contribution to the combined image that much more valuable. And ultimately this combined image, the mean subjective image, was much more trustworthy than any individual observer could ever hope to produce.

Photography as an Observational Tool

Pannekoek's extensive work on visual observations of the Milky Way did not mean that he was not interested in photography.[47] Quite to the contrary: from 1919 onwards, he worked for decades on a photographic representation of the Milky Way. This photographic research was noteworthy because Pannekoek was not interested in wide-angle photography like his contemporaries. Instead, he used extrafocal photography, which meant that the photographic plate was intentionally placed outside the focal plane. Furthermore, the presentation of this research was remarkably similar to that of his visual observations. It came in the form of isophotic diagrams and naturalistic drawings, and not, as one might expect, in the form of photographic reproductions. Analysing Pannekoek's photographic method of representing the Milky Way provides crucial insight into the application of astrophotography in the early twentieth century and the impact it had on the daily practice of astronomy.

When photography was first introduced in astronomy, it was primarily the domain of amateur astronomers, who had the freedom to experiment with photographic techniques, while professionals remained mainly focused on precision measurements using large visual refractors.[48] Even in the depiction of visually striking objects, like nebulae, planetary surfaces, or the solar corona, professional astronomers generally preferred drawings based on visual observations over photography. These were considered more

47 For an overview of Pannekoek's ideas on the role of photography in the historical development of astronomy, see Jennifer Tucker, 'Popularizing the Cosmos', in this volume, 173-195.
48 Lankford 1981; 1984.

trustworthy because the human eye was considered better at capturing large-scale structures and evaluating large differences in brightness.[49] Photography did have one major advantage over visual observations, however: photographic plates could be taken in large numbers and then be stored for later use.[50] This, in turn, enabled a division of labour among astronomical institutions. Since observatories with photographic instruments managed to produce far more photographic plates than they could possibly reduce, they could send photographic plates to institutions lacking photographic equipment. It even became possible to found astronomical institutes that lacked any kind of observatory, like the Astronomical Laboratory of Jacobus C. Kapteyn in Groningen. The success of collaborative projects like the *Cape Photographic Durchmusterung*, which was based on photographic plates taken by David Gill at the Cape Observatory and measured by Kapteyn in Groningen, helped to convince professional astronomers of the advantages of photography. By the early twentieth century, professional astronomers had started to embrace photography as new techniques and methods were developed that could work around its limitations. Meanwhile, drawing and visual observation increasingly became the domain of amateurs.[51] The case of the Milky Way, however, illustrates that the epistemic concerns surrounding photography persisted well into the twentieth century.

The Milky Way provided an interesting challenge for astronomers wanting to study it photographically, because telescopes – which were required to focus light onto the photographic plate – generally resolved the Milky Way into the many tiny individual stars that formed it. In the late nineteenth century, Barnard found that he was able to capture unresolved Milky Way clouds on the photographic plate using a wide-angle lens. Around the same time, German astronomer Max Wolf used a similar lens to obtain photographs of Milky Way clouds and other extended bodies in the night sky. Pannekoek considered these photographs a 'revelation' because they had provided definitive evidence that the Milky Way was formed by the combined light of countless stars too faint to see with the naked eye.[52] At the same time, the image these early photographic recordings revealed of the Milky Way was fundamentally different from what could be seen with the naked eye; it was much more detailed and irregular in structure.

49 For nebulae, see: Nasim 2013; for Mars, see: Lane 2011; Tucker 2005; for the solar corona, see: Pang 2002; Becker 2000; 2013.

50 This is particularly evident in the case of the Carte du Ciel, which is explicitly conceived as a photographic atlas of the stars that can serve as an archive for future astronomers. See Daston 2017.

51 Lankford 1984.

52 Pannekoek 1951, 409-411.

To some astronomers, this indicated that visual observations should no longer be trusted. Barnard, in particular, believed in the inherent value of photography: '[N]o matter how erroneous the various theories concerning the constitution of the Milky Way, the photographs are supposed to tell their own story, from which the student can judge for himself how well the theories fit into the actual appearance of this wonderful zone of stars'.[53] As we have seen, Pannekoek continued to value visual observations, but he was also enticed by the possibilities of Milky Way photography.

Pannekoek started his efforts to create a photographic representation of the Milky Way in 1919 while he was still refining his ideas on the mean subjective image, and many similarities exist between the two methods. The goal of both was to represent the large-scale distribution of galactic light. Wide-angle photography, as employed by Wolf and Barnard, was unsuited for this purpose because it emphasized minute structure over the general distribution of light. Pannekoek's alternative was extrafocal photography. The method of extrafocal photography was mainly developed by Karl Schwarzschild for photographic photometry of individual stars. As plates were taken out of focus, the light of stars was spread over a larger area, which allowed more accurate photometric measurements.[54] Pannekoek realized that this technique could be used to effectively produce the theoretical Milky Way – the Milky Way altered only by optical-anatomical conditions – as it would cause the light of the countless faint stars composing the Milky Way to overlap on the photographic plate.[55] While the mean subjective image could only eliminate the purely psychological conditions, extrafocal photography promised to also eliminate personal physiological-psychological conditions.

Since Pannekoek lacked his own observatory, he had to rely on the assistance of other astronomers for the implementation of his extrafocal photographic project, leading to its own set of logistical problems. For the northern Milky Way, the extrafocal plates were taken by Max Wolf in Heidelberg. The first batch of these plates, which arrived in 1920, turned out to be unsuited because they were not taken sufficiently out of focus.[56] Subsequent attempts were more successful, but even then, individual photographic plates were often found to have flaws and had to be replaced.

53 Barnard 1909, 89.
54 For more on Schwarzschild's extrafocal method, see Habison 2000.
55 Pannekoek 1923, 19.
56 Pannekoek to Max Wolf, 20 December 1920, MW.

All this meant that coverage of the northern Milky Way was not completed until 1928.[57] For the southern part of the sky, it took even longer. In 1926, Pannekoek instructed Joan Voûte of the Bosscha Observatory in Lembang on how to take the extrafocal plates (see Figure 11.3). Because the main telescope of the observatory was also used for other purposes, it took three years before Pannekoek received the plates.[58] Again, many of the photographic plates were found to have flaws and had to be retaken in 1933 and in the winter of 1938-1939. An added complication was that the southern-most part of the sky was not sufficiently visible from Lembang. For that part, Pannekoek had to turn to Harlow Shapley, director of the Harvard College Observatory, who agreed to have the plates taken at the Boyden Station in Mazelspoort, South Africa. These plates could only be taken in 1942 and by this time, they could not be shipped to the Netherlands until 1945 as a result of World War II. After they arrived, two of the Boyden-plates had to be rejected and retaken in 1946, finally completing the entire Milky Way.[59]

Getting a hold of the photographic plates was only the first step of the process, however. The plates first had to be systematically measured using a microphotometer.[60] These measurements then had to be corrected for both general systematic errors that resulted from the extrafocal method, as well as plate-specific systematic errors, which had to be determined empirically for each plate. To be able to combine the measurements and get a meaningful scale for the surface brightness, a reduction curve had to be derived separately for each individual plate.[61] For most of the Milky Way, multiple plates overlapped, and the average value was calculated. All these measurements and calculations were conducted by Pannekoek's longtime calculator David Koelbloed.[62] Pannekoek himself drew the isophotic diagrams, for which he used an episcope that projected the photographic plates onto paper. The isophotes were then drawn by tracing the features that the episcope had projected (see Figure 11.4).

57 Pannekoek 1933, 1-4; see also the Pannekoek-Wolf correspondence in MW.

58 These plates included exposures of the Large and the Small Magellanic Clouds, which were reduced by Gijsbert van Herk, then a student of the Astronomical Institute in Amsterdam, and published as van Herk 1930.

59 Pannekoek and Koelbloed 1949, 1-3.

60 A microphotometer is an instrument for measuring photographic plates that allowed both the coordinates and the blackening of the plate to be accurately determined.

61 The reduction curve is a formula that gives the relation between the incident light intensity of an object and the blackening it causes on the photographic plate.

62 Pannekoek 1933, 6-35; Pannekoek and Koelbloed 1949, 5-26.

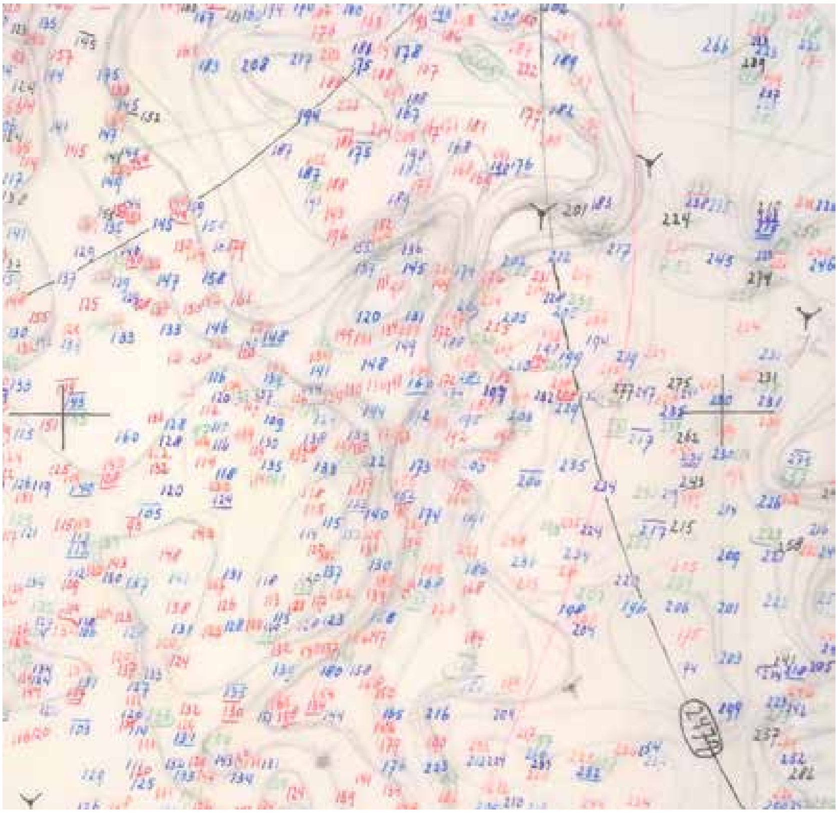
Figure 11.3 Extrafocal photographic plate of a portion of the southern Milky Way, taken at the Bosscha Observatory in Lembang by Joan Voûte

Source: Archive of the Anton Pannekoek Institute for Astronomy, University of Amsterdam

Throughout the entire measurement process, experience and expert judgement played a vital role. Pannekoek made this clear in a letter to Shapley that was sent only two days after the liberation of the Netherlands in World War II. In this letter, he requested that the remaining plates be sent as soon as safely possible, explaining that he had to finish the work himself 'during the years that will be allowed to me' as he was the only one with the skill and expertise needed to draw the isophotic diagrams. Similarly, he argued that only Koelbloed was capable of conducting the required measurements and calculations for this project.[63] Pannekoek's emphasis on the importance of his own hand in drawing the isophotic lines underlines a crucial aspect of his method of photographic photometry: it was never

63 Anton Pannekoek to Harlow Shapley, 7 May 1945, HCO.

Figure 11.4 Small part of one of Pannekoek's working sheets for photographic photometry



On these working sheets, Pannekoek traced isophotic lines based on multiple photographic plates. The lines are supplemented with numerical measurements of the same plates. The different colours represent information from different photographic plates.

Source: Archive of the Anton Pannekoek Institute for Astronomy, University of Amsterdam

meant to be objective in the sense that nature would represent itself. Not only should mechanical instruments mimic the human eye, expert judgement also remained crucially important.

In the presentation of the photographic research on the southern Milky Way, Pannekoek included naturalistic drawings of the Milky Way based on photographic photometry (Figure 11.5).[64] This inclusion reinforces what we have noticed throughout Pannekoek's photographic method: photographic

64 Pannekoek 1933.

Figure 11.5 Naturalistic drawing of the southern Milky Way based on measurements of photographic plates

Source: Anton Pannekoek and David Koelbloed, *Photographic Photometry of the Southern Milky Way*, Publications of the Astronomical Institute of the University of Amsterdam 9 (Amsterdam: Stadsdrukkerij, 1949)

plates were not intended to replace drawings as a way of depicting the Milky Way. Instead, they were meant to take over the role visual observations had played in Pannekoek's construction of the mean subjective image. Pannekoek's visual and photographic programmes displayed a clear continuity as they shared the principle aim of representing the Milky Way as it was seen by human eyes. This continuity from visual observations to photography was certainly not unique to Pannekoek, it can be seen in many astronomical subjects where photography made its entry.[65]

It is important to note that photographic plates were never meant to supplant visual observations completely. Pannekoek worked on both projects simultaneously throughout the 1920s and their results were intended to be complimentary. This was made when he discussed the differences between the two methods. While visual observation was better at revealing the general structure of the Milky Way, individual minor features were more clearly visible using the extrafocal photographic method. As such, the results of the extrafocal method occupied the space between visual observations and focal photography:

> We might describe the picture [produced by extrafocal photography] as the aspect the Milky Way would present to eyes that were far more sensitive to faint glares of light than ours and at the same time able to distinguish smaller details. A comparison with the focal photographs of Barnard and Ross shows a smoothing of all sharp detail, thus gaining a true representation of the surface intensity which is lacking there.[66]

Comparing the visual observations with photographic exposures had an additional practical benefit. Because photographic plates were more sensitive to blue light than the human eye, the difference in surface brightness found through both methods made it possible to determine the colour index of Milky Way clouds. For the Scutum cloud, for example, this colour index was found to be 0.43, similar to an F-type star. Evidently, the Scutum cloud had a similar constitution to the surroundings of the sun.[67] Being able to draw such conclusions illustrated the importance of providing both visual and photographic observations of the Milky Way light.

Conclusions

Despite the fact that Pannekoek acknowledged the artificial nature of the Milky Way phenomenon as an optical illusion created by the nature

65 See, e.g., Nasim 2011 for the case of depicting nebulae.
66 Pannekoek and Koelbloed 1949, 28.
67 Pannekoek 1923, 23-24.

of human physiology and psychology, he was convinced that an accurate description of the Milky Way was still scientifically relevant. It showed how the eyes and the mind processed the light of many faint stars into a coherent image, which in turn could be used for further scientific research. As he explained in his Marxist philosophy, usefulness, not truth, was his main criterium for scientific knowledge. The Milky Way image may have been a human construct, but then so were all scientific laws.

Because the Milky Way was intangible, many different representational methods were needed to capture all of its features. Pannekoek's depictions of the Milky Way ranged from naturalistic drawings and verbal descriptions to isophotic diagrams and numerical tables of surface brightness. This variation also reflected the various ways in which the Milky Way image could be useful. Verbal descriptions could be used to track changes in minor features of the Milky Way over time, while isophotic diagrams and numerical tables could be used for comparison with statistical research on the distribution of stars. Finally, naturalistic drawings were meant to display the aesthetic value of the Milky Way. The latter was important because aesthetics often proved to be an important incentive to pursue scientific research, as was demonstrated by Pannekoek's own career in astronomy.

Notably, photography was not one of the methods of depiction. Drawing and photography are often presented as distinct and competing methods of representation, but as Pannekoek's research makes clear, this was not always the case. This is worth emphasizing since mechanically produced photographic images were often used by advocates of mechanical objectivity to argue that one should let nature represent itself without human intervention.[68] According to Pannekoek, however, photography was inherently incapable of representing the Milky Way without human intervention. Before photography could produce scientific results, measurement and expert judgement was required from the astronomer. The drawings that resulted from this critical engagement with photography were not the result of nature unveiling itself, but constructed images highlighting the structure of the system. Photography, in this case, replaced visual observation, but not drawing.

Both Pannekoek's visual method as well as his photographic method of observing the Milky Way were developed to make optimal use of the desirable qualities of human perception. As he explained in his scientific writing as well as in his Marxist philosophy, human perception depended both on how information was received by the senses and on how it was transferred and

68 For more on photography and mechanical objectivity, see Daston and Galison 2007, 161-173; cf. Pang 1997; Tucker 2008; Wilder 2009b.

interpreted by the human brain. Individual psychological conditions were undesirable here, but as in the case of constant differences, their effects could be minimized in visual observations. In the case of the Milky Way, this was achieved through a combination of adhering to proper methodology and combining the work of independent observers. The resulting mean subjective image was capable of presenting the Milky Way as it was seen by the average human eye, unaltered by purely psychological effects. The goal of Milky Way photography, on the other hand, was to also remove physiological effects, much like mechanization had done in the case of the personal equation. By mechanizing observation, the image of the Milky Way would no longer be affected by personal physiological conditions like the strength of the eye's stimulus threshold. Crucially, in both photographic photometry and the mean subjective image, Pannekoek sought to eliminate personal alterations of the Milky Way image while striving to preserve the shared optical-anatomical conditions; these he considered crucial for the way that humans interpreted the Milk Way. In isolation, such a dichotomy can be difficult to understand, but it makes perfect sense in light of his Marxist philosophy of mind. Even if individuals could be led astray, without the interpretive and analytic abilities of the human mind, nothing could be known at all.

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MW	Nachlass Max Wolf, Heid. Hs. 3695 E. Universitätsbibliothek Heidelberg.
WdS	Leiden Observatory Archives, directorate W. de Sitter. Leiden University Library.

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