Anton Pannekoek, Marxist astronomer

*Photography, epistemic virtues, and political philosophy in early twentieth-century astronomy*

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Chapter 1

Milky Way Research

Ever since they were first published in the 1920’s, the Milky Way images created by Anton Pannekoek have captured the imagination of astronomers 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 ‘greatest 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 photographic methods to determine the distribution of galactic light, which he then represented using many different techniques, including naturalist

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27
1. **Milky Way Research**

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. By studying how and why Pannekoek employed such wide-ranging methods for observing and representing the visual aspect of the Milky Way, we gain 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.

To explain the co-existence 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 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 by the same methods, astronomers had to reconsider the role of human perception in visual observation and develop strategies to either minimize or stabilize these differences. This reflexive inward look of astronomers was part of a greater ‘reflexive turn’ in observational science during the mid-nineteenth century, and it caused several astronomers to venture beyond their own field and participate to a cross-disciplinary exchange of ideas. 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

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the Milky Way. He, too, ventured beyond astronomy to develop his ideas. In his case, however, it was not experimental psychology, but Marxism that he turned to.

There are clear advantages to actively considering Pannekoek’s Marxism when discussing his scientific methodology in representing the Milky Way. 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.6 Daston, in particular, has emphasized how the interaction between psychological-physiological concerns and scientific epistemology are especially prominent when considering the visual aspect of science.7 In Pannekoek’s Milky Way research, we find that he wanted to emphasize the innate capacity of the human mind to analyse sense perceptions while eliminating the effects of implicit bias. In doing so, he concurred with contemporary ideas on scientific collaboration. The late nineteenth century saw the emergence of large-scale scientific collaborations working on grand transnational projects. For the organizers of these projects, it was vital that participants showed self-restraint and followed predetermined methods. Subjective differences had to be minimized for individual contributions to be mutually compatible.8 Although Pannekoek’s Milky Way research was conceived on a much smaller scale, he advocated a similar ethos. In his case, he hoped to eliminate 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-

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1. Milky Way Research

century astronomy. When discussing the development of astrophotography, it is tempting to list vivid and increasingly detailed photographic images of visually striking astronomical objects, like nebulae, clusters, or the moon, produced by the latest technological innovations. Such an approach, however, would overlook 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. Most historical research on this subject has 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. The information they contained was then usually presented in the form of large tables of numbers. Pannekoek’s use of astrophotography fits 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.


1.1 The Milky Way as Optical Phenomenon

This chapter will begin by investigating Pannekoek’s ideas on what the Milky Way actually was; how, as a phenomenon, it was shaped by the particularities of 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 Pannekoek’s 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.

1.1 The Milky Way as Optical Phenomenon

At a young age, Pannekoek was already interested in the visual appearance of the Milky Way. His early journals contain many observations of various features of the Milky Way. At times, these were accompanied by rudimentary drawings or even contour maps of sections of the Milky Way that represented areas of equal brightness through isophotic lines (Figure 1.1).11 Taken together, these observations suggest that he was already en route to developing a distinct method of representing the Milky Way before he started his formal education in astronomy.

One of the reasons why Pannekoek developed his own method for observing the Milky Way was because little research had been done in that area so far. As Pannekoek noted in his History of Astronomy many decades later:

> It is a remarkable fact that [after Ptolemy had written verbal descriptions of the Milky Way] in all later centuries no attempt was made to repeat and improve his work and to depict the phenomenon as it appeared to the eye. Star maps mostly

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11. Pannekoek’s observational journals can be found in Archive of the Anton Pannekoek Institute, University of Amsterdam (API), except for the second one, which is located in Persoonlijk archief van Antonie Pannekoek, Museum Boerhaave (MB/AP), box 1. These journals also contain other astronomical and non-astronomical observations, such as of variable stars and of the plant life around the city of Apeldoorn where Pannekoek lived during this period.
1. Milky Way Research

Figure 1.1: A double page from one of Pannekoek’s observational journals. In the centre of the right page, there is an isophotic map of part of the Milky Way with a naturalistic drawing underneath. Surrounding these drawings are relative brightness estimates of various stars. Source: Dagboek 6, 272–273, API.

showed a worthless picture of a uniform, sharp-bordered river. Probably the reason is that what always remains the same does not draw the attention.12

It was thus unsurprising, so Pannekoek argued, that the first astronomer to publish systematic descriptions of the Milky Way, the British astronomer John Herschel, did so of a part of the sky that was unfamiliar to him. Herschel’s drawings, published in 1847, focused on the southern Milky Way and were based on observations made during his four-year trip to South Africa. It took three more decades before similar drawings were published for the northern Milky Way by Eduard Heis of the University of Münster in 1877, and by Jean-Charles Houzeau, director of the Brussels Observatory, in 1878. Houzeau’s atlas, Uranométrie générale, was the first to represent the brightness of the Milky Way with isophotic lines.13

In 1893, another drawing of the northern Milky Way was published; this was produced by Dutch journalist and amateur astronomer Cornelis

13. For an overview of Milky Way descriptions in the late nineteenth century, see History of Astronomy, 474–475; Cornelis Easton, La Voie lactée dans l’hémisphère boréal (Dordrecht: Blussé, 1893), 11–17.
1.1. The Milky Way as Optical Phenomenon

Easton with the assistance of Pannekoek, who was then a student in Leiden.\textsuperscript{14} This publication is especially noteworthy because, in the introduction, Easton explicitly discussed the nature of the Milky Way and the problems associated with accurately drawing it.\textsuperscript{15} He contended that, due to its extreme faintness, it was not only very difficult to compare the brightness of different parts of the Milky Way, but also deceptively easy to exaggerate the contrast in drawings. Moreover, because the Milky Way was built up from the collective light of many faint stars, it was ultimately a visual phenomenon created by the observer; it could even be called an optical illusion. To make matters worse, the appearance of the Milky Way could be altered easily by observational circumstances or by foreground stars. It was therefore important not to assign too much value to its appearance. Nevertheless, Easton still believed it was important to keep drawing it, as drawings provided a valuable opportunity to track changes in the large-scale structure of the Milky Way over time.\textsuperscript{16}

Pannekoek’s ideas on the nature of the Milky Way phenomenon coincided with those of Easton, as Pannekoek stated in the introduction to his 1920 publication on the northern Milky Way:

The Milky Way image that we observe is an optical phenomenon, which is created by various optical, physiological and psychological conditions working together. Easton once referred to the Milky Way as an optical illusion; this expression may be even more true than the author himself had intended.\textsuperscript{17}

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 take this optical illusion seriously and investigate and represent it in detail, even more so than Easton did. To understand why, we will turn to Pannekoek’s Marxist philosophy, where he examined both the essence of scientific laws and the nature of the human mind.

\textsuperscript{15} Easton, \textit{La Voie lactée}, 1–10.
\textsuperscript{16} Ibid.
1. **Milky Way Research**

According to Pannekoek, the task of the human mind was to analyse and abstract information that was provided from the sense organs. This intuitive abstraction was required to make sense of the external world, which Pannekoek conceived as 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. ... The world is a unity of the infinitely numerous multitude of phenomena and comprises within itself all contradictions, makes them relative and equalizes them. Within its circle there are no absolute opposites. The mind merely constructs them, because it has not only the faculty of generalization but also of distinguishing.\(^{18}\)

The human mind extracted information from the overwhelming amount of sense impressions of the outside world and organized and systematized this information into distinct categories and general laws. By abstracting the inflow of information, the mind could comprehend the world and predict future occurrences.\(^{19}\)

Pannekoek’s theory of the human mind also 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. Natural laws did not refer to the properties of real objects but only talked about the properties of universal, abstract entities. By identifying concrete and singular facts with universals, they were crafted into natural laws. Both universal entities and natural laws only existed as abstractions in human thought; they were fabricated constructions that brought order to the overwhelming stream of sense perceptions. The aim of scientific research then should not be to search for the true structure of reality but to summarize knowledge

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and provide economy of thought.\textsuperscript{20} By organizing and systematizing natural phenomena into laws and models, it became possible to comprehend them.\textsuperscript{21} 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 as such, it was still valuable as a \textit{scientific} object because it gave an intuitively created abstraction of the distribution of stars in the galaxy. This abstraction was useful for astronomers to track changes in the general distribution of stars, as Easton had also suggested, or as a comparison for the results of statistical astronomy, as will be discussed in the next chapter.

The Milky Way phenomenon is especially interesting in the context of Pannekoek’s philosophy of science because 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 distinct types: the optical–anatomical, the psychological–physiological, and the purely psychological. Optical–anatomical conditions referred to the physical properties of the eye, such 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 might have been too faint to detect individually, was combined onto a single nerve. At the same time, the light of each star was not just detected by a single 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 gradu-

\textsuperscript{20} On the topic of the essence of natural laws, Pannekoek agreed in broad terms with his contemporary Ernst Mach. At the same time, Pannekoek rejected what he considered Mach’s tendency toward subjectivism. He criticized Mach for prioritizing sense perceptions while stopping short of considering what caused them. This failure to take into account the external world made Mach an idealist rather than a materialist in Pannekoek’s opinion. For Pannekoek’s assessment of Mach’s philosophy, see Anton Pannekoek, \textit{Lenin as Philosopher: A Critical Examination of the Philosophical Basis of Leninism}, repr. (1948; repr., New York: Breakout Press, 1975), 45–56. For more on Mach’s ideas on natural law, see Erik C. Banks, \textit{Ernst Mach’s World Elements: A Study in Natural Philosophy} (Dordrecht: Kluwer, 2003), 123–135; Elske de Waal and Sjang L. ten Hagen, ‘The Concept of Fact in German Physics around 1900: A Comparison between Mach and Einstein’, \textit{Physics in Perspective} 22, no. 2 (2020): 55–80, 64–66.

ally changing surface brightness. This flat image, Pannekoek identified as ‘the theoretical Milky Way’.\textsuperscript{22}

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: the amount of light that was needed before a nerve would send a signal to the brain. This threshold was a function of both the size and brightness of an observed object. The smaller the object, the brighter it had to be to still be detectable.\textsuperscript{23} Additionally, small bright features were also blurred over a larger area, making them appear less distinct. Crucially, both optical–anatomical and physiological–psychological conditions depended on individual personal characteristics — like the number of retinal elements, visual acuity, or sensitivity to faint light — which meant that the Milky Way appeared differently to each observer.\textsuperscript{24}

It was impossible to discern the extent to which personal differences in physiology and anatomy affected the appearance of the Milky Way, however, as their effect was drowned out by the even more significant effect of purely psychological conditions. 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.’\textsuperscript{25} 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 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, it was an effect that could not be lessened by further observations: ‘No repetition of the work, no matter how often, can help here; personal touch [Manier] will not be reduced, but will only impress itself stronger and clearer.’\textsuperscript{26}

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 ex-

\textsuperscript{22} Pannekoek, \textit{Nördliche Milchstrasse}, 15.
\textsuperscript{23} Ibid., 15, n.1. Pannekoek explicitly referred to the work of physiologist Hans Edmund Piper, which later became known as Piper’s law.
\textsuperscript{24} Ibid., 14–16.
\textsuperscript{25} Ibid., 16. Translated from German.
\textsuperscript{26} Ibid., 16. Translated from German.
ternal material factors. What exactly encompassed these material factors, however, remained a point of contention among Marxists. Pannekoek’s interpretation, which was based on the work of Joseph Dietzgen, was remarkably broad. He considered everything that was objectively observable to be ‘material’, including ideas, thoughts, and theories:

[T]he surrounding real world ... is not restricted to physical matter only, but comprises everything that is objectively observable. The thoughts and ideas of our fellow men, which we observe by means of their conversation or by our reading are included in this real world. Although fanciful objects of these thoughts such as angels, spirits or an Absolute Idea do not belong to it, the belief in such ideas is a real phenomenon, and may have a notable influence on historical events.

Crucially, the influence of all these material factors was a ‘subconscious spontaneous process in our minds’. The human mind was always involved in knowing the outside world, and because it worked instinctively, it was not always aware of the material factors that influenced its thoughts and ideas. 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.

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

27. Pannekoek greatly valued the work of Dietzgen and considered it an indispensable supplement to the work of Marx. In creating his Marx–Dietzgen synthesis, however, Pannekoek may have given a too narrow view of Dietzgen’s philosophy while overstating its originality and importance, as historians of socialism have suggested. See Tony Burns, ‘Joseph Dietzgen and the History of Marxism’, Science & Society 66, no. 2 (2002): 202–227; Jasper Schaaf, De dialectisch-materialistische filosofie van Joseph Dietzgen (Kampen: Kok Agora, 1993), 242–253.
29. Ibid., 448.
30. Ibid., 451.
31. Pannekoek, Nördliche Milchstrasse, 16.
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 substantial 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.\(^{32}\) 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, that we may never expect to get anything like a fair delineation of the Milky Way by the human hand alone.’\(^{33}\) Pannekoek disagreed with this sentiment, however, primarily based on the comparison between the Milky Way drawings of Easton and the Irish astronomer Otto Boeddicker ‘which, though giving a very different representation of some parts, show in other parts a fair resemblance even of detail.’\(^{34}\) As we have seen, Pannekoek considered it valuable to create a representation of the Milky Way based on visual observations. The partial agreement between the drawings of Easton and Boeddicker gave him the confidence that such a representation could be constructed by combining the work of many different independent astronomers in such a way that eliminated personal biases while preserving the innate advantages of human perception.\(^{35}\)

This section has revealed some notable 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


\(^{34}\) Pannekoek, ‘Existing Drawings of the Milky Way’, 41.

\(^{35}\) Ibid., 42.
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 his 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 onward. 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. These 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 by keeping track of who made each measurement. This ultimately led to the measurement of each observer’s characteristics.

36. 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.
1. Milky Way Research

in order to calculate their so-called ‘personal equation’.\(^{37}\) 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 method and collaboration. Physiological conditions, on the other hand, could only be eliminated through photography.

1.2 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 a 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 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 \([\text{durchschnittlich-subjektive Bild}]\), 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.\(^{38}\)


1.2. How to Represent the Milky Way

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. In both 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 what he termed 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. He also collaborated with Easton to create star charts that were specifically suited for observing the Milky Way. In calling amateur astronomers to contribute, he followed in the footsteps of Friedrich Argelander who, in 1844, had written an ‘appeal to the friends of astronomy’ to contribute by making easily conducted observations of the night sky, including of the Milky Way.

Before beginning their observations, 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 most importantly, they had to avoid learning about any previous research:

39. For nebula drawings, see Omar W. Nasim, Observing by Hand: Sketching the Nebulae in the Nineteenth Century (Chicago: University of Chicago Press, 2013), 38–65; for the Solar corona, see Pang, Empire and the Sun, 96–105.
41. Pannekoek owned a Dutch translation of Argelander’s article: Friedrich Argelander, Handleiding voor vrienden der sterrekunde, tot het volbrengen van belangrijke waarnemingen, die gecne werkтуigen vorderen, ed. Frederik Kaiser, trans. W. F. Kaiser (Zwolle: De erven J. J. Tijl, 1855), which is located at API.
'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.' Here, we see a clear example of how Pannekoek believed thoughts and ideas could influence on scientific observations. It should be noted, however, that this epistemic fear of prior knowledge altering what was seen was quite common among astronomers of his time. When Irish astronomer Otto Boeddicker was working on his drawing of the Milky Way, which was published in 1889, he wanted to exclude the influence of prior knowledge to the point that he avoided looking at any earlier drawing — including his own — so that he could ‘remain as long as possible in ignorance of [the Milky Way’s] appearance as a whole’.

To record observations of the Milky Way, Pannekoek proposed a dual method that combined verbal descriptions with visual diagrams. When observing particular features, it was important to investigate only small parts of the Milky Way at a time and provide a detailed description of the position, boundaries, and interconnections of each Milky Way stream and cloud. Often, it was advantageous not to look directly at a bright spot but slightly next to it, as indirect vision could reveal details that were not seen by direct vision. Recording detailed features 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. 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...

43. For example, among astronomers observing the surface of Mars, see K. Maria D. Lane, *Geographies of Mars: Seeing and Knowing the Red Planet* (Chicago: University of Chicago Press, 2011). Argelander also asserted that observers of the Milky Way should work independently from other observers. Argelander, *Handleiding voor vrienden der sterrekunde*, 78.
1.2. How to Represent the Milky Way

upon the chart, another is chosen, shaping its course along a track of greater or lesser brightness.\textsuperscript{46}

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. This 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 to 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.

When Pannekoek was hired as observer at the Leiden Observatory in 1899, he abandoned his research on the appearance of the Milky Way. In 1910, he again picked up the subject, but he noticed that he had failed to cover the whole of the northern Milky Way in his observations. He attributed this to the fact that he had deliberately avoided looking back at his earlier observations during this research. From 1910 to 1913, he worked on the missing areas until he had finally covered the northern Milky Way in its entirety. The results of these observations were only published in 1920.

Throughout this period, Pannekoek’s ideas on how to represent the Milky Way continued to develop, however. He concluded that the dual method of verbal descriptions and isophotic diagrams was insufficient; they had to be supplemented with naturalist white-on-black drawings that showed the Milky Way ‘as it appeared to [Pannekoek’s own] eyes’ (Figure 1.2).\textsuperscript{47}

This inclusion is significant as these naturalistic drawings would have been the most difficult and expensive to reproduce while serving no immediate scientific purpose, like the isophotic diagrams and verbal descriptions did. An isophotic diagram (Figure 1.3) 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 Way.\textsuperscript{48} Instead, the naturalistic drawings were included because they had aesthetic value. Conveying this aesthetic value was important,

\textsuperscript{46} Pannekoek, ‘Best Method of Observing the Milky Way’, 79.

\textsuperscript{47} Pannekoek, \textit{Nördliche Milchstrasse}, 11. These drawings were made with chalk on black paper.

Figure 1.2: Naturalistic drawing of a section of the northern Milky Way drawn by Pannekoek. Source: Pannekoek, *Nördliche Milchstrasse*, plate 1.
1.2. How to Represent the Milky Way

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.'

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. 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. 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 veracity of the incredibly rich and detailed structure displayed in Hopmann’s southern Milky Way. To extend the research himself, he first came up with the idea to travel to South Africa, but 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 on Java instead.

Before his expedition to the Dutch East Indies, Pannekoek had never been able to follow his own instructions in earnest as he had already been

used the appearance of the Milky Way for his research on the statistical distribution of stars will be discussed in the next chapter

53. Anton Pannekoek to Cornelis Easton, 19 Apr 1926, Correspondentie, aantekeningen Cornelis Easton, Museum Boerhaave (MB/CE) 427f.
54. Anton Pannekoek to Willem de Sitter, 22 Sep 1923, Leiden Observatory Archives, directorate Willem de Sitter, Leiden University Library, Special Collections (UBL/WdS), 45.2.
Figure 1.3: Isophotic diagram drawn by Pannekoek of the same section of the Northern Milky Way as depicted in Figure 1.2. The lines indicate areas of equal brightness while the numbers give a numerical value for the brightness at a specific point. Source: Pannekoek, *Nördliche Milchstrasse*, plate 4.
1.2. How to Represent the Milky Way

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 provided him with a systematic way 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. 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 importance of the aesthetic aspect of the Milky Way for Pannekoek. Of course, presenting his own Milky Way observations was only the first step of the process for Pannekoek. His ultimate goal was to produce a 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 Boedicker, Cornelis Easton, and J.F. Julius Schmidt. Pannekoek had initially intended to present the mean subjective image in the form of separate

56. Pannekoek, Südliche Milchstrasse, 6. I have not found any other instance where Anna Pannekoek-Nassau Noordewier assisted Anton Pannekoek in his astronomical research.
57. Anton Pannekoek to Cornelis Easton, 19 Apr 1926, MB/CE, 427h.
58. The drawings of Boedicker and Easton had been published in 1892 and 1893 respectively. Following the efforts of Pannekoek and Willem de Sitter the drawings of Schmidt were published in 1923 as J. F. Julius Schmidt, Dessins de la Voie lactée faites à Athènes par J. Fr. Julius Schmidt dans les années 1864–1876, Annalen van de Sterrewacht te Leiden 14, pt. 2 (Haarlem: Joh. Enschedé en Zonen, 1923). See the correspondence between Pannekoek and De Sitter, 21 Jul 1919 – 29 Aug 1923, UBL/WdS, 45.1–2.
Figure 1.4: The mean subjective image of the same section of the Milky Way as depicted in Figure 1.2 and Figure 1.3. This diagram is created by averaging over several drawings made by independent observers. Source: Pannekoek, *Nördliche Milchstrasse*, plate 7.
reproductions of each individual drawing from which the readers could draw their own conclusions about the structure of the Milky Way by comparison.\textsuperscript{59} 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.\textsuperscript{60}

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.\textsuperscript{61} 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 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 attributed greater weight to the work of Boeddicker and Schmidt in detailed features of the Milky Way, while ignoring them to calculate the general structure — a striking example of how he relied heavily on his own judgement in creating the mean subjective image.\textsuperscript{62} Pannekoek was 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.\textsuperscript{63} The calculated mean subjective image was presented both in the form of an isophotic diagram (Figure 1.4) and as a numerical table. Additionally, for each section of the Milky Way, verbal descriptions by multiple observers were placed side by side.\textsuperscript{64} All these different methods of representation were needed because, due to the intangible nature of

\textsuperscript{59} This strategy was later used by Fritz Goos in his depiction of the Milky Way. Fritz Goos, Die Milchstrasse (Hamburg: Henri Grand, 1921).
\textsuperscript{60} Anton Pannekoek to Willem de Sitter, 11 Aug 1920, UBL/WdS, 45.1.
\textsuperscript{61} Anton Pannekoek to Willem de Sitter, 21 Jul 1919; Pannekoek to De Sitter, 24 Jan 1920, UBL/WdS, 45.1.
\textsuperscript{62} Pannekoek, Nördliche Milchstrasse, 90. In a review of Pannekoek’s publication, Easton remarked that Pannekoek had ‘sinned somewhat’ by being too modest and that the result would have been even better if he had attributed double weight to his own estimates, which would have been warranted because of his ‘impeccable method and precision’. Cornelis Easton, ‘De Noordelijke Melkweg’, review of Die nördliche Milchstrasse, by Anton Pannekoek, Hemel en Dampkring 19, no. 5 (1921), 68–69. Translated from Dutch.
\textsuperscript{63} Anton Pannekoek to Willem de Sitter, 20 Sep 1920 UBL/WdS no. 45.1: 83–84.
\textsuperscript{64} For an example of these descriptions, see Appendix A.
the Milky Way phenomenon, it was the only way to capture its appearance to the human eye.\(^{65}\)

Pannekoek’s strategy for constructing the mean subjective image from existing depictions of the Milky Way illuminates 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 the image that any individual observer could ever hope to produce.

1.3 Photography for Measurement

Pannekoek’s extensive work on visual observations of the Milky Way did not mean that he was not interested in photography. Quite the contrary: from 1919 onward, 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 was given 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 in the second half of the nineteenth century, it was primarily the domain of wealthy self-funded astronomers, who had the freedom to experiment with photo-

\(^{65}\) Historian of science Omar W. Nasim has recently argued that, in Pannekoek’s Milky Way research: ‘The active alternation of different media and techniques of representing — naturalistic and schematic — is certainly indicative of drawing used not for presentation but as tools for observing.’ Nasim, ‘Labour of Handwork’, 270.
1.3. Photography for Measurement

graphic techniques. Astronomers employed by large observatories, meanwhile, remained primarily focused on precision measurements using large visual refractors. Even in the depiction of visually striking objects, like nebulae, planetary surfaces, or the Solar corona, most astronomers generally preferred drawings based on visual observations over photography. These were considered more trustworthy because the human eye was considered better at capturing large scale structures and evaluating large differences in brightness. 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. 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. 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 to 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, Edward Emerson Barnard found that he was able to capture unresolved Milky Way clouds on the photographic plate using a wide-angle lens. Although his first photographs were published in 1889,
the final work was only published posthumously in 1927.\textsuperscript{72} 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.\textsuperscript{73} 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.\textsuperscript{74} 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. To some astronomers, this indicated that naked-eye observations should no longer be trusted. Barnard, in particular, believed in the inherent value of photography:

\begin{quote}
[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.\textsuperscript{75}
\end{quote}

And Edward S. Holden, director of the Lick Observatory, stated that:

\begin{quote}
After taking into account all the advantages and disadvantages of the best possible representations of the Milky Way made by the eye and made by photography, it seems to be unquestionable that the latter process is the only one which should be employed in the future.\textsuperscript{76}
\end{quote}

As we have seen, Pannekoek continued to value visual observations, but he was also impressed by the possibilities of Milky Way photography.


\textsuperscript{73} Max Wolf, \textit{Die Milchstrasse} (Leipzig: J. A. Barth, 1908).

\textsuperscript{74} Anton Pannekoek, \textit{De groei van ons wereldbeeld} (Amsterdam: Wereldbibliotheek, 1951), 409–411. For more on Pannekoek’s assessment of focal Milky Way photography, see Tucker, ‘Popularizing the Cosmos’, 180–182.

\textsuperscript{75} Edward Emerson Barnard, review of \textit{Die Milchstrasse}, by Max Wolf, \textit{Astrophysical Journal} 29, no. 1 (1909), 89.

1.3. Photography for Measurement

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 not suitable 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 developed primarily 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.  

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.

If … each starpoint is extended to a circle, the mean surface brightness of the sky over such a circle may be measured by the blackness of the plate; the scale being afforded by the extrafocal images of the bright stars on the plate. Such a picture will bear a much greater resemblance to the visual aspect of the Milky Way than an ordinary photograph.

While the mean subjective image could only eliminate the purely psychological conditions, extrafocal photography promised to eliminate personal physiological–psychological conditions as well.

Since Pannekoek lacked an observatory, he had to rely on the assistance of other astronomers for the implementation of his extrafocal photographic project, leading to logistical problems on top of the technical challenges associated with the project. The extrafocal plates of the northern Milky Way were taken by Max Wolf in Heidelberg, which took him several years to complete. One of the main delaying factors was the long


exposure time — three to six hours of continuous exposure — that the plates required. In case bad weather interrupted the exposure, the plate had to be discarded and the exposure started anew.\textsuperscript{79} Moreover, the first batch of these plates, which arrived in 1920, turned out to be unsatisfactory because they were not taken sufficiently out of focus.\textsuperscript{80} After receiving a more suitable batch of plates, Pannekoek decided to try out his method for a section of the Milky Way in Scutum. He encountered various minor issues with the reduction of these photographic plates. On the plates, stars

\textsuperscript{79} Anton Pannekoek, \textit{Photographische Photometrie der nördlichen Milchstrasse}, Publications of the Astronomical Institute of the University of Amsterdam 3 (Amsterdam: Stadsdrukkerij, 1933), 2.

\textsuperscript{80} Anton Pannekoek to Max Wolf, 20 Dec 1920, Nachlasse Max Wolf, Universitätsbibliothek Heidelberg (UBH/MW), EP 7.
were not visible as uniformly dark circles, but had a small border ring which was darker than the rest of the disk. At the edges of the plates, they were stretched out to ellipses rather than circles. And the image was much fainter than a focal photographic image because the radiant energy had been diluted over a larger surface instead of a concentrated point. Finally, the darkening on the photographic plates had to be converted to a scale that correctly represented the visual brightness of the Milky Way. These problems, however, could all be overcome and the result was worth it, according to Pannekoek: the measurements from extrafocal plates managed to reflect the brightness distribution of the Milky Way light, and in more detail than drawn representations could. Like with the visual mean subjective image of the Milky Way, Pannekoek presented his results in the form of isophotic graphs supplemented with numerical values for the brightness of the Milky Way light (Figure 1.5).

In the extended programme, the quality of extrafocal photographic plates remained an issue; individual photographic plates were often found to have flaws and had to be replaced. Additionally, because Pannekoek had no access to the telescope himself, he was unable to experiment with the setup. He had to work with what he was given. All this meant that coverage of the northern Milky Way was not completed until 1928. For the southern part of the sky, it took even longer. In 1926, while Pannekoek was visiting the Bosscha Observatory in Lembang as part of his expedition to Java, he instructed the director Joan Voûte on how to take the extrafocal plates (Figure 1.6). Because the main telescope of the observatory was also used for other purposes, it took three years before Pannekoek received the plates. 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.

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81. Pannekoek, 'Photographic Photometry of the Milky Way', 22. Nasim argues that the manual labour associated with measuring and reducing photographic plates reflected the prominence that Pannekoek placed on the hand in both human and societal evolution — 'Handwork is crucial to both sides of Pannekoek’s oeuvre.' See Nasim, 'Labour of Handwork', quote is on 276.

82. Pannekoek, Photometrie der nördlichen Milchstrasse, 1–4; Pannekoek to Johan Stein, [ca. 1935], Archive of the Vatican Observatory (VO). See also the correspondence between Pannekoek and Max Wolf, UBH/MW, EP 7.

83. These plates included exposures of the Large and the Small Magellanic Clouds, which were measured and reduced by Gijsbert van Herk, then a student of the Astronomical Institute in Amsterdam, and published as Gijsbert van Herk, 'Photographic Photometry of the Magellanic Clouds', Bulletin of the Astronomical Institutes of the Netherlands 6, no. 209 (1930): 61–64.
not sufficiently visible from Lembang. For that part, Pannekoek wanted to enlist the assistance of Willem Hendrik van den Bos at the Union Observatory in Johannesburg, but that location turned out to be unsuitable due to light pollution.84 On the suggestion of Van den Bos, Pannekoek

84. By this time the Second World War had started in Europe and communications with South Africa had been cut off, so Pannekoek corresponded with Van den Bos via Otto Struve, director of the Yerkes Observatory near Chicago. Anton Pannekoek to Otto Struve, 29 Jul 1940; Struve to Pannekoek, 18 Nov 1940, Otto Struve correspondence, Niels Bohr Library & Archives, American Institute of Physics (AIP/OS) reel 9.

56
turned 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 only shipped to the Netherlands in 1945 after the war in Europe had ended. After they arrived, two of the Boyden-plates had to be rejected and retaken in 1946, finally completing the entire Milky Way.

Getting hold of photographic plates was only the first step of the process, however. The plates next had to be systematically measured using a microphotometer. 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. 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 long-time computer David Koelbloed. 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 (Figure 1.7).

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 the Second World War. 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 (Figure 1.8). Similarly, he argued that only Koelbloed was capable of

85. Anton Pannekoek to Harlow Shapley, 11 Dec 1940; Shapley to Pannekoek, 17 Jan 1941, HUA/HCO box 45 folder 332; Pannekoek to Shapley, 20 Feb 1941, Papers of Harlow Shapley, Harvard University Archives (HUA/HS) box 22a.
87. A microphotometer is an instrument for measuring photographic plates that allowed both the coordinates and the blackening of the plate to be accurately determined.
88. 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.
1. Milky Way Research

conducting the required measurements and calculations for this project.\textsuperscript{90} 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 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.

\textsuperscript{90} Anton Pannekoek to Harlow Shapley, 7 May 1945, HUA/HCO, box 45, folder 332.
1.3. Photography for Measurement

Figure 1.8: Isophotic diagram made by Pannekoek of a section of the southern Milky Way. The diagram is based on photometric measurements of extrafocal photographic plates. Source: Pannekoek and Koelbloed, *Photometry of the Southern Milky Way*, chart 13.

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 1.9). This inclusion reinforces what we have noticed throughout Pannekoek’s photographic method:

photographic 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 attempted to represent 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 also be seen, for example, with astronomers using photography to depict spiral nebulae.\footnote{Omar W. Nasim, ‘The “Landmark” and “Groundwork” of Stars: John Herschel, Photography and the Drawing of Nebulae’, Studies in History and Philosophy of Science Part A 42, no. 1 (2011): 67–84.}

It is important to note, however, that photographic plates were never meant to supplant visual observations completely.\footnote{See also Hoel, ‘Measuring the Heavens’, 63.} Pannekoek worked on both projects simultaneously throughout the 1920s and their results were intended to be complimentary. This was made clear 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.\footnote{Pannekoek and Koelbloed, Photometry of the Southern Milky Way, 28.}

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.\footnote{Pannekoek, ‘Photographic Photometry of the Milky Way’, 23–24.}
1.3. Photography for Measurement

Figure 1.9: Naturalistic drawing of the southern Milky Way by Pannekoek, based on measurements of extrafocal photographic plates. Source: Pannekoek and Koelbloed, *Photometry of the Southern Milky Way*, plate 3.
1. Milky Way Research

able to draw such conclusions illustrated the importance of providing both visual and photographic observations of the Milky Way light.

1.4 Conclusions

Although Pannekoek acknowledged the artificial nature of the Milky Way phenomenon as an optical illusion created by the nature of human physiology and psychology, he was convinced that an accurate description of the Milky Way was 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, for example in statistical astronomy. 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.96 According to Pannekoek, however, photography was

96. For more on photography and mechanical objectivity, see Daston and Galison, Objectivity, 161–173; cf. Alex Soojung-Kim Pang, "Stars Should Henceforth Register Themselves": Astrophotography at the Early Lick Observatory, British Journal for the History of
1.4. Conclusions

inherently incapable of representing the Milky Way without human intervention. Before photography could produce scientific results, measurement and expert judgement were 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 and 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 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, in contrast, 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 Milky Way. In isolation, such a dichotomy can be difficult to understand, but it becomes clearer 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, the Milky Way image would not exist at all.