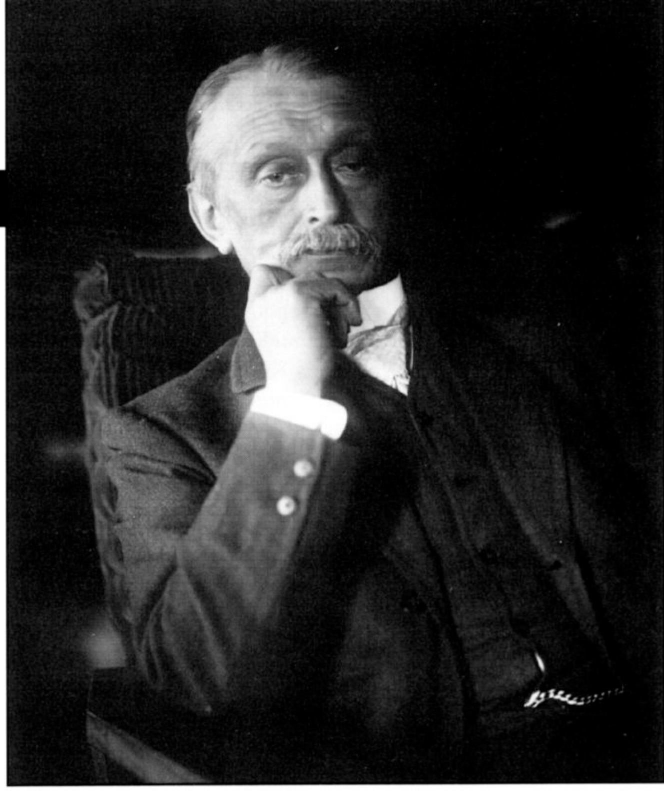
Jacobus Cornelius Kapteyn: The Tenth Bruce Medalist

Joseph S. Tenn
Sonoma State University



Jacobus Cornelius Kapteyn
19 January 1851 - 18 June 1922
1913 Bruce Medalist

(Photograph courtesy of the Observatories of the Carnegie Institution of Washington.)

How is the universe structured? To find out, astronomers today measure positions and radial velocities of galaxies, which we currently regard as the building blocks of the observable universe.[1] Perhaps some day our successors will do the same for the dark matter that observations hint may make up a substantial part (and perhaps a majority) of the cosmos.[2] But just a century ago, *stars* were thought to be the fundamental components of the universe, and those who wanted to know how the cosmos was ordered sought to determine *stellar* positions and motions.

In the year 1878, few would have seemed less likely to make progress in this area than Jacobus C. Kapteyn. Three years earlier, after completing his doctorate in physics (with a thesis on the vibration of a membrane) at the University of Utrecht, he had sought any job in scientific research. Finding one at the Leiden Observatory, he had learned such practical astronomy as how to measure positions with the meridian circle. Now, at 27, he was appointed to a new chair of astronomy and theoretical mechanics at the University of Groningen. He was faced with a heavy teaching load and absolutely no equipment. What could he do?

In his inaugural address on the parallaxes[3] of the stars he made it clear that he would tackle "the sidereal problem," even though the distances of only a handful of stars had been measured in the forty years since Friedrich W. Bessel detected the first parallax. He would never waver from this goal.

At first he tried measuring a few parallaxes with a meridian circle by traveling to the observatory at Leiden. He also looked into the great German catalogues of hundreds of thousands of stars produced by Bessel and Friedrich Argelander. It was just at this time that he learned that David Gill, Her Majesty's Astronomer at the Cape of Good Hope, was *photographing* vast fields of stars. We quoted from Kapteyn's 1885 letter to Gill, in which he volunteered to measure the plates and make the many tedious reductions necessary to produce a southern catalogue, in the article on Gill in this series (*Mercury*, May/Jun 1990). He thought he could do it in six years; it took thirteen. He devised an ingenious method to determine coordinates of the stars directly from the photographic plates by examining them with a small surveyor's telescope from a distance equal to the focal length of the telescope.

The *Cape Photographic Durchmusterung*, published in 1896-1900, gave the positions and photographic magnitudes of 454,875 southern stars, all measured and reduced in what was now called the Astronomical Laboratory at Groningen. Kapteyn produced it with one permanent assistant and an assortment of temporary unskilled workers, including convicts from

1. See M. Geller, "Mapping the Universe: Slices and Bubbles" in the May/Jun 1990 issue of *Mercury*.
2. See W. & K. Tucker, "Dark Matter in our Galaxy," in the Jan/Feb and Mar/Apr 1989 issues of *Mercury*.

3. The parallax of a star is defined as half the angle through which the star appears to change position as the Earth moves halfway around the Sun. If the parallax of a star can be measured, its distance follows immediately. Only a few stars are close enough to show a measurable parallax. Astronomers often use the word parallax when they mean distance.

a local prison. According to Gill, "Probably no work of this kind of like extent has ever been issued so free from typographical and other errors."

Kapteyn was becoming known as an indefatigable and extremely careful worker. But cataloguing was not enough. He wanted to construct the correct model of the universe of stars, as Johannes Kepler had done for the planets three centuries earlier. However, both northern and southern catalogues gave only positions and magnitudes. He needed distances and velocities to determine the structure of the sidereal universe, and he needed a lot of them. To obtain distances, he developed a new method of determining parallaxes photographically, and he urged astronomers with suitable equipment to measure the distances to more stars.

When astronomers measure the motion of a star, they generally divide it into two perpendicular components. The component of the velocity of a star in space along the line of sight, the *radial velocity,* can be determined directly, in kilometers per second, from the Doppler shift of the spectral lines. The motion of a star across the sky, the *proper motion*, can only be found, in seconds of arc per year, by comparing measurements made years apart. (For both kinds of motion astronomers subtract out the motion of the Earth and compute velocity with respect to the Sun.) A star's proper motion is proportional to its actual velocity across the line of sight and decreases with its distance from the solar system, just as nearby fence posts move across one's line of sight faster than distant mountains when one is driving down the highway.

By the 1890s proper motions had been measured for a few thousand stars, and trigonometric parallaxes for perhaps a hundred. Kapteyn developed statistical methods to determine whether their motions were truly random, and what the Sun's motion was with respect to the average (the local *standard of rest*). With 2400 stars, which he divided into 28 areas, he hoped to improve on earlier work, which had begun with William Herschel in the 1780s. In 1901 Kapteyn published a major contribution to statistical astronomy: the "mean parallax" formula which gave a method of determining the average distances of groups of stars of measured apparent magnitude and proper motion. Later he found the number of stars per unit volume of space as a function of distance from the solar system and the number of stars of each luminosity per unit volume.

He then made what was considered his greatest discovery. Hermann Kobold had shown that the stars do not move randomly with respect to the local standard of rest. Now Kapteyn found that stellar motions could be explained as two intermingled "star streams" moving in opposite directions. Both streams were found to be in the plane of the Milky Way.

Kapteyn announced the star streams at a meeting of most of the world's major astronomers at the St. Louis Exposition in 1904, where he met George E. Hale. The energetic young founder and director of the Yerkes Observatory was already building a new observatory on Mt. Wilson to be devoted to astrophysics of the sun and stars.

It was at this meeting that Kapteyn announced his famous *Plan of Selected Areas*. Noting that progress was being made on determining the spectra, proper motions, radial velocities, and parallaxes of the brighter stars, he pointed out that "The aspect of the Milky Way is mainly dependent on the distribution of the very faint stars." It would be too much work to obtain proper motions for all of the dim stars, so he proposed "For 206 areas, regularly distributed over the sky and for another, little extensive series of particularly interesting regions, to obtain astronomical data of every kind, for stars down to such faintness as it will be possible to get in a reasonable time."

The goal was to obtain rough positions and visual magnitudes for approximately 200,000 stars down to the 14th magnitude, and proper motions and parallaxes for some 20,000 of them. He also wanted spectral classes (this would fit into work already being done under Edward C. Pickering at Harvard) and radial velocities (already being measured under W. Wallace Campbell at Lick) for as many as possible of the 20,000. He called on the world's astronomers to cooperate in this work, and many agreed to do so, fitting his goals into their own research. Hale, for example, was quite willing to choose the stars to be studied spectroscopically at the new 60-inch telescope (the world's largest when completed in 1908) from Kapteyn's selected areas.

Hale was very impressed with Kapteyn, and invited him to visit Mt. Wilson on a regular basis. From 1908 until his retirement, Kapteyn was a Research Associate of the Carnegie Institution of Washington, the institution that was the wealthy patron of Hale's observatory on Mt. Wilson. The added income this brought was most welcome to Kapteyn, and he enjoyed the annual visits to Mt. Wilson where he could exchange views directly with the observers (especially Frederick H. Seares) who were obtaining many of the plates being measured in Groningen.

One result of these visits was the integration of Mt. Wilson. No women were allowed in the aptly-named Monastery where the astronomers stayed, but Kapteyn was unwilling to leave his wife behind, so Hale had a small house built on the mountain for the couple. Generations of astronomers have stayed in the "Kapteyn cottage."

In 1915 Kapteyn wrote Hale, "My studies have made of me more and more of a statistician and for statistics we must have real masses of data of course." In that same letter he described his unsuccessful efforts to model the Milky Way as rotating. Unlike his lifelong friendly rival, Hugo von Seeliger at Munich, with whom he shares the title of founder of modern statistical astronomy, Kapteyn much preferred induction to deduction. He always started with the data and sought patterns in the numbers. Disdaining the method of starting with a mathematical model followed by Seeliger and his student Karl Schwarzschild, he wrote "The deductive problem can be solved by any well skilled mathematician."

The data led him to a conclusion that justifiably made him apprehensive: "One of the somewhat startling consequences is, that we have to admit that our solar system must be in or near the center of the universe, or at least to some local center."

"Twenty years ago this would have made me very skeptical in regard to the result of the investigation. Now it is not so. Seeliger, Schwarzschild, Eddington and myself have found that the number of stars [per] unit of volume is greatest near the sun. I have sometimes felt uneasy in my mind about this result, because in the derivation the consideration of scattering of light in space has been neglected. Still it appears more and more that the scattering must be too small, and also somewhat different in character from what would explain the change in apparent density. This change is therefore pretty surely real."

He knew full well that interstellar absorption could make stars appear dimmer and therefore more distant than they really were. He knew that the shorter wavelength violet and blue light would be scattered more than the longer wavelengths by interstellar dust, and that hence "reddening" (more accurately, de-blueing) would be an indicator of absorption. Unfortunately, he looked for reddening away from the plane of the Milky Way, where it really is negligible; it is precisely in the Milky Way that the interstellar absorption is so great that his final model for the distribution of stars is totally incorrect.

The First World War interrupted the Mt. Wilson trips, as did Hale's intermittent nervous breakdowns. Kapteyn did not get along with Hale's deputy, Walter S. Adams, and in 1921 Hale asked him not to come, as Adams would be acting director again. Kapteyn was shocked, but agreed that "without you to stand between us, misunderstandings might easily arise again." Kapteyn was relieved when Hale, ever the conciliator, assured him that his status and salary as Research Associate would continue with or without the visits.

In the last two years of his life, Kapteyn, with his student and successor Pieter J. van Rhijn, produced a model that has come to be called the Kapteyn Universe. They con-

continued on p. 159

cluded that, like it or not, the Sun was located quite near the center of the universe of stars, about 650 parsecs (about 2100 light years) away in the final version. The number of stars per unit volume was found to decrease in all directions from the center, with the surfaces of constant density ellipsoidal in shape. The system was about 17,000 parsecs (55,000 lightyears) wide in the plane of the Milky Way, but only one-fifth as thick. Kapteyn noted that the system had to be rotating to be stable, and that the star streaming was observational evidence for rotation. He also noted that, "when the theory is perfected it may be possible to determine *the amount of dark matter* from its gravitational effect."[(emphasis in original][4]

By this time Harlow Shapley, using the 60-inch telescope at Mt. Wilson, had determined the distances to the globular clusters and proclaimed that they outlined a system some six times larger. Both Shapley and Kapteyn believed that the latter's much smaller system represented a local portion of Shapley's gigantic galaxy. Kapteyn did not believe Shapley's distances, based on the period-luminosity relation for Cepheid variable stars, were reliable. (The actual size of the visible Galaxy was not known until the 1950s, and the dimensions of the halo of dark matter are still unknown today.)

Besides co-founding statistical astronomy and promoting international cooperation in astronomy, Kapteyn made one other great contribution to science: He founded the enormously successful Dutch school of astronomy. Ever since Kapteyn, tiny Holland has produced astronomers far out of proportion to its population. For example, among the 84 Bruce medalists to date, eight were born and nine were educated in the Netherlands. No fewer than seven medalists, including the Americans Jesse Greenstein ~~and Allan Sandage,~~ were students, grandstudents, great grandstudents or great great grandstudents of Kapteyn. His influence lives on. Earlier this year, the 1942 Bruce medalist Jan H. Oort, who started his studies under Kapteyn, wrote in a letter to the author,

> A characteristic feature of J.C. Kapteyn was that he always endeavoured to make other people feel the interest and beauty of astronomy whenever he met them, either at a dinner party or in a train compartment, or anywhere else. For his students he was an inspiring guide and a leader who taught them how to approach a scientific problem in the most efficient manner.

Not a bad way to be remembered sixty-nine years after one's death. ■

---

4. Kapteyn, J.C., *Astrophysical Journal* **55,** 302 (1922).

Acknowledgements:

Reproduction of the quotation from the 23 September 1915 letter of Kapteyn to Hale is by permission of the Huntington Library, San Marino, California [F.H.Seares papers]. The letter of 24 April 1921 is quoted courtesy of the Caltech Archives [Hale collection]. The author has benefitted from several publications of E. Robert Paul.