Anton Pannekoek, Marxist astronomer

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

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Statistical Astronomy

The early twentieth century was one of the most exciting periods in the history of astronomy. During this period, the entire conception of the universe was overturned. While at the start of the century the prevailing belief was that the Sun was near the centre of a single small star system, by the 1930s the consensus was that the Sun was located in the outer regions of a vast rotating system that was only one of many such systems.¹ These drastic changes in the conception of the universe were the result of several important breakthroughs in various subjects within astronomy occurring at around the same time. Measurements of the size of our galactic system indicated that it was much larger than previously thought, while distance measurements of spiral nebulae indicated they had to be separate galaxies independent from our own. The apparent contradiction of these results led to a prolonged discussion between astronomers about the shape and structure of the galactic system, exemplified by the public meeting at the National Academy of Sciences, held in 1920, that has become known as ‘The Great Debate on the Scale of the Universe’.

This episode in the history of astronomy has received plenty of attention from historians, but primarily from the perspective of the United

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While they have discussed the important contributions of Dutch astronomers like Jacobus C. Kapteyn and Jan Oort, the discussions occurring within the Netherlands during the 1920s have largely been ignored. This is unfortunate because there, too, the topic of the size and structure of the galactic system was lively debated, not only in professional scientific publications but also in popular magazines like Hemel en Dampkring, which inspired young readers like Bart Bok to study astronomy. Anton Pannekoek was a prominent figure in these discussions; through his research, we can investigate how the debate developed in other settings than the United States. In the case of the Netherlands, as we will see, the primary focus was on the size and structure of the universe, with much less attention being given to the potential existence of external galaxies.

Pannekoek had a peculiar and original approach to statistical astronomy. While he used the same statistical models as his nineteenth-century predecessors, Kapteyn and Hugo von Seeliger, he did not follow their example of developing all-encompassing smoothened models for the distribution of stars. Instead, he acknowledged the irregular and complicated character of the Milky Way and stressed the importance of investigating individual particularities. Marcel Minnaert described the difference as follows: ‘Kapteyn designed a general picture of the universe that surrounds us, a grand but smoothened picture. Pannekoek sought a more faithful representation of the complicated bright and dark patches, of the natural object as it truly manifests itself to us.’ Similarly, Edward van den Heuvel has suggested that ‘[Pannekoek] does not follow in the footsteps of Seeliger, who designed a strongly systematized mathematical model of our star


4. Marcel Minnaert, eulogy at the funeral of Anton Pannekoek, 2 May 1960, Archief Anton Pannekoek, International Institute of Social History (IISH/AP), 294b. Translated from Dutch
system. Rather he responded to the call of Argelander to systematically observe the Milky Way.5

Pannekoek’s rejection of idealized representations in favour of more complicated structures seems to coincide with how historians of science Lorraine Daston and Peter Galison describe an interesting aspect of the wider development of the sciences during the last two centuries, as we have discussed in the introduction. During this period, scientists shifted away from a focus on the universal, which was inherent to truth-to-nature science, and started to appreciate the particular and idiosyncratic. This changing perspective was tied to a change in epistemic virtues and scientific persona. Whereas, in the early nineteenth century, scientists were expected to rely on their intuitive genius and experience, by the late nineteenth century, the ideal was someone who suppressed their personal interventions to the extent that they may best be compared with a recording machine.6 Daston and Galison’s account is unapologetically mesoscopic as it tracks the \textit{longue durée} dynamics of epistemic virtues, their associated personae and their larger cultural and scientific reverberations.7 However, a focus on epistemic virtues can also be quite useful as a historiographical tool for studying individual cases because they make it possible to bridge the gap between the microscopic and the mesoscopic, by relating these case studies to wider developments in science.8

Furthermore, a focus on personae enables us to look beyond the constraints of disciplinary boundaries in scholarship and thus contributes to a post-disciplinary approach to the historiography of knowledge. As historians have shown, epistemic virtues and ideal personae can be shared across disciplines and knowledge domains and then be adapted according to the specific needs of each discipline.9 This property makes it a promising perspective for investigating the relations between Pannekoek’s as-

7. Daston and Galison have even stated that their approach may be considered \textquoteleft{}superficial\textquoteleft{} as they do not dig too deep into individual cases. Lorraine Daston and Peter Galison, ‘Response: \textit{Objectivity} and its Critics’, \textit{Victorian Studies} 50, no. 4 (2008): 666–677, 666.
9. On how virtues and personae were shared across disciplines and knowledge domains, see e.g. Matthias Dörries, ‘Heinrich Kayser as Philologist of Physics’, \textit{Historical Studies in the Physical and Biological Sciences} 26, no. 1 (1995): 1–33; Matthew Stanley, ‘Religious
tronomical research and his Marxist philosophy. In the previous chapter, we have discussed how his philosophy of mind led Pannekoek to emphasize the importance of judgement in the representation of the Milky Way. As we will find in this chapter, judgement also played an important role in his statistical astronomy, where he used the distribution of Milky Way light as a guide in his statistical research on the distribution of stars. Judgement was an epistemic virtue because it warded against the pitfalls of a purely mechanical approach to stellar statistics. Likewise, in his Marxist writings, Pannekoek warned against a purely mechanical approach to studying societies and the limitations caused by ignoring human judgement.

This chapter will start with a historical survey of the field of statistical astronomy, which sought to investigate the structure of the galactic system through the statistical distribution of stars. Special attention is given to the research of Jacobus Kapteyn, which acted as a starting point for Pannekoek. The next two sections describe Pannekoek’s statistical research and the various debates he engaged in with contemporaries. These debates will be explored through the lens of epistemic virtues to highlight the differences in their various methodologies. The final section will discuss various aspects of Pannekoek’s Marxist philosophy to explore the intersections with his scientific methodology and epistemic virtues in astronomy. The goal is to situate Pannekoek’s statistical research in the context of both his own Marxist philosophy and contemporary developments in astronomy and science as a whole, and investigate how this, in turn, can provide a better understanding of Pannekoek’s particular approach to the subject.
2.1 Statistical Cosmology

In the early twentieth century, the question of the structure of the stellar system and its relation to the Milky Way was at the forefront of astronomical research. The predominant method of researching this topic through statistical analysis of the location, apparent magnitude, and proper motion of stars and clusters. Since many of the astronomers involved believed that through such methods, not just the stellar system, but the entire universe could be understood, historian of astronomy E. Robert Paul has argued that this research program can retrospectively be called ‘statistical cosmology’.

One of the earliest examples of such research was conducted by William Herschel in his 1785 paper ‘On the Construction of the Heavens’. It is worth briefly discussing this paper as it serves well to illustrate the basic principles and goals of statistical astronomy. Herschel’s main goal was to determine the dimensions of the stellar system by simply counting the number of stars in each direction of the sky. He based his research on three assumptions: that all visible stars were contained in the stellar system, that stars were distributed roughly uniformly, and that his telescope could penetrate to the edge of the system. If these assumptions were valid, then the number of stars in a certain direction of the sky was a direct indication of the distance to the edge in that direction. The system he deduced using this method was roughly shaped like a flattened rhombus and can be seen in Figure 2.1. Further research made Herschel disavow his foundational assumptions in later life; his investigation of binary stars and star clusters indicated that stars were certainly not uniformly distributed, while his newly constructed 40-foot telescope indicated that the edges of the system were far more distant than he had anticipated. It was clear that to understand the structure of the stellar system, much more data are needed.

10. Apparent magnitude indicates the brightness of a star as seen from Earth. Lower magnitude indicates that a star is brighter. The brightest stars in the sky are about zeroth magnitude, and sixth-magnitude stars are the faintest ones that can be detected by the naked eye. Proper motion is the apparent movement of a star in the sky as seen from the Sun.
were needed, and in the following century, many astronomers devoted their attention to counting and measuring the stars.

Statistical astronomy continued to be practised in the nineteenth century, most notably by William’s son John Herschel, German astronomer Friedrich von Struve, and his son Otto Wilhelm. The most important development for statistical astronomy, however, was the increasing amount of stellar data that became available during the century in the form of star catalogues, the pinnacle of which was compiled by Friedrich Argelander of the University of Bonn between 1852 and 1863. The resulting Bonner Durchmusterung contained the position and brightness of 324,198 stars in the northern hemisphere brighter than tenth magnitude.

One of the first astronomers to make extensive use of this new data was Hugo von Seeliger of the University of Munich, who had worked as an assistant to Argelander in Bonn. Seeliger managed to derive an equation that could calculate the star density distribution as a function of distance from the Sun from the observed ‘star-ratio’, the ratio between the number of stars of a given apparent magnitude and the number of stars one magnitude fainter. In 1898, he determined this star-ratio for the stars in the Bonner Durchmusterung and found that it was lower than what would be expected for a uniform distribution of stars, especially in the direction of the galactic poles. From his investigations, Seeliger derived a model of

the galactic system as a flattened ellipsoidal system, approximately 10,000 parsecs in diameter along the galactic equator and 1,800 parsecs in the direction of the galactic poles. The Sun was placed in the centre of this system, and the star density thinned out exponentially toward the edges of the system. Seeliger’s method relied heavily on complex mathematical manipulations and theoretical presuppositions. In particular, he required the luminosity function, which describes the relative number of stars as a function of absolute brightness, to be shaped like a Gaussian distribution. Only then was his mathematical analysis valid.

Seeliger’s approach to statistical astronomy was widely adopted by astronomers in the early twentieth century, including Carl Charlier, Arthur Eddington, and Karl Schwarzschild, who all developed different analytical methods to investigate the statistical distribution of stars in the stellar system. An alternative method for statistical astronomy was developed by Dutch astronomer Jacobus Kapteyn. Unlike Seeliger’s mathematical analysis, Kapteyn approached the topic empirically and numerically.

Kapteyn’s first goal was to determine the luminosity function, which he did empirically by analysing the distribution of absolute magnitudes for nearby stars. He published his first results of this research in 1901. By assuming that this luminosity was valid throughout the stellar system, he could then use it to compute the density distribution empirically as well. He developed his first model in 1908, for which he divided the night sky into three sections: the galactic plane, covering the sky from −20° to 20° galactic latitude; the galactic poles, covering the sky above 40° and be-

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16. Parsec is a measure of distance, with one parsec being 3.26 lightyear.
19. For a technical comparison between the methods used by Kapteyn and Seeliger, see Hans Kienle, ‘Historical Development of Our Ideas Concerning the Structure of the Galaxy’, in *Structure and Evolution of the Galaxy*, ed. Lyssimachos N. Mavridis (Dordrecht: D. Reidel, 1971). Although Kapteyn and Seeliger both worked in the same field, there was remarkably little interaction between the two. Kapteyn believed that Seeliger’s method depended too strongly on presuppositions, but he never expressed his criticism publicly. When his PhD student Willem J. A. Schouten strongly criticized Seeliger’s method in his dissertation, Kapteyn refused to have it published as part of the *Groningen Publications* because he considered it too polemical. Schouten then decided to publish the dissertation himself, which was predictably ill-received by Seeliger. Bok, interview by DeVorkin, AIP/OH; Paul, *Milky Way Galaxy*, 176–177.
20. Ibid., 94–99.
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Figure 2.2: Kapteyn’s final dynamical model of the stellar system, published in 1922. The half ellipses indicate areas of equal star density. The small circle right of the centre indicates the location of the Sun in this model, which, according to Kapteyn’s calculations, was located at 650 parsec from the centre. Source: Kapteyn, ‘First Attempt’.

low –40° galactic latitude; and the transition zone in between those two sections. For each of these three sections, he determined the star-ratio separately and derived in the star density distribution from it. The results were very similar to those produced by Seeliger: Kapteyn’s model too was a flattened ellipsoid with gradually decreasing star density toward the edges. Kapteyn kept refining his results throughout the years, and by the end of his life, his model had become known as the Kapteyn Universe.

Kapteyn was initially skeptical of the fact that the Sun had such a central place in his system and suspected that this was caused by absorption from interstellar matter. He searched actively for evidence of the existence of this extinction until, in 1916, Harlow Shapley produced results that indicated space was indeed free of interstellar absorption. Knowing this result, Kapteyn continued his statistical approach and eventually came up with a dynamic model of the stellar system, seen in Figure 2.2, in which the stars had an orbital rotation and the Sun was located very near the centre of the system at only 650–parsec distance.

Kapteyn is still fondly remembered by astronomers for his numerical and open-minded approach to statistical astronomy. In the words of Dutch astronomer Adriaan Blaauw:

Kapteyn’s approach was basically different from that of contemporaries such as Hugo von Seeliger and Karl Schwarzschild. The latter proposed certain analytical expressions for the [density and luminosity] functions, as well as for the distribution of observed quantities, and then tried to solve for the parameters involved by means of integral equations. Kapteyn, on the other hand, preferred the purely numerical approach, allowing full freedom for the form of the solution.24

Historian of astronomy Elly Dekker summarized:

[Kapteyn] never sacrificed clarity of treatment or exposure of essential details for elegance of presentation; and, although a mathematician himself by his early training, he strongly disliked treatises in which emphasis lay more on the form of the mathematical expression than on proper evaluation of the basic observation.25

It is undeniably true that Kapteyn took a more inductive approach than Seeliger, one that prioritized the observational data over sophisticated mathematical techniques. This is especially evident in their different approaches to the luminosity function. Where Seeliger postulated an equation that allowed for easy mathematical manipulation, Kapteyn provided a table with observational data to allow the numbers to speak for themselves, in line with the virtue of mechanical objectivity.

At the same time, Kapteyn had his own preconceived ideas about the distribution of stars. Although he insisted that he was building up from below where others were building from the top down,26 he still prioritized the shape of the overall system over the existence of individual particularities. He felt confident that these could be ignored because they were only small deviations from the otherwise symmetrical distribution of stars.27

This decision shows more in common with the ontological concerns of

truth-to-nature and, as will be shown, had a crucial impact on the results of his research. It led to criticism from astronomers like Heber D. Curtis, who wrote: ‘While I am ready to worship Kapteyn’s methods ..., I can not, as most astronomers do, fall down and worship all the results which have come out of this mathematical mill.’ Likewise, Pannekoek also admired Kapteyn’s numerical methods, while believing his results were inaccurate because they did not reflect the visual appearance of the Milky Way.

As we have seen in the previous chapter, Pannekoek spent considerable effort to obtain an accurate, reliable, and complete measurement of the distribution of Milky Way light. The following sections will indicate how he applied these results to his statistical astronomy.

### 2.2 Particularities in Statistical Distribution

One of the main reasons why Pannekoek valued an accurate representation of the distribution of Milky Way light was because it should guide statistical studies of the structure of the stellar system. He felt that this aspect was being ignored by Seeliger and Kapteyn. Pannekoek’s first paper on the statistical distribution of stars was a direct reaction to the symmetrical ellipsoidal distribution of stars presented by Kapteyn in his 1908 publication on the distribution of stars. In the introduction, Pannekoek explicitly mentioned the problem with this model:

[Kapteyn’s] conclusion ... is in direct opposition to the appearance of the galaxy. We see the galaxy as a belt of more or less circular masses, patches and drafts designating a totally different structure. ... The appearance of the galaxy shows ... that the zone between +20° and −20° galactic latitude should by no means be treated as one whole. In that way parts of the universe of really great diversity of structure would be mixed up .... It may be necessary to take all these different parts together for arriving at an average representation of the distribution of the stars in space, but this is obscuring the especially striking character of this distribution, which shows

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in the aggregation of stars into clouds and drifts; and it is giving a false impression of the real Milky Way if the star-density is represented as a simple function of [distance] and [galactic latitude].

Pannekoek’s criticism was specifically aimed at the mechanical way in which Kapteyn had organized the stellar data at his disposal, rather than at his numerical methods. He argued that, by dividing the sky only according to galactic latitude, Kapteyn had already presupposed a symmetry in galactic longitude; the ellipsoidal shape of the resulting system was an artefact of this symmetry. His alternative was to assess the star density distribution separately for particular regions in the Milky Way, as a function of both latitude and longitude. This could be done by using the equation Seeliger had derived to determine the star density distribution of the entire system. From this equation, Pannekoek derived that clusters would reveal themselves in star counts through higher than expected star-ratios at a certain apparent magnitude; and that the apparent magnitude at which this happened directly correlated with the distance to the star cluster. Thus both the direction and distance of star clusters could be found by investigating star counts of specific locations of the sky.

To demonstrate his method, Pannekoek selected five regions to investigate, which he chose based on the visual aspect of the Milky Way. These were two particularly bright spots in Cygnus and Aquila, two faint parts directly adjacent to these clusters, and a fainter part of the Milky Way as a comparison. The star counts for these areas were taken from several sources: the Bonner Durchmusterung, the Carte du Ciel, and star gauges from William Herschel and Th. Epstein in Frankfurt. In the case of the two brighter regions, Pannekoek found that they had significantly more stars than one would expect from Kapteyn’s results, especially around ninth and twelfth magnitude. He concluded that this likely meant that there were indeed multiple star clusters in the directions of Cygnus and Aquila that caused those brighter regions of the Milky Way. Furthermore, in the case of Cygnus, he found that the higher star density was also present in the adjacent darker part, but only in the case of ninth-magnitude stars, not in the case of twelfth-magnitude stars. Apparently,

31. Ibid., 243–245.
32. Ibid., 245–248.
there was ‘no organic relation’ between the stars of ninth to eleventh magnitude and the Milky Way clouds, because the cluster of ninth-magnitude stars seemed to extend into the dark stroke in Cygnus where the Milky Way phenomenon was absent. Instead, the Milky Way light was probably caused by stars fainter than twelfth magnitude.\(^{33}\)

Already from this first paper by Pannekoek, it is clear that there are stark differences between his approach and that of Kapteyn. One of the major differences was the perceived goal of sidereal astronomy. For Kapteyn, his research was a first step toward developing a grand scheme that would describe the general distribution of stars in the entire stellar system. In this scheme, the irregularities in the distribution could be discarded because they represented only small deviations from the mean distribution.\(^{34}\) Pannekoek, on the other hand, emphasized exactly those irregularities and argued that to understand the entire system, we first need to understand how particular areas of the stellar system corresponded with the visual appearance of the Milky Way.\(^{35}\) Another important difference was the role assigned to the astronomer. For Kapteyn, the astronomer had to minimize his own role in interpreting the data. This could be achieved by using systematically organized sections that allowed a mechanical way to sort the data and eliminated the need for interpretation. Pannekoek, on the contrary, constantly emphasized the importance of human judgement in organizing and analysing the data. Judgement was needed to choose which areas to investigate, and deciding on the relation between statistical data and the brightness distribution in the stellar system. Where interpretation was a vice for Kapteyn, it was a virtue for Pannekoek.

A problematic issue in statistical astronomy was the lack of complete and homogeneous data. Published star catalogues often registered only the position of stars, not their apparent magnitudes. That meant the actual number of stars of a certain magnitude had to be calculated by determining a limiting magnitude for each catalogue: the magnitude of the faintest stars still included in the catalogue. Even then, the limiting magnitudes were far from systematic because the star counts did not always cover


\(^{34}\) Kapteyn justified his decision to discard deviations in the star distribution in Kapteyn,\textit{ Number of Stars of Determine Magnitude}, 2–3.

the entire area homogeneously. This was a significant problem because the statistical method of Pannekoek and Kapteyn relied heavily on knowing the relative number of stars for various magnitudes. As a solution to this problem, Pannekoek proposed a photographic method for obtaining star counts. According to this method, multiple wide-angle photographs had to be taken of a single region, using geometrically increasing exposure times. By increasing the exposure times geometrically, the limiting magnitude would increase by a constant number with each photograph. The exposures could be taken on a single photographic plate with the plate being slightly shifted in between exposures. This way, the magnitude for each star could easily be determined by the number of times it appeared on the plate.

Since Pannekoek had no photographic observatory of his own, he requested photographic plates from Ejnar Hertzsprung at the Potsdam Observatory. He received photographic plates of the Aquila region in 1910–1911. It took him close to a decade to reduce the plates, with the results of this research being published in 1919. In processing these plates, Pannekoek decided to divide the area into 100 squares, which were grouped into five regions. As can be seen in Figure 2.3, these regions did not have regular shapes. Instead, it seems that the squares were grouped according to a combination of star density and location, with Sections I and II having the most stars, while Section V was relatively poor in stars.

Although there were large differences in the total number of stars for each section of the plate, Pannekoek found no significant difference in the star-ratios. Denser sections had more stars at every magnitude, rather than at a few magnitudes, as would be expected in the case of star clusters. According to Pannekoek, this indicated that the number of distant stars was actually consistent for the entire area. The relatively low number of stars in Section V was probably caused by a triangle-shaped dark nebula, rather than an actual deficiency of stars. This nebula had to be located close enough to darken all but the brightest stars. Rather than forming an ‘organic’ connection with the distant clouds of the Milky Way, the neb-
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Figure 2.3: This table indicates the star counts of the photographic plates taken of Aquila. The top number shows the number of starts visible at 1900 seconds exposure time, and the following numbers indicate the number of stars that were also visible with exposure times of 600, 190, 60, 19, and 6 seconds, respectively. The bold lines represent the division of the area into five equally large sections.

Source: Pannekoek, 'Galactic Cloud in Aquila', 1324.

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Table I. Number of stars.

Figure 2.3: This table indicates the star counts of the photographic plates taken of Aquila. The top number shows the number of starts visible at 1900 seconds exposure time, and the following numbers indicate the number of stars that were also visible with exposure times of 600, 190, 60, 19, and 6 seconds, respectively. The bold lines represent the division of the area into five equally large sections.

Source: Pannekoek, 'Galactic Cloud in Aquila', 1324.

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 ula was 'only accidentally projected’ in front of it.\(^\text{39}\) Despite these results, Pannekoek felt that the photographic method was inadequate. It proved impossible to penetrate much further than the fourteenth magnitude, as increasing noise levels made plates with even longer exposure times unreliable.\(^\text{40}\)

It is interesting to note that, even in a strictly systematic photographic scheme, Pannekoek felt the need to intervene with the organization of the stellar counts. He organized the field into intuitively determined sections following interesting features — dense clouds in Sections I and II, and a dark void in Section V — and decided that they should be investigated separately. This division allowed him to compare the different sections, which in turn led him to postulate the existence of a dark cloud in the region. This need to interfere with the organization of data can easily be understood in light of his epistemic virtues. If the data were simply organized mechanically, valuable information might be lost that the human mind could intuitively grasp and use to create structure.

The Great Debate

To make better use of the limited data available for stars fainter than the fourteenth magnitude, Pannekoek constructed a model of a single star cluster placed in an otherwise uniform system. For this model, he could compute a theoretical star count, which could be fitted to observed star counts by adjusting the distance and size of the theoretical cluster. This method had the advantage that a fairly precise measure of the distance could be provided with only a limited amount of data; the downside, however, was that small variations in the measured counts could have a significant effect on the final results. In 1919, he used this method to derive distances of 40,000 parsecs to the cluster that formed the Cygnus cloud.
and 60,000 parsecs to the cluster that formed the Aquila stream.\footnote{Anton Pannekoek, ‘The Distance of the Milky Way’, \textit{Monthley Notices of the Royal Astronomical Society} 79, no. 7 (1919): 500–507, 504.} This result was especially significant because it firmly placed these branches of the Milky Way beyond the limits of both Seeliger’s and Kapteyn’s systems, which were both less than 20,000 parsec in diameter. Despite using the same basic numerical techniques, Pannekoek had now found results that directly contradicted the model of Kapteyn.

Pannekoek was not the only one to challenge the models of Seeliger and Kapteyn. The previous year, in 1918, American astronomer Harlow Shapley had presented a model of the galactic system that was stretched some 100,000 parsec with the Sun located 20,000 parsec from the centre.\footnote{Harlow Shapley, ‘Globular Clusters and the Structure of the Galactic System’, \textit{Publications of the Astronomical Society of the Pacific} 30, no. 173 (1918): 42–54, 54.} This model was based on his investigations on globular clusters. Shapley had found that these clusters were distributed symmetrically around the galactic plane (Figure 2.4), indicating that they outlined the galactic system, and located mostly in the direction of Sagittarius (Figure 2.5), which meant that the Sun was placed in the outer regions of the system. To determine the distances of the globular clusters, Shapley used a particular class of variable stars, known as Cepheids, as a yardstick. Cepheids showed a remarkable relation between their variation period and their absolute magnitude, as Henrietta Swan Leavitt of Harvard College Observatory had found a decade earlier. These distances turned out to be much larger than previously thought, which led Shapley to postulate his extended galactic system.\footnote{Ibid. See also Smith, \textit{The Expanding Universe}, 59–77; Paul, \textit{Milky Way Galaxy}, 191–202.}

Pannekoek recognized that his results were complementary to Shapley’s, as he stated in his paper:

\begin{quote}
The results we have arrived at here are in accordance with [Shapley’s results], as they place some of the bright parts of the Milky Way at a distance of 40–60,000 parsec. So the starry masses of the galaxy are spread over space as far as the remotest clusters, and clearly both belong together to one system. In this system the dense agglomerations of stars are spread over a flat disc of about 2000 parsec thickness, and in the empty space above and below it the globular clusters are dispersed.\footnote{Pannekoek, ‘Distance of the Milky Way’, 507.}
\end{quote}
2.2. Particularities in Statistical Distribution

Figure 2.4: Diagram by Shapley showing the distance of globular clusters from the galactic plane and projected on the galactic plane. Globular clusters tend to avoid the galactic plane, which is shaded grey. Source: Shapley, 'Globular Clusters', 47.

Figure 2.5: Diagram by Shapley showing the spatial distribution of globular clusters projected on the galactic plane. The solid circles show distance from the Sun in steps of 10,000 parsec, except the smallest circle, which indicates 1000 parsec. The dashed circles show the distance from the galactic centre. Source: Shapley, 'Globular Clusters', 53.
Besides the agreement in distance scales, there was another reason for Pannekoek to prefer Shapley’s model of the galaxy. He believed that it better reflected the appearance of the Milky Way. The eccentric position of the Sun explained why the Milky Way in Sagittarius — where the centre of Shapley’s system was located — was much brighter than in the opposite direction toward Perseus.\footnote{Pannekoek, ‘Distance of the Milky Way’, 507. See also Robert W. Smith, ‘Astronomy in the Time of Pannekoek and Pannekoek as an Astronomer of his Times’, in Anton Pannekoek: Ways of Viewing Science and Society, ed. Chaokang Tai, Bart van der Steen and Jeroen van Dongen (Amsterdam: Amsterdam University Press, 2019), 126–128.}

Shapley’s expanded galactic system was a much-debated topic in the years following its publication. The most prominent challenge came from Heber Doust Curtis of the Lick Observatory. Curtis had done photographic research on novae in spiral nebulae and found that these novae, on average, appeared to be a hundred times more distant than novae located in the Milky Way. That would mean that these novae and the spiral nebulae in which they resided were located well outside the borders of the galactic system. Curtis concluded that these spiral nebulae were ‘island universes’, independent star systems that were similar in size to our own galactic system.\footnote{Michael Hoskin, ‘Ritchey, Curtis and the Discovery of Novae in Spiral Nebulae’, Journal for the History of Astronomy 7, no. 1 (1976): 47–53; Smith, The Expanding Universe, 77–87.}

Initially, these two results — the increased size of the galactic system and the existence of independent galaxies outside our own — seemed to contradict one another. Supporters of Shapley’s system believed that it was large enough to incorporate the entire universe including the spiral nebulae, whereas those who advocated for the island universe theory believed that Shapley’s extended galactic system was much too large in comparison with the size of the spiral nebulae. The discussions led to a public debate held at the National Academy of Sciences in 1920, which has become known as ‘The Great Debate on the Scale of the Universe’. During this meeting, Shapley and Curtis debated the merits of their respective theories. Curtis questioned the reliability of using Cepheids as a measurement tool, while Shapley argued the island universe theory was incompatible with the rotation measurements of spiral nebulae by Dutch-American astronomer Adriaan van Maanen.\footnote{For a detailed analysis of the Great Debate in the United States, see Hoskin, “The “Great Debate””; Smith, The Expanding Universe, 77–90.} Van Maanen had taken photographs of spiral nebulae over a prolonged period of time and investigated how...
2.2. Particularities in Statistical Distribution

stars moved within spiral nebulae over time. His conclusion was that stars rotated within the spiral nebulae far too quickly to believe they could be as large as the Milky Way system.48

Despite Van Maanen’s role in the discussion over the island universe theory, this topic was not much debated in the Netherlands. Instead, the debate in the Netherlands mainly focused on the size of the galactic system, as this directly pertained to the status of the Kapteyn Universe.49 Most of the Dutch astronomers — Pannekoek being an exception — initially remained loyal to Kapteyn’s smaller model. One of Kapteyn’s students, Willem Schouten, provided his own measurements of galactic clusters conducted with traditional statistical means and found much smaller distances than Shapley, while Kapteyn and Pieter van Rhijn challenged Shapley’s use of Cepheids to measure distance. Kapteyn also argued that Shapley’s eccentric position of our Solar system did not coincide with the symmetry the star density distribution displayed in all directions of galactic latitude.50 Kapteyn felt that, where Shapley was building from above, he was building from below.51 Meanwhile, the distances that Pannekoek had derived for the Cygnus and Aquila clouds were challenged by Cornelis Easton.

As we have seen in the previous chapter, Easton was keenly interested in the appearance of the Milky Way and had published detailed drawings

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2. Statistical Astronomy

Like with Pannekoek, these drawings played an important role in investigating the structure of the universe for Easton. In 1895, with the assistance of Pannekoek, he compared the brightness distribution of the Milky Way light in his drawings with the distribution of stars in the *Bonner Durchmusterung*. He found that the intensity of galactic light corresponded well with the distribution of stars and concluded that most likely a real connection existed between the distribution of faint and bright stars.  

A few years later, in 1900, Easton extended his research in an effort to derive the shape of the whole galactic system using his own observations of the Milky Way light in combination with various star counts. From this comparison, he concluded that the most likely shape of the system was a ‘galactic spiral’ which ‘curiously resembles the spiral nebulae’. The Sun was located close to the centre of the system, which he placed in the direction of Cygnus because of the high star density and bright Milky Way

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in that direction.\textsuperscript{54} The drawing that Easton made of this model can be seen in Figure 2.6. He insisted, however, that

\begin{quote}
[Figure 2.6] does not pretend to give an even approximate representation of the Milky Way. It only indicates in a general way how the stellar accumulations of the Milky Way might be distributed so as to produce the galactic phenomenon, in its general structure and its principal details, as we observe it.\textsuperscript{55}
\end{quote}

He revisited this model in 1913 when he used published photographic plates to test his hypothesis. Again he found that his spiral theory was perfectly capable of explaining the appearance of the Milky Way, although he stressed that this did not mean spiral nebulae were also independent galaxies.\textsuperscript{56}

While Pannekoek and Easton both used star counts in comparison with the appearance of the Milky Way, there is a stark contrast in how they approached this research. Pannekoek used the Milky Way image to locate areas of interest for which he then determined the individual characteristics. Easton, on the other hand, was interested in the Milky Way because it gave an impression of the general shape of the galactic system, without the necessity of accurately representing the actual distribution of stars. This difference in approach also played a prominent part in their discussion on the distance to the galactic clouds in Cygnus.

Easton’s criticism of Pannekoek’s distance measurements was founded on his earlier research on the correlation between the number of bright stars and the distribution of Milky Way light in Cygnus. In his reaction to Pannekoek, published in 1921, Easton stated that ‘it is obviously improbable that a real condensation of stars in the neighbourhood of the Sun and an extremely distant galactic cloud should be seen almost exactly in the same direction without their being physically related.’\textsuperscript{57} It was much more likely that the brightest stars of the galactic clouds revealed themselves already at ninth magnitude, while the bulk presented itself only around twelfth magnitude. As evidence, Easton presented a comparison

\textsuperscript{55} Ibid., 157. Emphasis in the original.
between star counts in the brighter sections and fainter sections of the Milky Way. Three aspects stood out in this comparison: in dense sections, there were more bright stars, a higher proportion of intrinsically bright B and A stars, and the average proper motion was lower. These results all pointed toward the conclusion that distant galactic stars revealed their presence among the brighter stars. Subsequently, the fact that, in the case of Cygnus, the effect was already noticeable at the ninth magnitude, indicates that these galactic clouds must then be much closer than Pannekoek had calculated.58

Pannekoek felt Easton’s arguments were inconclusive at best. His main counterargument was that the correlation between the distribution of bright stars and galactic light was not as strong as Easton had presented. To illustrate his point, Pannekoek created a diagram (Figure 2.7) that compared the distribution of galactic light with star counts from the Bonner Durchmusterung, representing the bright stars, and John Herschel’s star gauges, representing the faint stars. He argued that the diagram clearly showed that the distribution of the galactic light corresponded well with Herschel’s star gauges but not with the number of Bonner Durchmusterung stars. He felt reinforced in his theory that there were two clusters—one nearby cluster within a few hundred parsecs of the Sun, which revealed itself in the Bonner Durchmusterung stars, and one distant galactic cloud, which could be seen as galactic light and in John Herschel’s star gauges. One concession he was willing to make was that he had overestimated the distance to the galactic cloud, which he now calculated to be only 18,000 parsecs.59

Pannekoek’s diagram, however, failed to convince Easton, who even felt attacked by Pannekoek’s paper. He demanded he should be allowed to publish a retort in the same journal, which was normally restricted to astronomers working at one of the astronomical institutes in the Netherlands. Although initially reluctant, Pannekoek was eventually persuaded to have the paper published under the auspices of the Amsterdam Institute.60 In his reply, Easton repeated his earlier argument that the correlation between Bonner Durchmusterung stars and galactic light distribution

58. Easton, ‘Distance of the Galactic Star-Clouds’.
60. Anton Pannekoek to Willem de Sitter, [ca. May 1922], Leiden Observatory Archives, directorate Willem de Sitter, Leiden University Library, Special Collections (UBL/WdS), 45.2.
Figure 2.7: Pannekoek’s diagram of the Milky Way in Cygnus. The distribution of Milky Way light is indicated by isophotic lines, and the distribution of stars is indicated by shaded areas and dashed lines. Denser shading indicates a higher number of stars, and the shaded areas indicate fewer stars. Pluses and minuses indicate whether the star gauges by John Herschel revealed a high or a low number of stars. Source: Pannekoek, 'Distance of the Galaxy in Cygnus', 55.
was too strong to be coincidental and presented his own chart (Figure 2.8) to illustrate this. In the discussion of the charts, Easton appealed strongly to the common sense of the reader: ‘We cannot of course expect a perfect agreement, but who could believe that these two diagrams represent two distinct and independent agglomerations of stars, situated respectively at distances of 400 and 18,000 parsec?’ Pannekoek never reacted to this paper as he felt that Easton had simply rehashed his initial arguments, and that therefore the rebuttal was still valid. Easton, meanwhile, interpreted Pannekoek’s silence as his own victory, especially because he had managed to counter Pannekoek with his own data.

That same year, in 1922, Harlow Shapley visited the Netherlands after attending the first meeting of the International Astronomical Union in Rome. Pannekoek considered this occasion to be an ideal opportunity for the Dutch astronomical community to come together to discuss the size

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63. Cornelis Easton, Kort overzicht van mijn sterrenkundig en meteor. werk, Correspondentie, aanteekeningen Cornelis Easton, Museum Boerhaave (MB/CE), 427g.
64. Harlow Shapley to Anton Pannekoek, 27 Dec 1921, Harvard College Observatory, Records of the Director, Harlow Shapley, Harvard University Archives (HUA/HCO), box 14, folder 108.
2.2. Particularities in Statistical Distribution

and structure of the galactic system because many Dutch astronomers had expressed their scepticism toward Shapley’s extended galactic system. Together with Willem de Sitter, he organized a special conference to debate this topic on 28 May. This meeting started with a talk by Shapley in which he presented his most recent results and expressed his confidence that, unless there was a fundamental source of error, his distance measurements could not be far off. To the disappointment of Pannekoek, however, there was little debate following this presentation. Both Schouten and Kapteyn were absent from the meeting, the latter because he was seriously ill, and Van Rhijn refrained from opposing Shapley’s result because he had already conceded by then that Shapley’s distance scale was correct and that the Kapteyn Universe was only a small subsystem of a larger Milky Way system. The only one who decided to challenge Shapley was Easton.

According to Easton, the system outlined by Shapley’s distance measurements was not reflected in the star counts nor in the appearance of the Milky Way. In Shapley’s system, the Sun is situated very eccentrically, near the edge of the system, so that a large asymmetry would be expected in both the statistical distribution of stars and the distribution of light in the Milky Way, so Easton argued. Although there was a slight decrease in both the number of stars and the brightness of Milky Way in the direction of Auriga, opposite to the centre of Shapley’s system, it was far less than was expected from the extremely eccentric location postulated for the Sun.

Shapley responded by stating that the Milky Way is ’a dangerous place’ in which everything was a ’mixture’ with dark rifts filled with ’obscuring things’. He argued that Kapteyn’s Plan of Selected Areas, which Easton had used for his star counts, was not suited for investigating the galactic plane because the selected areas were distributed systematically without regard for the idiosyncrasies of the Milky Way. This mechanical way of

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65. Anton Pannekoek to Harlow Shapley, 28 Jan 1922, HUA/HCO, box 14, folder 108; Pannekoek to Willem de Sitter, 28 Jan 1922, UBL/WdS, 45.2.
67. Anton Pannekoek to Willem de Sitter, 7 Jun 1922, UBL/WdS, 45.2.
68. Bok, interview by DeVorkin, AIP/OH.
70. Easton, Bezoek van Harlow Shapley, MB/CE, 427b.
choosing areas meant that selected areas were often located in dark spots or extraordinary areas, which meant they were not representative for the galactic plane as a whole. He disagreed with Easton about the distribution of galactic light as well, stating that the Milky Way showed more light, features, and special objects in the direction of Sagittarius, which was the centre of the Shapley’s system. Pannekoek also countered Easton’s criticism by stating that the star counts Easton had used did not penetrate far enough to already display the asymmetry in the distribution of stars in the galactic system. Pannekoek argued this asymmetry could only reveal itself at sixteenth magnitude and fainter. Easton conceded that this was a possible solution, but that it was by no means certain that it was actually the case.\textsuperscript{71}

The discussions between Pannekoek and Easton illustrate how differences in epistemic virtues can influence observers in their research. For Easton, it was crucial that astronomers used common sense and guarded against misinterpretations of minor deviations leading them astray. In his models of the Milky Way system, he did not attempt to provide an accurate image, but one that showed the impression of the shape of the system. In his discussion with Pannekoek, he repeatedly emphasized how ‘remarkable’ a ‘chance coincidence’ of two superimposed clusters would be.\textsuperscript{72} From his diagrams of Cygnus, he expected the reader to recognize the rough similarities between the two distributions. In contrast, Pannekoek appealed to the active judgement of the observer while warning against predetermined ideas. His diagram of Cygnus allowed a more direct comparison of the data, and he left it to the reader’s own judgement to reflect on the differences in the distributions and determine that they are in fact not that similar. Implicit in this debate were the different roles of the astronomer. Where Easton expected the astronomer to use their creativity and common sense, in line with the epistemic virtue of truth-to-nature, Pannekoek expected the astronomer to be a consciously intervening, yet open-minded judge of empirical data.

2.3 Star Densities in the Local System

The period surrounding the Great Debate was a turning point for statistical astronomy. While there may have been disagreement between the pro-

\textsuperscript{71} Easton, Bezoek van Harlow Shapley, MB/CE, 427b.

\textsuperscript{72} Easton, ‘Correlation of Bright Stars and Galactic Light’.
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ponents of the island universe theory and those of the extended galactic system, they both agreed in assigning a reduced status to the Kapteyn Universe: it was either only one of many independent spiral nebulae or a small part of a vastly bigger system. Statistical astronomy had proven incapable of providing a cosmological model of the entire universe, leading to the decline of statistical cosmology as a major research program.\(^73\) But when we take a closer look at the situation in the Netherlands during the 1920s, we find that research on the structure of the galactic system remained an important topic here.\(^74\) Dutch astronomers remained invested in statistical astronomy; not to understand the cosmological universe, but to understand our local stellar surroundings. The work of Pannekoek is a clear example of this shift in focus.

Pannekoek continued using Kapteyn’s statistical methods because he never had the goal to derive a single model for the entire universe in the first place. His interest was always in how the collection of particular features, such as star clusters and dark nebulae, together formed the Milky Way phenomenon. He emphasized this difference in approach in his memoir:

> I strongly sympathized with the work of Kapteyn, but always felt I viewed it differently. He treated the star density distribution only as a function of distance and galactic latitude, ignoring the variance in galactic longitude. Throughout my youth, I always watched the Milky Way and never perceived it as a gradually thinning ellipsoid, but rather as a collection of individual accumulations, similar and equally important as Kapteyn’s local system. I saw it as my duty to follow my own ideas and determine the structure of the Milky Way as a collection of corporal clouds and streams.\(^75\)

When statistical astronomy was understood to be fundamentally incapable of providing a cosmology, Pannekoek was not deterred, because it


\(^75\) Pannekoek, *Herinneringen*, 247. Translated from Dutch.
could still provide insight into the structure of the galactic system, even if only on a local level.

Pannekoek believed that the structure of the galactic system should be researched using a variety of methods, which he outlined in a letter to Shapley after their meeting in 1922. He argued in this letter that different techniques were needed to find the density of stars at different distances. For the local system up to 1000 parsec it was still possible to make use of the techniques of statistical astronomy to determine the distribution of stars. For the area between 1000 and 10,000 parsec, however, matters were different. At these distances, it was almost impossible to distinguish bright distant stars from faint nearby stars. This problem could be circumvented by researching stars of each spectral type separately. For the intrinsically bright A and B-type stars, there was only a small window of absolute magnitudes, which meant that their apparent magnitude was an excellent indication for the distance of the star. Finally, for features in the galactic system beyond 10,000 parsec, like the galactic clouds in Cygnus and Sagittarius, the only visible stars had to be supergiants. Because photographic plates and the human eye detect colours differently, these supergiants were more readily detected in visual counts than in photographic counts. When Pannekoek wrote his letter to Shapley, on 1 July 1922, the first part of this research, the investigation of the star densities in the local system, was already underway.

Pannekoek’s first paper on the distribution of stars in the local system was a reaction to the PhD research of Utrecht astronomer Isidore Henri Nort, who had completed his dissertation in 1917. Nort had determined the distribution of stars down to the eleventh magnitude in all directions of the sky by counting the number of stars on the photographic Harvard Map of the Sky. In line with Kapteyn’s results, he found that there were significantly more stars in the direction of the galactic plane than in the direction of the galactic poles. At the same time, he was also critical of Kapteyn’s model, especially the untested assumption that the stars were evenly distributed over galactic longitudes. Nort’s results, in contrast, showed that distribution of stars did vary with galactic longitude, especially in the galactic plane. The highest number of stars could be found in the direction of Centaurus, while the lowest number could be found in

76. Anton Pannekoek to Harlow Shapley, 1 Jul 1922, HUA/HCO, box 14, folder 108.
the direction of Auriga. Like Easton before him, Nort also investigated the correlation between the calculated number of stars and the brightness of the Milky Way light. Contrary to Easton, however, he found that the distribution of Milky Way light was not reflected in the stars down to the eleventh magnitude. This conclusion, Nort stated, was ‘in harmony with the results of Pannekoek’. For the local system as a whole, he found an ellipsoid system with three unequal axes in which the Sun placed in a slightly eccentric position.

Despite their shared assessment of the work of Easton and Kapteyn, Pannekoek did not agree with Nort’s research either. His criticism was aimed at two specific points. The first was aimed at how Nort had collected his data from the *Harvard Map of the Sky*. Pannekoek believed that the numbers could be calibrated more harmoniously by comparing the areas of the plates that overlapped with one another. His second point of criticism was directed at how Nort had constructed the system of stars as a triaxial ellipsoid, which Pannekoek believed was ‘inadequate to represent the irregularities of the star distribution’. A better way to represent these features, according to him, was to create a diagram which showed the deviation of the measured number of stars from an averaged distribution of stars. Such a diagram, Pannekoek believed, would make the detailed structure of the distribution more pronounced.

Indeed, when Pannekoek created such a diagram himself (Figure 2.9), it was immediately apparent to him that two opposite regions existed where

79. Ibid., 129. The disagreement between Easton and Nort was the main topic of a meeting of the *Nederlandse Astronomenclub* in 1921. Easton made the argument that, although the ninth-magnitude stars may not cause the Milky Way light, if was still very probable that they were correlated with one another. And if that correlation exists, then there is no reason not to believe there was not also a physical connection. For a report on this meeting, see *Hemel en Dampkring*, ‘Verslag van de vergadering van de Nederlandse Astronomenclub op 28 mei 1921 te Amsterdam’, *Hemel en Dampkring* 19, no. 3 (1921): 36–39.
the star count was much lower than expected: one in the direction of Ophiuchus and one in the direction of Aquila. Since these sparse regions were not reflected in the appearance of the Milky Way, Pannekoek once again concluded that the light of the Milky Way could not be caused by the light of stars of eleventh magnitude and brighter.\(^{82}\) Again, we recognize Pannekoek’s emphasis on judgement to detect and investigate individual idiosyncrasies in the distribution of stars, rather than ignoring them to find an overarching solution for the distribution.

A few years later, Pannekoek conducted his own extensive research on the structure of the local system based on the numbers in various Durchmusterung catalogues. As in his earlier statistical research, Pannekoek relied on the calculation of star ratios to determine the distances of star clusters. A marked difference in approach, however, was that he was not looking at specific clusters. Instead, he investigated the density distribution of the entire galactic zone between -20° and 20° galactic latitude as a function of both galactic longitude and distance. As we can see in Figure 2.10, he tried to accomplish this by dividing the galactic plane into twelve sections of 30° longitude each. The results, which extended to about

\(^{82}\) Pannekoek, ‘Stars of the 11th Magnitude’. 

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**Figure 2.9:** Diagram of the distribution of stars down to the eleventh magnitude, according to Pannekoek. These show the deviation in the number of eleventh-magnitude stars from an averaged stellar system through lines of equal density in the southern (left) and northern sky (right). Source: Pannekoek, ‘Stars of the 11th Magnitude’, 341.
2.3. Star Densities in the Local System

1,000 parsecs from the Sun, were presented through lines of equal star counts on a cross-section of the galactic zone. Notable features in the distribution were the condensations that appear in the direction of Cygnus, but especially those in the direction of Scorpio (around 315°–330°), where the density rose to 1.25 times the average density around the Sun at a distance of 100–200 parsecs.83

Although Pannekoek was now looking at the entire galactic plane, he did not neglect his initial project of investigating specific irregularities of the Milky Way. Although he condensed large portions of the sky into a single section by dividing the sky into only twelve parts, he still determined the star count for each section separately without attempting to smoothen the distribution as Nort had done in his research. Pannekoek’s approach still focused on deviations from the mean and the particular

structure of the density distribution — aspects that would remain hidden in an approach that smoothed out the data.

Pannekoek’s methods were picked up by Egbert Albert Kreiken, who was preparing a PhD in Groningen, the following year. Kreiken had investigated the colour and magnitude of stars for various regions of the Milky Way, which drew his attention to the Scutum cloud where the density of stars was significantly higher than what would be expected from the Kapteyn Universe. Moreover, the stars in that region, especially the brighter stars, were much bluer than average. Kreiken decided to calculate the distance to the cluster responsible for the Scutum cloud, for which he found a distance of 1500 parsec. In other regions, he found no such a deviation from the Kapteyn Universe, which led him to conclude that ‘only in the case of the Scutum-cloud we may speak of a distinct group.’

84. Later that year, Pannekoek found that the visual aspect of the Scutum cloud was bluer than the rest of the Milky Way as well, Anton Pannekoek, ‘Photographic Photometry of the Milky Way and the Colour of the Scutum Cloud’, *Bulletin of the Astronomical Institutes of the Netherlands* 2, no. 44 (1923): 19–24.

Kreiken’s background in Groningen gave him early access to the *Plan of Selected Areas* data, which were far more detailed and homogeneous than the catalogues that Pannekoek had used. Kreiken used this data to investigate the star density as function of galactic longitude and distance, first only in the galactic plane and later throughout the entire sky. To represent the results, he made diagrams that showed various cross-sections of the system (Figure 2.11) in a similar fashion to Pannekoek. Kreiken concluded that the star density was much higher in the southern sky — where Pannekoek’s results had been tentative — than in the northern sky, especially in the direction where Shapley had found the centre of his extended galactic system. He calculated a distance to the centre of the local system at a distance of 2270 parsec from the Sun. Although Kreiken recognized that many of the individual features of the local system were down to the clustering of stars and dark nebulae, he was certain that there was a strong dependence of the star density on both galactic latitude and longitude.

Third Approximation

Understanding the star densities in the galactic plane was not the end goal for Pannekoek; it was only the first step to providing a complete investigation of the local system that determined the distribution of stars as a function of latitude, longitude, and distance. In this way, it would be possible to ‘[treat] the different galactic features as special objects and [determine] the distribution functions separately for all these special regions in the sky’. This new research was not limited to the galactic equator alone but covered the entire sky. Pannekoek called this approach a ‘third approximation’ to the structure of the galactic system. With this term, he

86. Kreiken later worked as *privaatdocent* at the University of Amsterdam from 1926 to 1928. Lewis Pyenson, *Empire of Reason: Exact Sciences in Indonesia, 1840–1940* (Leiden: Brill, 1989), 76.
89. Kreiken, ‘Centre of the Local Star System’.
91. The original publication in 1924 only covered the sky down to −65° declination. The final southern part was added in 1929 in Anton Pannekoek, *Researches on the Structure of the Universe: 2. The Space Distribution of Stars of Classes A, K and B, Derived from the Draper Catalogue; 3. The Cape Photographic Durchmusterung*, Publications of the Astronomical
referred to the fact that he conducted a three-dimensional investigation of the density distribution, taking into account distance, galactic latitude, and galactic longitude, as opposed to Kapteyn’s second approximation which only used two, namely galactic latitude and distance.

It may seem as if Pannekoek simply wanted to add more detail to Kapteyn’s tried method, but that would neglect the significant differences in the fundamental goal of their research. Pannekoek was not looking for a single star density distribution that could capture the shape of the entire system; he was looking for specific features and irregularities that indicated the existence of star clusters in the Solar neighbourhood. Whether these clusters formed a complete system or were only a small part of a larger system was not of immediate concern. The acquired knowledge would be useful either way.\(^{92}\) This attitude, as we have seen, can be explained by his particular epistemic virtues that shunned the desire for grand schemes and instead called for structures to be created from the bottom up. In light of these goals, there was no reason for Pannekoek to abandon his research, despite the rapidly changing theories of the universe, and even when many other astronomers saw no benefit in continuing this line of research.

In practice, the third approximation meant that Pannekoek calculated the density distribution of stars in each direction of the sky by investigating the relative star-ratios for three different visual magnitudes, 5.7, 7.4, and 8.6. The results were represented as azimuthal projections of the northern and southern sky for each magnitude (Figure 2.12). Parts of the sky where the density distribution deviated strongly from the mean were highlighted in the diagram: red for relatively dense areas and blue for relatively sparse areas. The primary conclusion of this investigation was that no central condensation of stars could be found that acted as the centre of the system. Instead, he found multiple accumulations and clusters that were roughly comparable with each other, such as those in the directions of Cygnus, Monoceros, and Carina. For each cluster, the distance, size, and density were determined.\(^{93}\) The results were placed in a schematic top-down projection of the stars in the Solar neighbourhood that can be seen in Figure 2.13.

While Pannekoek, Kreiken, and Nort had all found reasons to doubt the Kapteyn Universe, the definitive rejection came in 1927 as a result

\(^{92}\) Pannekoek, Structure of the Universe I, 2.

\(^{93}\) Ibid.
2.3. Star Densities in the Local System

Figure 2.12: Diagram showing the density distribution of stars of visual magnitude 8.6 in the northern sky. Areas of relatively high density were indicated by increasingly darker shades of red, while fainter areas were indicated with blue shading. Source: Pannekoek, Structure of the Universe 1, Plate 3 North.

of Jan Hendrik Oort’s research on the differential rotation of the galactic system. Oort, the last of Kapteyn’s students, began his career conducting extensive research on the distribution of high-velocity stars. Early on, he found that these high-velocity stars were distributed asymmetrically throughout the galactic system, were almost exclusively intrinsically faint stars, and moved with the same speed and direction as the globular clusters.94 His initial theory for the Kapteyn Universe was as a local

94. Jan Hendrik Oort, ‘Some Peculiarities in the Motion of Stars of High Velocity’, Bulletin
cluster of stars that moved with high speed through a larger collection of similar clusters, which was outlined by the globular clusters. Before long, however, Oort learned of the work of the Swedish astronomer Bengt Lindblad, who developed a mathematical theory of differential rotation to explain the fact that stars appeared to move in two preferential directions. The centre of this rotational system, Lindblad reckoned, was very near the centre of Shapley’s system. Oort soon realized that his work on high-velocity stars provided immediate supporting evidence for Lindblad’s theory. He constructed a model of a differentially rotating stellar system that made it possible to derive both the size and the mass of the galactic system.

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96. This was known as the star streaming and was first announced by Kapteyn in 1905. See Paul, *Milky Way Galaxy*, 84–94; Smith, ‘Beyond the Big Galaxy’, 314–315.
2.3. Star Densities in the Local System

from observational data.\textsuperscript{97} Oort’s new system was an almost immediate triumph and, although it was smaller than Shapley’s model, it ended the debate on the eccentric position of the Sun and the location of the galactic centre.\textsuperscript{98}

For Pannekoek, Oort’s research confirmed his intuitions on the structure of the universe, and he immediately sought to find the central masses that could be responsible for the rotation.\textsuperscript{99} He also further investigated the distribution of stars in the local system by focusing on the distribution of specific spectral classes of stars. One major complication with statistical astronomy was always that the spread of absolute magnitudes in the luminosity function was much larger than the spatial spread of star clouds. This made it notoriously difficult to pinpoint the exact distance and size of star clusters because their presence was scattered throughout multiple magnitudes. By looking at specific spectral classes, however, this problem could be circumvented, as the spread of absolute magnitudes within a single spectral class was much smaller. The publication of the \textit{Henry Draper Catalogue} in 1924, which not only contained the visual magnitude of every star down to the ninth magnitude but also their spectral class, provided Pannekoek with an excellent opportunity to derive the distance and size of star clusters with much greater accuracy than before.\textsuperscript{100}

For his investigation, Pannekoek focused on three star classes that were particularly bright: the B-type stars, the A-type stars, and the K-type giants. The B-type stars, which were very limited in number, could


\textsuperscript{100} Pannekoek, \textit{Structure of the Universe} 2, 1–69.
Figure 2.14: The location of clusters of B stars, as calculated by Pannekoek from the Henry Draper Catalogue, projected on the galactic plane. The circles represent distances of 300 and 1000 parsec from the Solar System, which is placed in the origin. Source: Pannekoek, *Structure of the Universe* 2, 65.
be individually placed on a map after their distance was calculated. Figure 2.14 shows the location of each projected on the galactic plane as derived by Pannekoek. The most distant B-type stars in the catalogue were located at a distance of 661 parsec from Earth. For the A-type stars and K-type giants, the number of stars was much greater, making it impossible to draw them individually on a map. The distributions of these two star classes were presented in an azimuthal projection that showed the density distribution of these stars up to 300 parsec (Figure 2.15). Pannekoek noticed some unexpected and interesting patterns that revealed how these stars were clustered. The A and especially B-type stars appeared to be strongly constrained to the galactic plane, while the K-type giants were much more evenly spread through the entire galactic system. B-type stars were also usually clustered near galactic clouds and irregular nebulae, and every cluster of B-type stars was associated with a cluster of A-type stars. Accumulations of K-type giants could also occasionally be found in the presence of A-type clusters, but they were never found in the presence of B-type clusters. From these patterns, Pannekoek argued that there might exist two stellar evolutionary tracks; one which included K-type giants and another which included B-type stars, with A-type stars featuring in both. He also suggested that, for the first evolutionary track, stars were created outside of the galactic zone as K-stars and slowly moved into the galactic zone as they evolved to A-stars. These suggestions were soon rejected as the theories of stellar evolution changed, but knowledge of the complicated structure of the local system remained vital for investigating the evolution of the galactic system. Nevertheless, it took astronomers a long time before they picked up the subject again in a similar fashion as Pannekoek; only in the 1950s did the study of O associations, as they came to be called, really take off.

102. Ibid., 69.
104. In a 1964 review on O associations, Adriaan Blaauw mentioned: 'Of the early investigations of the space distribution of the early-type star groups, we mention only that by Pannekoek ..., the results of which show some striking resemblances to those of the modern investigations'. Adriaan Blaauw, 'The O Associations in the Solar Neighborhood', *Annual Review of Astronomy and Astrophysics* 2, no. 1 (1964): 213–246, 213.
In the preceding pages, we have seen how Pannekoek managed to adapt his research to the changing opinions on the structure of the universe. His focus was on how the stars were distributed throughout the universe, and not necessarily on the overall shape and size of this universe. When forced to choose, he stayed true to Kapteyn’s statistical method of deriving star densities from star counts rather than his goal of determining the size and shape of the entire galactic system, as the other Dutch astronomers did. Pannekoek’s focus on individual clusters could also lead to disputes, as we have seen in the case of Easton and Nort. Crucially, in these disputes, different methodologies related to different epistemic virtues, and vice versa.
2.3. Star Densities in the Local System

The rejection of a certain method could go hand in hand with the rejection of a persona, as illustrated by the assessment of Pannekoek and his approach to astronomy by Pieter van Rhijn, one of Kapteyn’s students and his eventual successor in Groningen. For Van Rhijn, individual features were useless for understanding the galactic system. Only by working systematically on the entire system could it be understood. When graduate student Bart Bok submitted his PhD thesis on the η Carinae region to van Rhijn, the latter initially dismissed it because it focused only on a single region in the sky rather than multiple regions distributed equally over galactic longitude, stating that: ‘it’s the sort of thing that that man Pannekoek would do’.105

The realization that statistical astronomy could only provide a model for a small portion of the universe did not diminish its value for Pannekoek, since it was still capable of uncovering the structure of the star distribution in our particular local system in high detail. This knowledge, in turn, could also have implications on the understanding of our entire system. In 1930, however, convincing evidence for the existence of interstellar absorption was provided by the American astronomer Robert Trumper. The presence of interstellar absorption meant that Shapley had likely overestimated the distances to the globular clusters, and that the actual size of Shapley’s system was in line with the size Oort had measured for the rotational system.106 Moreover, the interstellar matter responsible for this absorption turned out to be irregularly distributed throughout the entire system, meaning that it was nearly impossible to correct for its effect in statistical studies, even for such a limited scope as the local system. Whereas the various larger systems of Shapley, Curtis, and Oort provided interpretive difficulties that were easily accommodated in Pannekoek’s methodology, the discovery of interstellar absorption provided a practical objection to sidereal astronomy to the point that it could no longer be defended. The features of the Milky Way that Pannekoek had been chasing turned out to be shadows.107 Nevertheless, in the final years of his professional career, he decided to chase these shadows for one last time with an extensive statistical investigation of the distribution of dark nebulae in the local system.108

105. Bok, interview by DeVorkin AIP/OH.
2.4 Historical Materialism

While Pannekoek was exploring new methods to investigate the Milky Way system, he was also exploring methods to investigate the development of human society. Like with galactic astronomy, Pannekoek’s most active period as a Marxist was during the first few decades of the twentieth century when he formulated the philosophical foundations of his Marxism. While his conception of the socialist revolution and tactics changed over time, the underlying philosophy remained largely consistent. It is hardly surprising then that there are some meaningful connections between Pannekoek’s epistemic virtues in these different domains of investigation. As this section will illustrate, two recurring themes in his statistical astronomy also played a prominent role in his Marxist writings: the emphasis on thought and judgement over purely mechanical methods, and the rejection of a top-down approach to organization.

As has been discussed in the previous chapter, Pannekoek’s emphasis on the importance of judgement coincided with his Marxist philosophy of mind. The task of the human mind was to process sense perceptions and abstract this information and categorize them into concrete objects and ideas, something which happened constantly and could not be prevented. This ability to abstract was what set humankind apart from other animals; it allowed us to understand and eventually manipulate the external world. At the same time, the mind was susceptible to indoctrination and bias, as sense perceptions were not limited to impressions of physical objects alone according to Pannekoek; they also included information received from other people as well as one’s own memory. Judgement was an important epistemic virtue for Pannekoek because it emphasized the capabilities of the human mind to quickly categorize statistical information into something meaningful, while it could also detect biases and presuppositions.

Translated to the science of astronomy, the emphasis on judgement meant astronomers should interpret their results and counteract presuppositions where needed, whereas with a strict adherence to mechanical objectivity such presuppositions would remain undetected. In the case of statistical astronomy, judgement meant that astronomers had to acknowledge particular features that they noticed in the distribution of stars and
needed to constantly compare their statistical result with the visual appearance of the Milky Way. This was especially true because, even if it were somehow possible to prevent the human mind from interfering with the registration and collection of phenomena, then it would still only lead to a multitude of particularities without structure or order. Such an unsorted collection of events would have no value in helping to understand the world. Not only was human intervention inevitable — it was desirable.

Pannekoek’s criticism of proponents of mechanical objectivity in natural science strongly resembles his criticism of mechanical materialism in his Marxist writings. To illustrate this, we must understand how he interpreted Marxism. For Pannekoek, Marxism was not a political theory but a scientific research method that was specifically designed for analysing society. In fact, he used the terms ‘Marxism’, ‘social science’, and ‘historical materialism’ interchangeably.110 This tendency can already be found in his first major philosophical paper, published in 1901, where he wrote: “The materialist conception of history is not a fixed system, or a certain theory; it is a method of research, a method, that asks for the causes of all historical occurrences; that searches for a plausible explanation of social developments.”111

Of course, Pannekoek was far from unique in believing that historical materialism was a research method; many Marxist theorists agreed with him on this point. They also agreed that this meant that the historical development of society should be studied through an analysis of material factors. The exact nature of these material factors, however, has been a source of constant debate. Often, the focus was on economic factors such as ownership of the means of production, labour relations, and the distribution of capital. Pannekoek, on the other hand, distinguished himself by strongly emphasizing the importance of the human mind in interpreting these material factors. This emphasis on the role of the mind, he argued, was what differentiated historical materialism from mechanical materialism — or ‘bourgeois’ materialism as he called it — which, according to him, reduced the entire world to the deterministic movement of particles.112

To explain the differences between the two kinds of materialism, Pannekoek often referred to their historical development. As Pannekoek argued, mechanical materialism as a way of understanding nature was developed in the late eighteenth century when the bourgeoisie started their struggle with the aristocracy for political power. It served the needs of the rising bourgeoisie because it could act as an ideological weapon in that struggle. By eliminating the need or even the possibility of divine intervention, it undermined the traditional foundations of absolutism, such as the divine right of kings.

Mechanical materialism also served as the philosophical foundation of natural science and provided a method for investigating the physical world. It was not, however, without its flaws, according to Pannekoek. In reducing everything to the movement of matter and energy, it failed to describe the dynamics of human society or the function of the human brain. The inevitable result was that mechanical materialism contained a strict demarcation between mind and matter. Where natural science could, in principle, completely explain the realm of physical matter, it had nothing to say about the realm of the mind. Consequently, bourgeois scientists would invariably fall back on mysticism in order to make sense of the latter. Either this mysticism could come in the form of a return to religion and the reintroduction of divine intervention; or it could come in the form of absolute principles, like causality and natural law, and bourgeois ideals, like personal and economic freedom.

Pannekoek’s emphasis on Marxism as a scientific method also reflected on the role he believed Marxists should play in society. Pannekoek believed it was important to differentiate between Marxists, who researched society, and the members of the working class, who were responsible for changing society. According to Pannekoek, the sole responsibility for initiating and leading the revolution should lay with the latter group. Once

114. About mysticism in causality and natural law, Pannekoek wrote: 'Unaware of their origin and nature, physicists see [causality and natural law] as independently existing beings or powers. Thus their entire worldview, which is based on causality and natural law, eventually becomes as narrowly mystical as the old one: instead of one God that rules everything, there are countless mysterious demons, forces, who manipulate everything. Instead of one will, nature must obey natural laws that prescribe what is allowed and what is not.' Ibid., 504.
the working class had found the right revolutionary spirit, they would organize themselves and through spontaneous mass actions slowly weaken the foundation of the existing state. When this finally collapsed, the working class would create a new, truly democratic society that was organized from the bottom up according to the principles and methods that they had developed as they lived through the struggle. Since the new society had to be developed by the workers themselves, Marxist scholars had to play a part on the side-lines. They should avoid trying to dictate the direction of the social revolution from the top down and instead focus on educating the workers and helping them understand why they took certain courses of action. Marxists had to analyse the revolution as it happened, devoid any theoretical presuppositions, as an open-minded yet trained expert.

Pannekoek’s ideal of the Marxist persona as a detached scholar led him to play a passive role in the labour movement. Even in Germany during his most active period, he focused on writing opinion pieces and teaching historical materialism rather than participating in political action himself. By the mid-1910s, Pannekoek had completely rejected parliamentarianism and trade unionism as paths toward the new society. He believed that any top-down organization would inevitably turn its leadership into a labour aristocracy, who would benefit from perpetuating the status quo within the existing government. Instead, the workers should organize themselves from the bottom up, by congregating into factory councils that together formed the new council communist government.

From the 1920s onwards, Pannekoek was no longer an official member of any socialist organization and focused primarily on theoretical and philosophical discussions on the nature of historical materialism. Although his retreat into theory was partially the result of his isolation from the working class, the fear of influencing their revolutionary spirit would no doubt also have played an important role. On this point, we can find an analogy with

116. Tai and Van Dongen, ‘Personae and the Practice of Science’, 68.
119. Unsurprisingly, Pannekoek’s analytic yet expectantly observant and academic persona was seen as a vulnerable point for the attacks of his opponents. He became known as a perpetual critic who lacked political pragmatism. Karl Radek called him an ‘astro-nomer gazing only at the stars, and never at a living worker’, while Willem van Raven-
his astronomical research. His bottom-up conception of the ideal society is reminiscent of the bottom-up method he applied in sidereal astronomy, where individual stars congregated into clusters and the combination of clusters formed the Milky Way system. In both cases, there was no need for an overarching, top-down system to control the basic structure.

2.5 Conclusions

We started this chapter by asking whether an investigation of the epistemic virtues and scholarly personae of Pannekoek would lead to a deeper understanding of his Milky Way research in the context of contemporary developments in science, and in relation to his Marxist philosophy. Throughout the chapter, we have seen that both the astronomical persona and the Marxist persona, as conceptualized by Pannekoek, had to be actively involved in systematizing and analysing information. How this worked in practice depended on the specific field of research. The galactic astronomer had to look for the structure in the Milky Way and determine how this coincided with the clustering in the distribution of stars. The Marxist theorist had to analyse how material factors — social, economic, or ideological — determined the behaviour of social classes, and develop tactics that would optimize the odds for creating a truly democratic society. In both cases, these personae needed to be open-minded; they should not let themselves be guided by preconceived ideas about how the structures should look or how the revolution should play out, because such preconceptions would alter their perceptions and would lead them to see what they expected to see. Rather than there being some fundamental disconnect, Pannekoek’s conception of the ideal scientist and the ideal Marxist were both rooted on the same epistemic concerns, each adapted to suit its specific field of research. This, of course, should hardly be surprising because they were ultimately created by the same person: Pannekoek.

Although this study has revealed a strong relation between Pannekoek’s epistemic virtues in his approach to socialism and science, their
2.5. Conclusions

relation was certainly not limited to these virtues alone. It is also possible to draw an analogy between his model of the local system and his model for council communism. In both cases, he rejected a predetermined top-down strategy that emphasized the overarching system as a meaningful entity. Instead, he promoted a bottom-up strategy that emphasized the way in which individual persons or stars congregate into larger systems. The collection of these individual clusters provides sufficient structure for the system as a whole without requiring an additional overarching layer. Similarly, his rejection of mechanical materialism shows some striking parallels with his rejection of mechanical sorting schemes in astronomy. In both cases, by neglecting the potential role of the human mind, crucial information was overlooked or misinterpreted.

The focus on Pannekoek’s epistemic virtues also helped considerably with the other goal of this chapter, which was to situate his astronomical research within the greater developments of contemporary science. Here, Daston and Galison’s mesoscopic narrative provides a useful context for Pannekoek’s novel methods. We have seen that Pannekoek was involved in lively discussions on the construction of the universe with other Dutch astronomers like Kapteyn, Easton, and Nort. In the Netherlands, these discussions focused primarily on the question of the size and structure of the galactic system, rather than on the nature of the spiral nebulae. Pannekoek’s rejection of the methods of Kapteyn and Nort can be understood in light of typical rejections of both truth-to-nature and mechanical objectivity. He argued that Kapteyn’s mechanical method of sorting star counts according allowed no way of correcting preconceived structures that were built into the sorting scheme. By doing so, Kapteyn could find no other shape for the system than the one he already had in mind. He believed that by idealizing a fully mechanical approach to science, the most defining aspect of human beings — their ability to analyse — would be lost.

Instead, Pannekoek can be seen as one of the earliest adepts of the twentieth century epistemic virtue of trained judgement. He was part of a growing movement of scientists who increasingly emphasized the need for interpreted structure and systematized data. His ideal astronomer was actively involved in systematizing and analysing the information provided by instruments or sense perceptions. His task was to recognize characteristic or distinguishing features of particularities and highlight them for other astronomers. This strongly reminds us of his socialist philosophy of mind. The very nature of the human mind is to organize and distinguish sense perceptions; this ability to make sense of the infinitely varied
external world is its greatest strength. If scientists are to understand the world, they ought to use this strength.

Yet — obviously — upon closer inspection, there are also ways in which this story reveals that Daston and Galison’s narrative needs to be nuanced. Kapteyn is difficult to place as he seems to occupy a position that floats somewhere in between truth-to-nature and mechanical objectivity, and Pannekoek is hardly the archetypical trained judgement expert, since he assigned no specific importance to the role of professional training in developing scientific intuition. Of course, this is a common occurrence when grand historical schemes are applied to specific case studies; strict categories of these schemes fall apart in a sea of context. The overwhelming complexity within the history of science refuses to be captured in a single big picture. This does not mean, however, that these grand schemes are without value. Despite its flaws, the narrative of objectivity as an epistemic virtue, as described by Daston and Galison, helped to situate the development of Pannekoek’s astronomy within the broader historical context. It helped to highlight the differences between him and Kapteyn, which led them to contradictory results despite their use of the same mathematical methods and statistical data. It helped to understand why Pannekoek continued to contribute to a field of research that was essentially declared dead several years earlier.