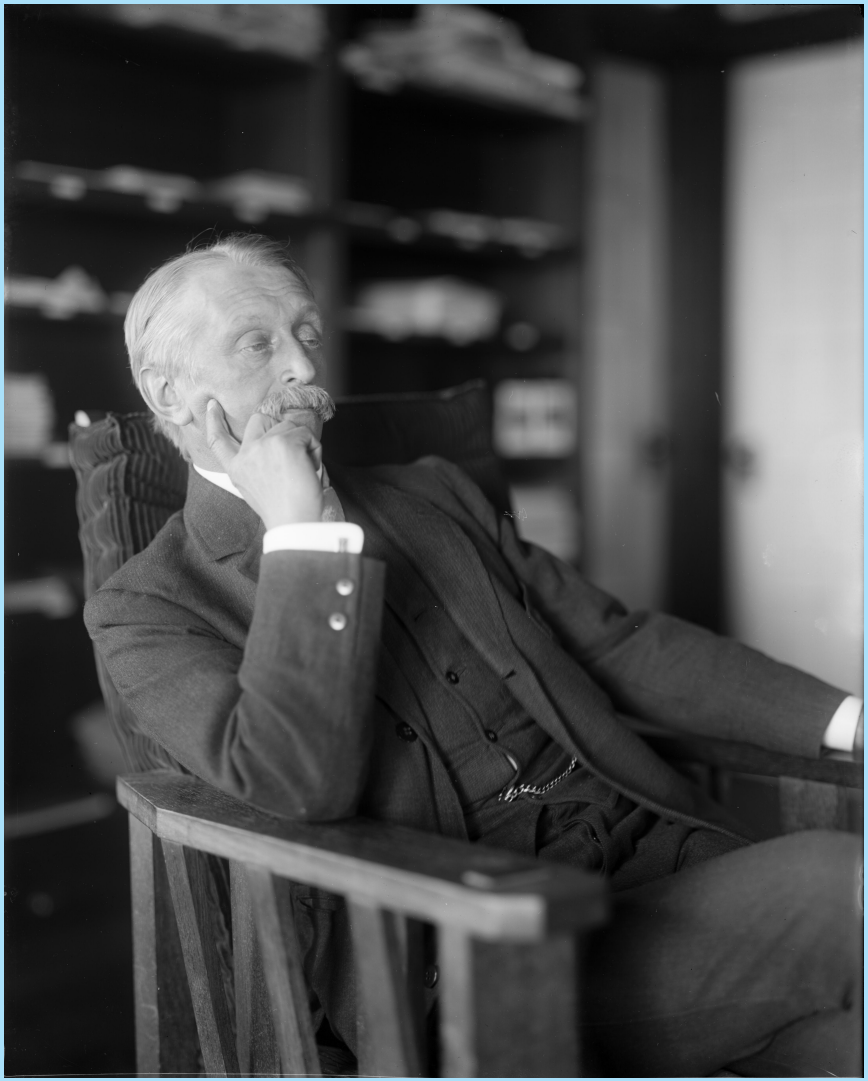
The Born Investigator of the Heavens

Jacobus Cornelius Kapteyn (1851–1922)

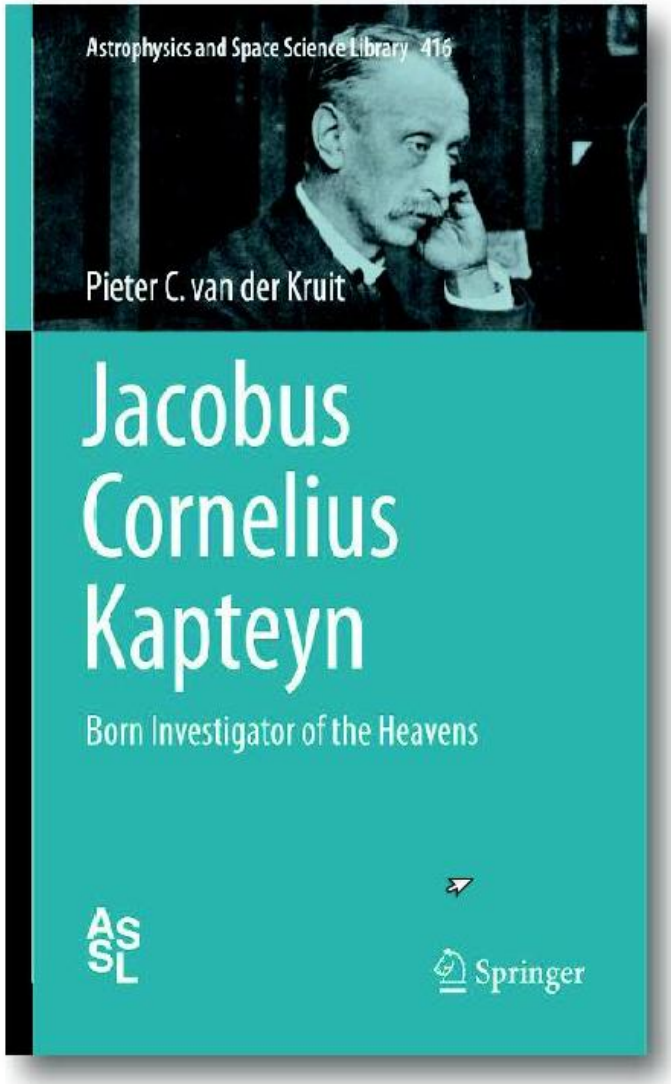
Pieter C. van der Kruit
Jacobus C. Kapteyn Professor of Astronomy
Kapteyn Astronomical Institute, Groningen
www.astro.rug.nl/∼vdkruit

Groningen, February 2015

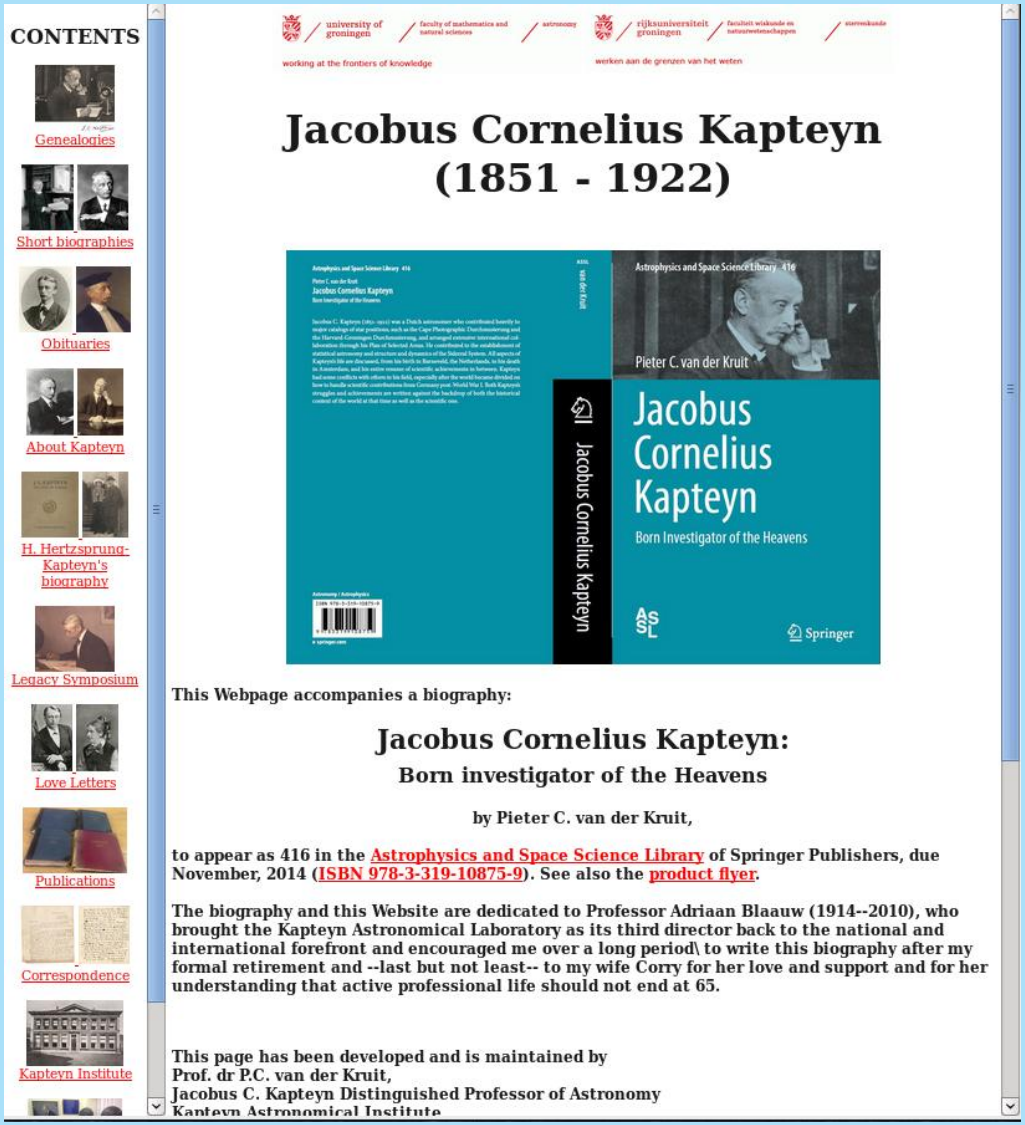
Background



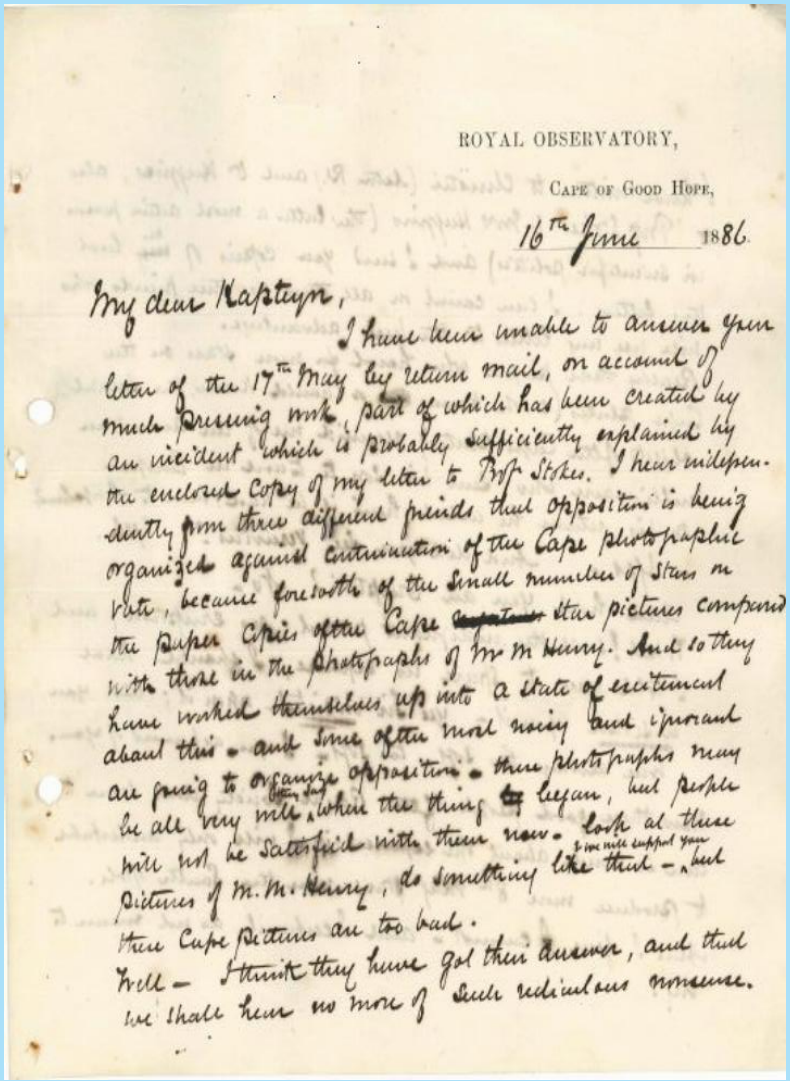
- What I will be presenting is based on my biography of Kapteyn.
- Appeared in November 2014 (©2015) in the Astrophysics and Space Science Library of Springer.
- This makes it very expensive; unless your library subscribes to the relevant 'collection' of Springer.



2015, XXIV, 698 p. 296 illus., 99 illus. in color.



- I have designed a special Webpage to accompany the book.
- It provides access to any material on Kapteyn not protected by copyrights.
- Papers and publications of and about Kapteyn, Henriette Hertzsprung-Kapteyn's biography, letters from David Gill, etc.
- The URL is: **www.astro.rug.nl/JCKapteyn**



ROYAL OBSERVATORY,

CAPE OF GOOD HOPE,

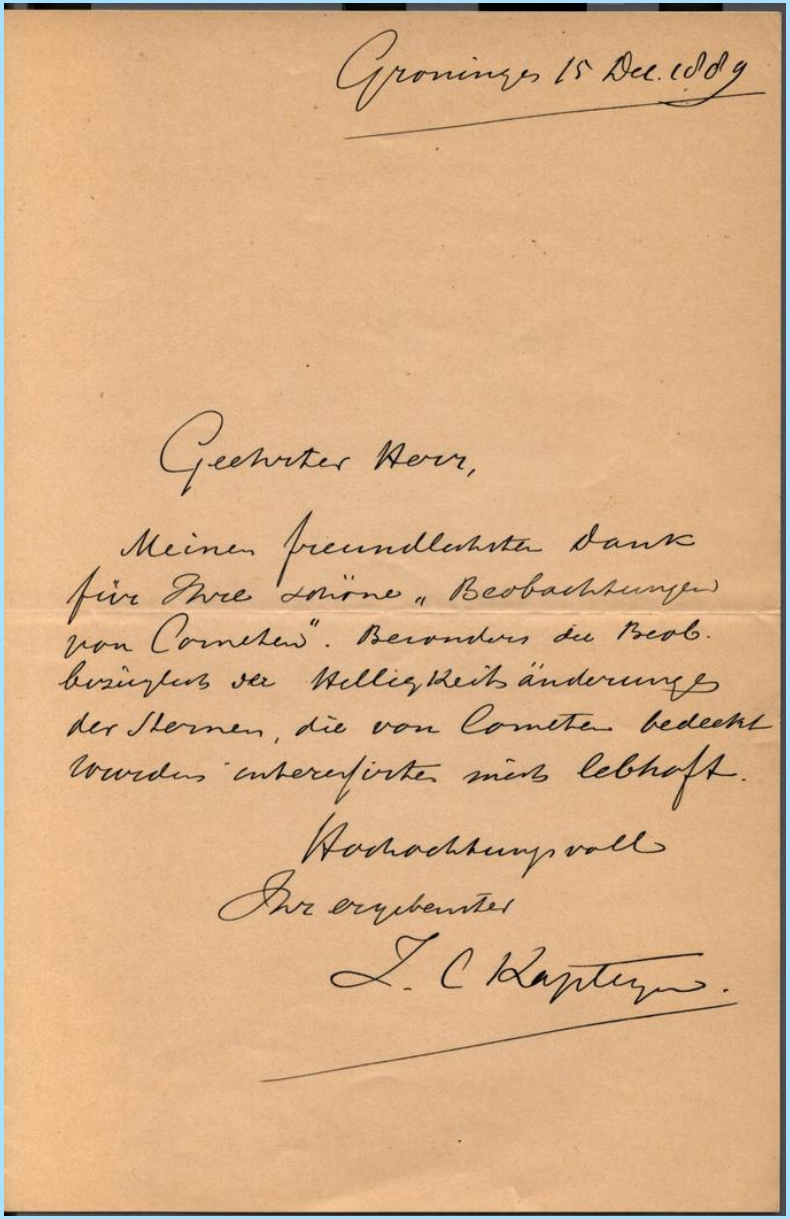
16th June 1886.

My dear Kapteyn,

I have been unable to answer your letter of the 17th May by return mail, on account of much pressing work, part of which has been created by an incident which is probably sufficiently explained by the enclosed copy of my letter to Prof. Stokes. I hear independently from three different quarters that opposition is being organized against continuation of the Cape photographic work, because four-tenths of the small number of stars in the paper copies of the Cape pictures compared with those in the photographs of Mr M Henry. And so they have worked themselves up into a state of excitement about this - and since after most noisy and ignorant are going to organize opposition - these photographers may be all very well when the thing began, but people will not be satisfied with them now. Look at those pictures of M. M. Henry, do something like that - but these Cape pictures are too bad.

Well - I think they have got their answer, and that we shall hear no more of such ridiculous nonsense.

- Almost all correspondence of Kapteyn is lost.
- Willem de Sitter and Johan Huizinga were contemplating writing a biography, but never did.
- Maybe Aernout de Sitter wanted to do this and shipped papers to Lembang.
- Everything presumable lost in Rotterdam bombing in 1940.
- We do have all letters by David Gill.
- And there are some Kladboeken left with his notes.

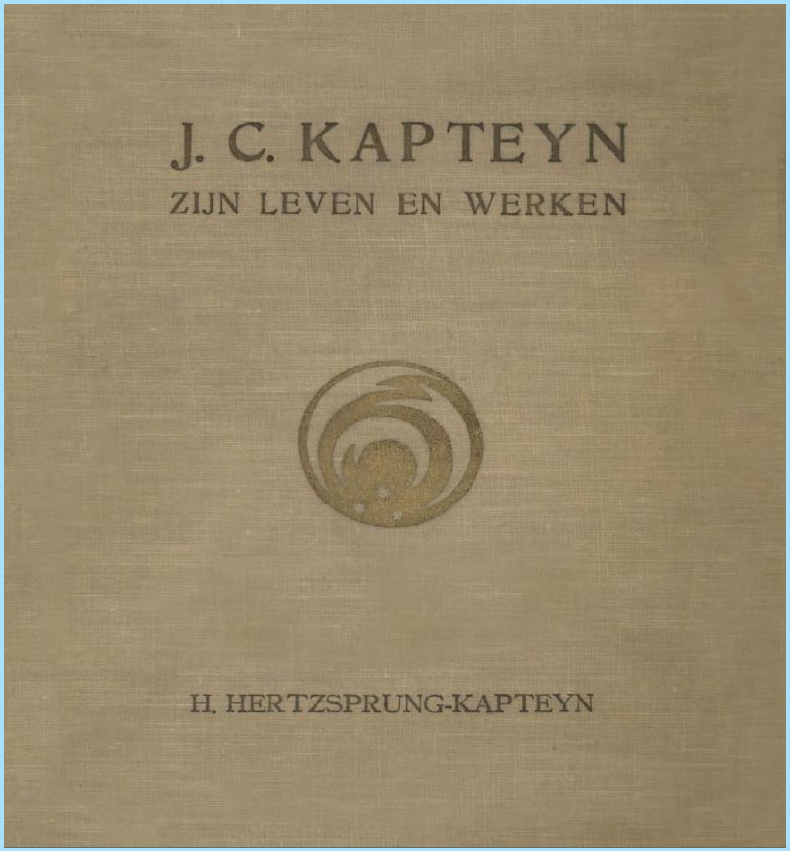

Groningen 15 Dec. 1889

Geehrter Herr,

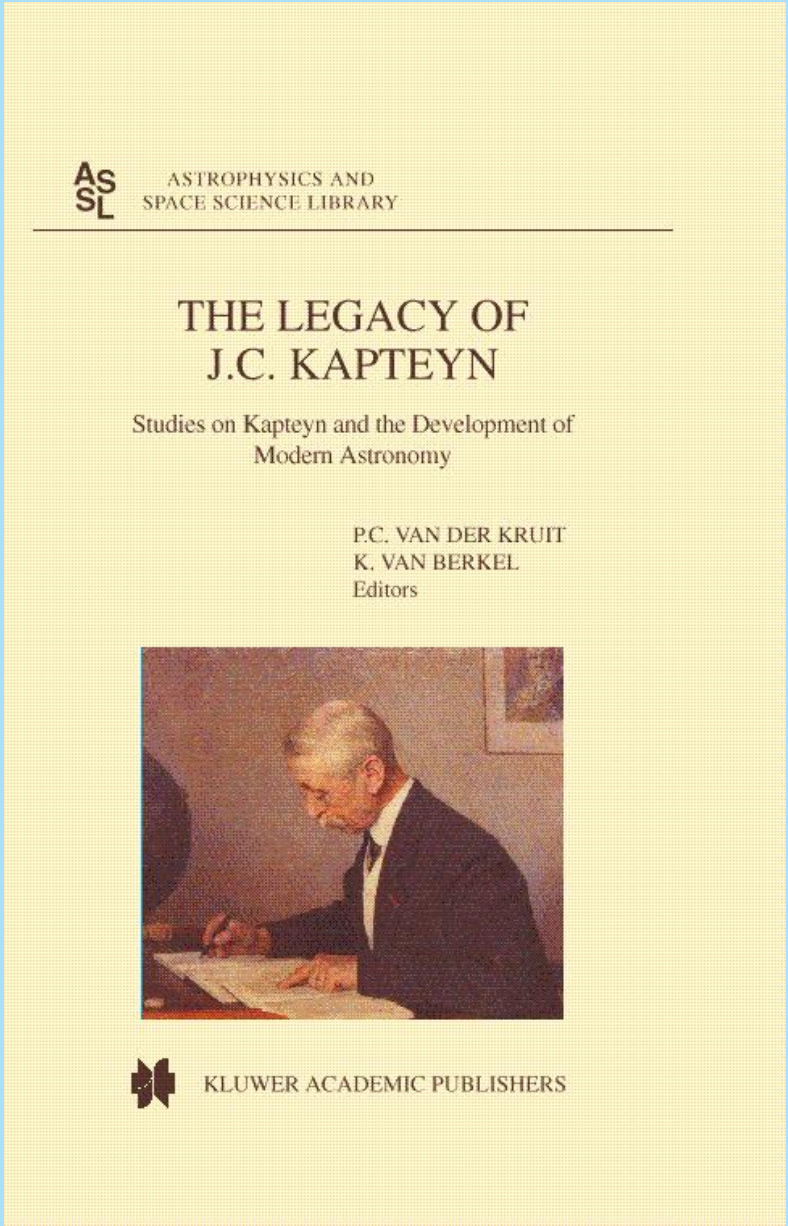
Meinen freundlichsten Dank für Ihre schöne „Beobachtungen von Cometen". Besonders die Beob. bezüglich der Helligkeitsänderung der Sternen, die von Cometen bedeckt wurden interessirten mich lebhaft.

Hochachtungsvoll
Ihr ergebenster
J. C. Kapteyn.

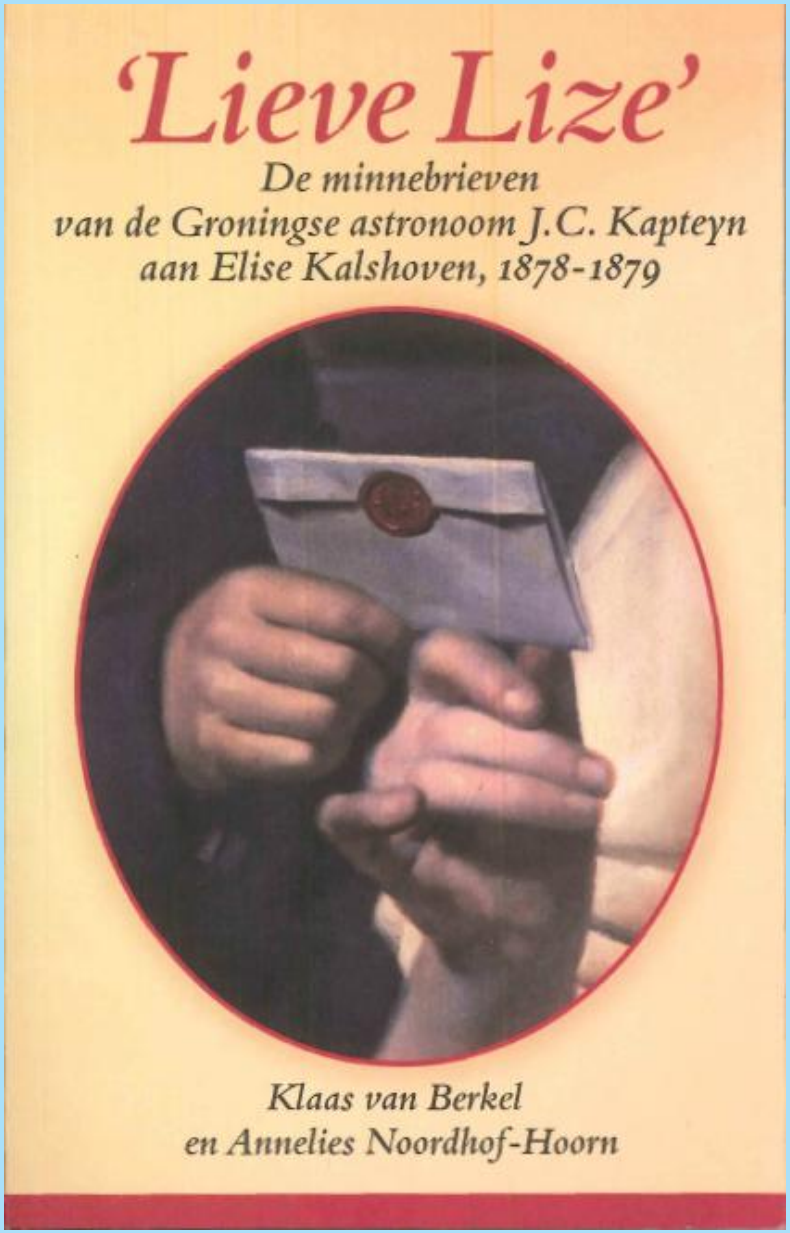
- There is correspondence of Kapteyn in archives elsewhere.
- In 1999, Petra van der Heijden has made an inventory of this and obtained copies.
- Some of this is also on the Web.
- Mostly letters *by* Kapteyn rather than *to*.
- Sometimes drafts or carbon copies of letters to Kapteyn.



- Henriette Hertzsprung-Kapteyn has written a biography in 1928.

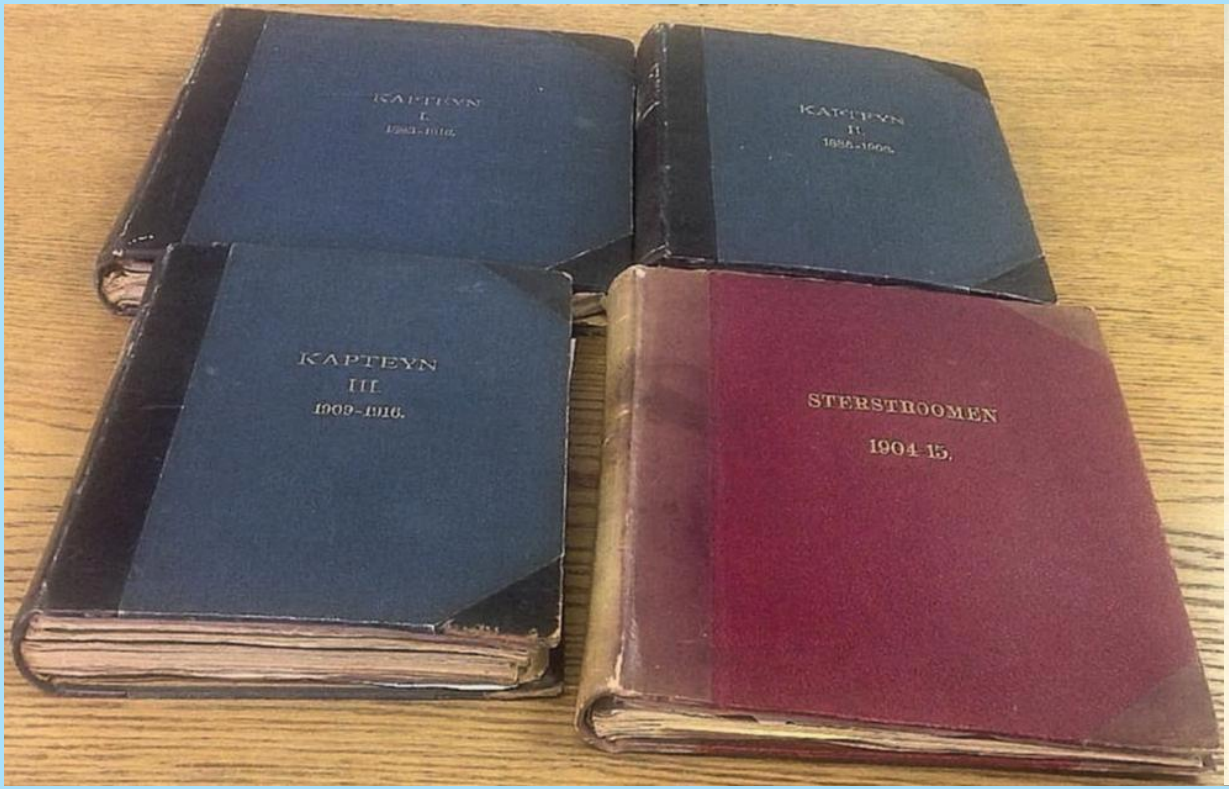


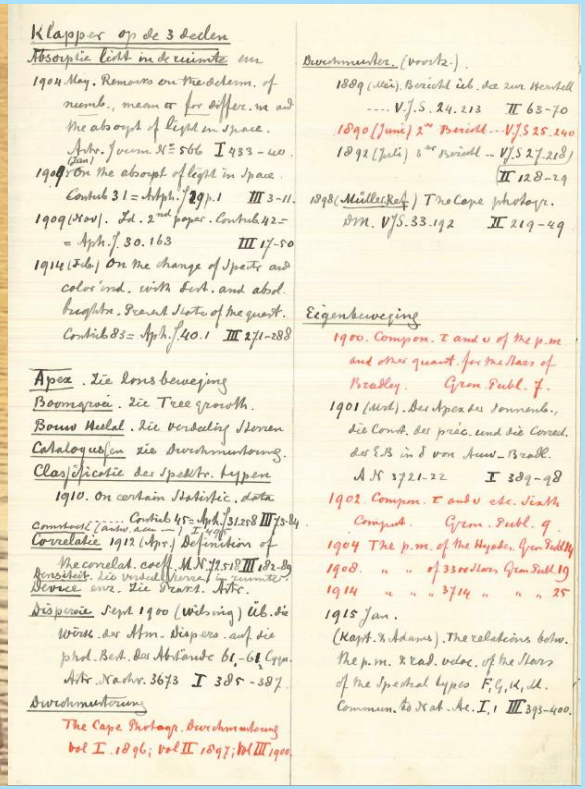
- In 1999 Klaas van Berkel and I organized a Legacy symposium on Kapteyn.
- There were participants from all over the world.
- This is an important source for studies on Kapteyn.
- But expensive: 209\$, 140£, 166€ at Springer-site.



- Klaas van Berkel has found a set of Love Letters that Kapteyn wrote to his fiancee Elise Kalshoven.
- These started in 1878, after Kapteyn was appointed professor in Groningen.
- It leads up to the time they married in July 1879.
- Most are transcribed in this book (in Dutch).

- In the Kapteyn Room in the Kapteyn Astronomical Institute we have copies of all his publications.
- Many of these are in book form (Catalogues, Groningen Publications).





- But Kapteyn collected his reprints in bound volumes together with a systematic index.

The Born Investigator of the Heavens

Simon Newcomb, *The Stars: A study of the Universe*[1] (1901).

'This work of Kapteyn offers a remarkable example of the spirit which animates the born investigator of the heavens. Although the work was officially that of the British Government, the years of toil devoted to it were, as the writer understands, expended without other compensation than the consciousness of making a noble contribution to knowledge, and the appreciation of his fellow astronomers of this and future generations.'

[1] Footnote on page 49.

Short biography
(traditional version)

- Kapteyn was born on January 19, 1851 in the municipality of Barneveld.
- In the middle of the 'Bible Belt'.
- His parents were Gerrit Jacobus Kapteyn (1812–1879) and Elisabeth Cornelia Koomans (1814–1896).
- They ran a boarding school for boys.

- He was the tenth (not ninth) child of fifteen.
- This is a family reunion around 1877 or so.

- Kapteyn was educated at the boarding school of his parents.
- He always complained of a lack of attention by his parents.
- He enrolled at the University of Utrecht in 1868 to study mathematics and physics.

ONDERZOEK

DER

TRILLENDE PLATTE VLIEZEN.

Akademisch Proefschrift

TER VERKRIJGING VAN DEN GRAAD VAN

DOCTOR IN DE WIS- EN NATUURKUNDE,

AAN DE HOOGESCHOOL TE UTRECHT,

NA MACHTIGING VAN DEN RECTOR MAGNIFICUS

D^R. C. H. C. GRINWIS,

GEWOON HOOGLEERAAR IN DE FACULTEIT DER WIS- EN NATUURKUNDE,

MET TOESTEMMING VAN DEN ACADEMISCHEN SENAAT

EN

VOLGENS BESLUIT VAN DE FACULTEIT DER WIS- EN NATUURKUNDE,

TE VERDEDIGEN

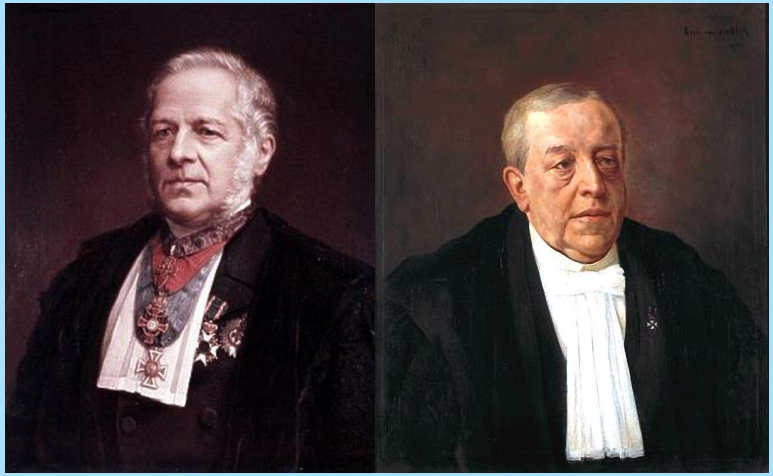
Op Donderdag, 24 Juni 1875, des namiddags ten 7 ure,

DOOR

JACOBUS CORNELIUS KAPTEYN,

GEBOREN TE BARNEVELD.

BARNEVELD,
P. ANDREÆ MENGER.
1875.



- He studied with C.H.D. Buys Ballot and C.H.C. Grinwis.
- And obtained his PhD in 1875 under Grinwis.
- The title was 'A study of vibrating, flat membranes'.

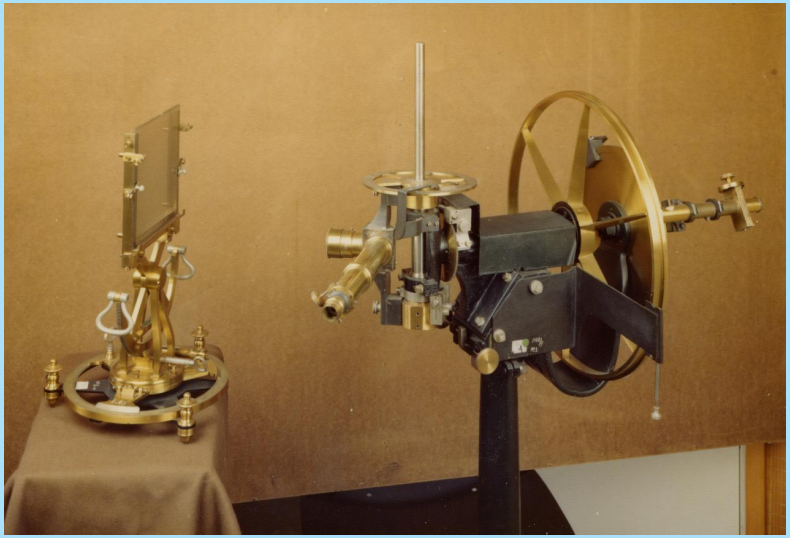
- In 1875 he was appointed observator at Leiden Observatory.
- The director was Hendricus G. van de Sande Bakhuyzen.
- The Observatory was mainly involved in positional astronomy.

- In 1877 he was appointed Professor of astronomy and theoretical mechanics at the University of Groningen.

- The chair was a result of the Law on Higher Education of 1876.
- He took up his chair in 1878.
- He married Catharina Elisabeth Kalshoven (1855–1945) on July 16, 1879.

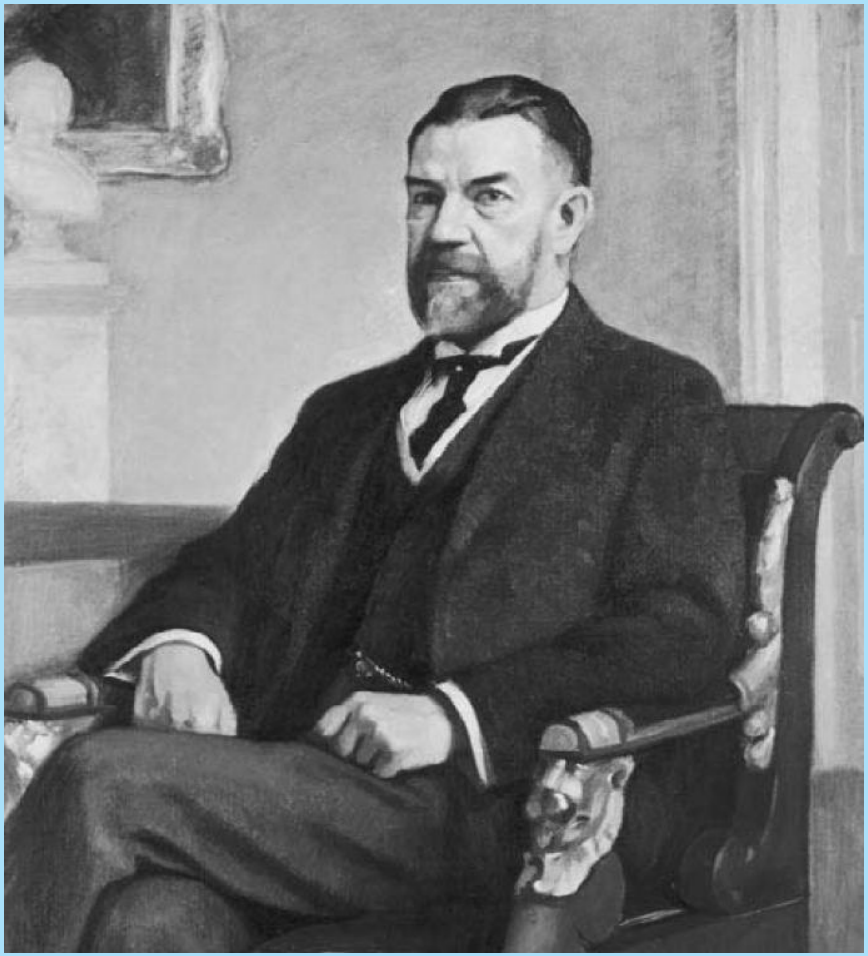
- In spite of many efforts he failed to obtain his own observatory.

- He heard about the efforts of David Gill at the Royal Observatory at Cape of Good Hope to produce a photographic Durchmusterung.
- He offered to measure Gill's plates and produce the star positions and magnitudes.
- The Cape Photographic Durchmusterung was published in three volumes in 1896, 1897 and 1900.

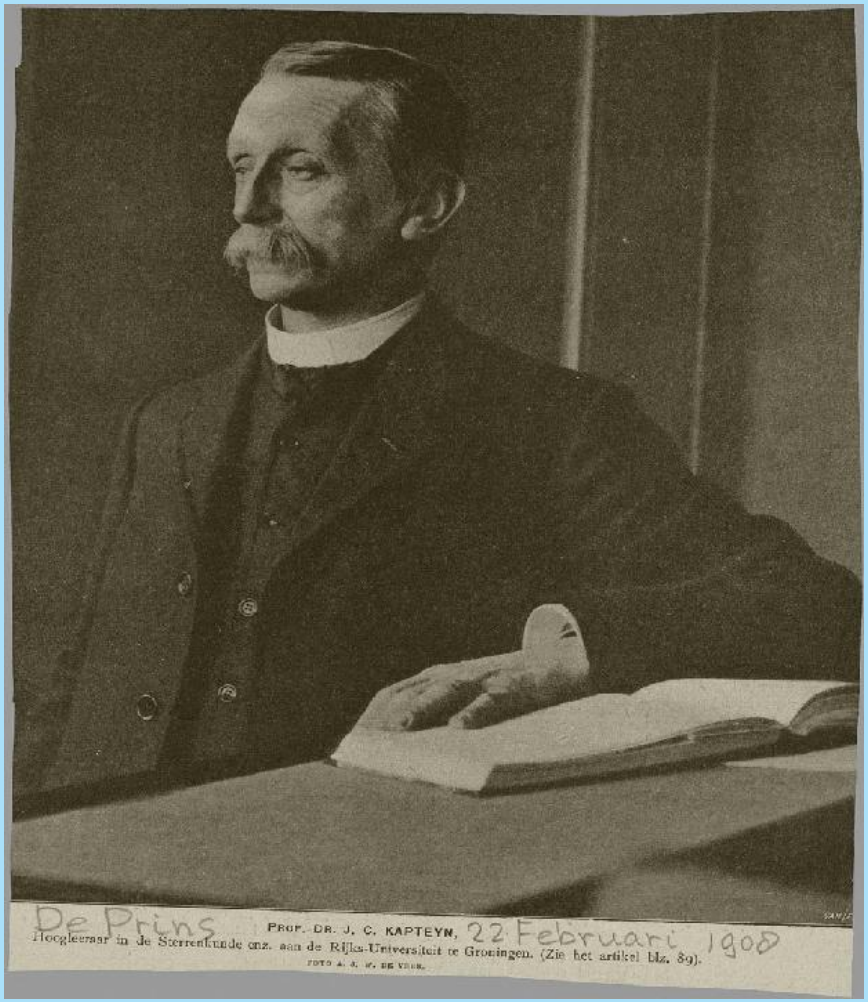


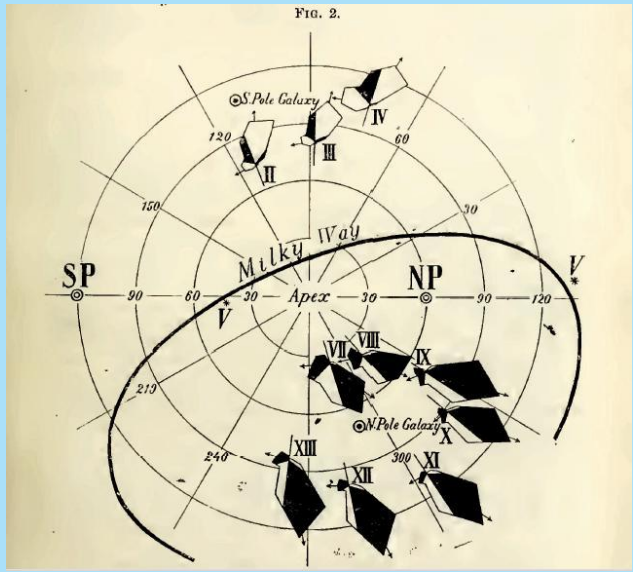
- He devised the parallactic method and measured the positions and magnitudes of 454,875 stars.
- He was given two small rooms in the laboratory of G. Heymans, professor of psychology and philosophy.

- Kapteyn devoted his carreer to the problem of the Construction of the Heavens or the Structure of the Sidereal System.
- He gave up measurement of direct trigonometric parallaxes.
- He used proper motions and made the assumptions that
  - Luminosity curve everywhere the same.
  - Stellar motions in space have no prefered direction.
  - No insterstellar absorption.

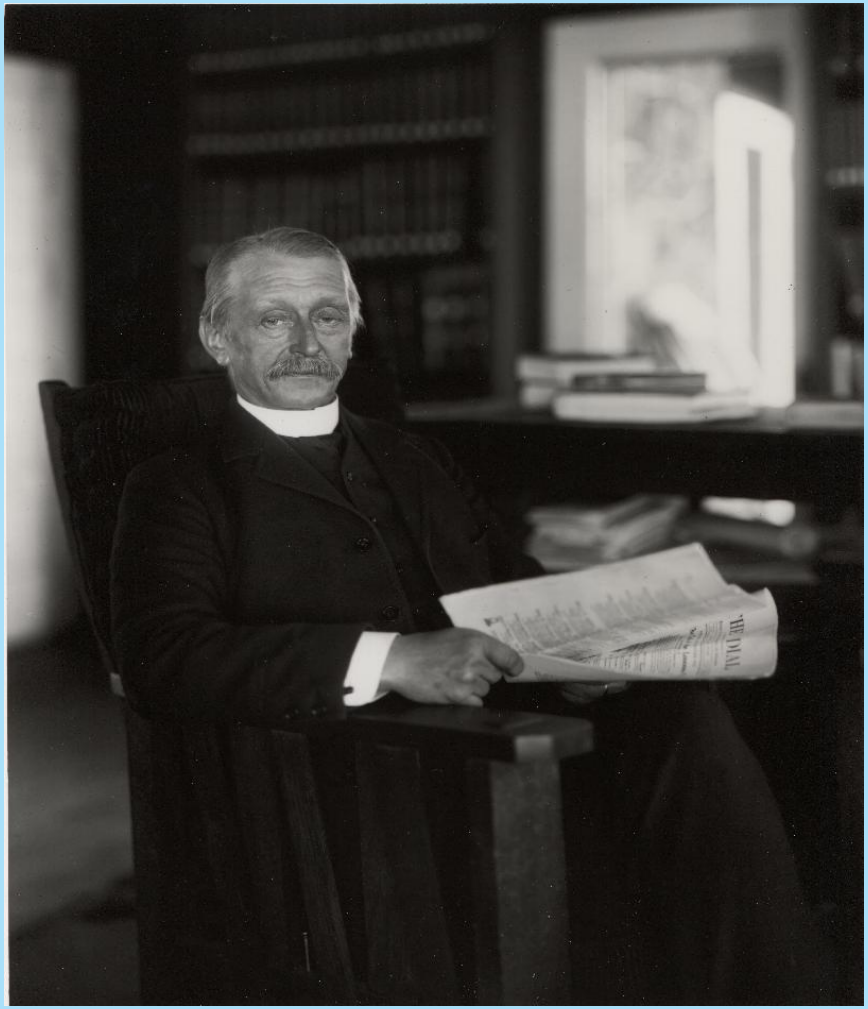


- Anders Donner from Helsingfors provided him with many plates for both proper motions and parallax determinations.
- He had met Donner at the meeting of the Carte du Ciel in Paris in 1887.

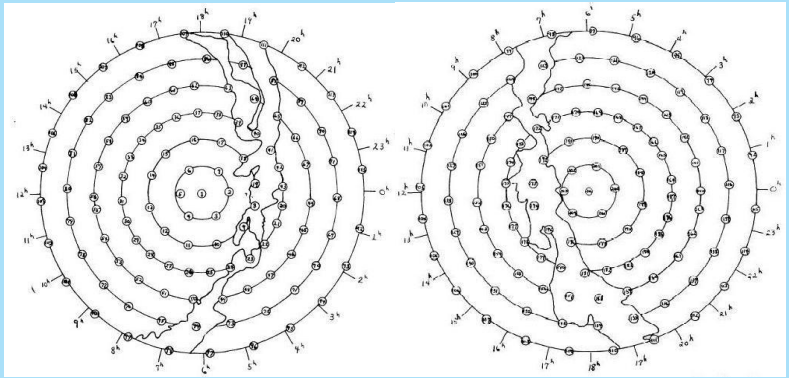




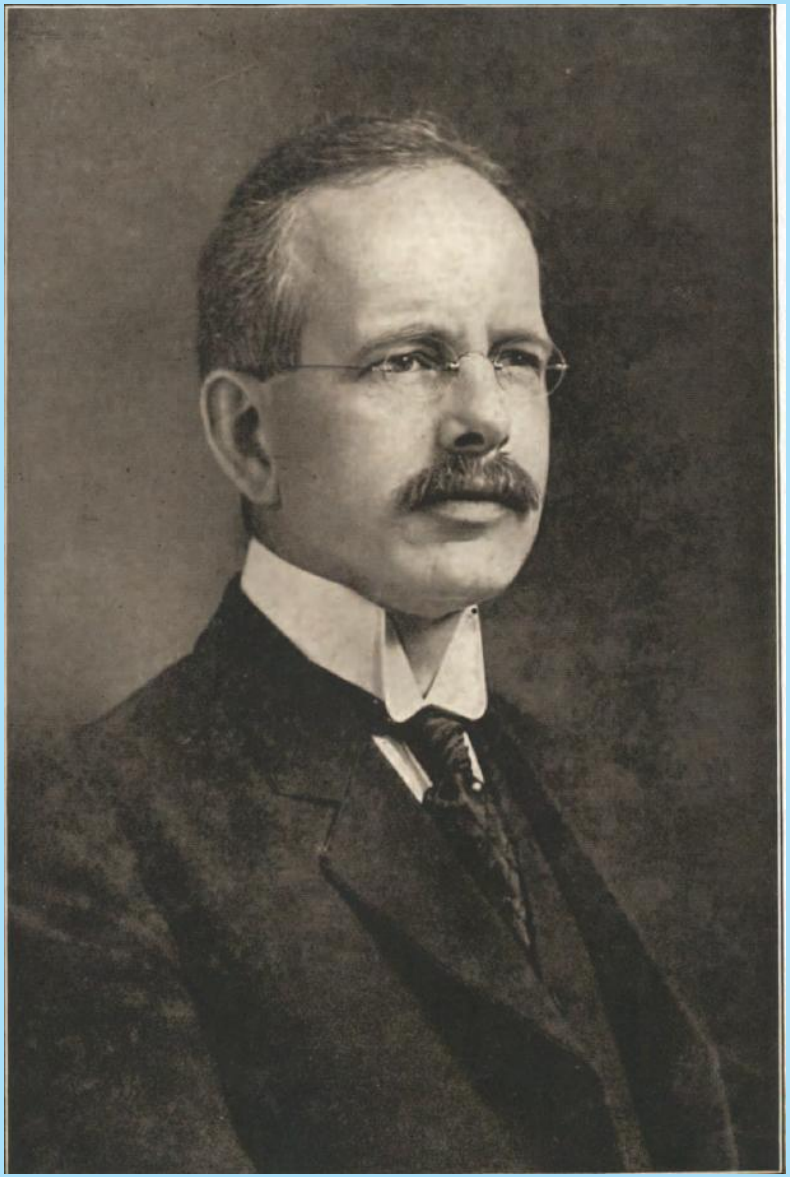
- However, Kapteyn discovered the Two Star Streams, showing two preferred directions.
- He first presented that at a Congress during the 1904 Louisiana Purchase Exposition.

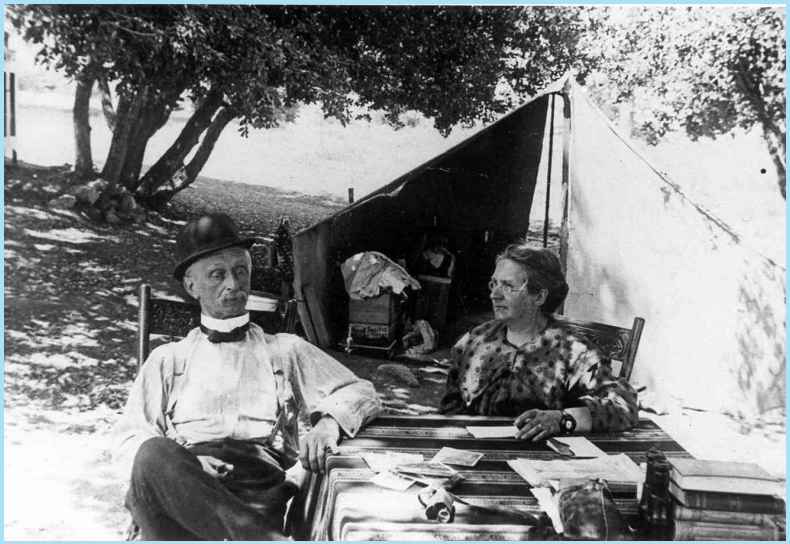


- The concept of Star Streams was quickly confirmed, a.o. by Arthur Eddington.
- Karl Schwarzschild proposed that the explanantion was an anisotropic velocity ellipsoid.
- But the stellar composition of the two Streams was very different.
- The Streams had to be taken into account in the study of the distribution of stars in space.

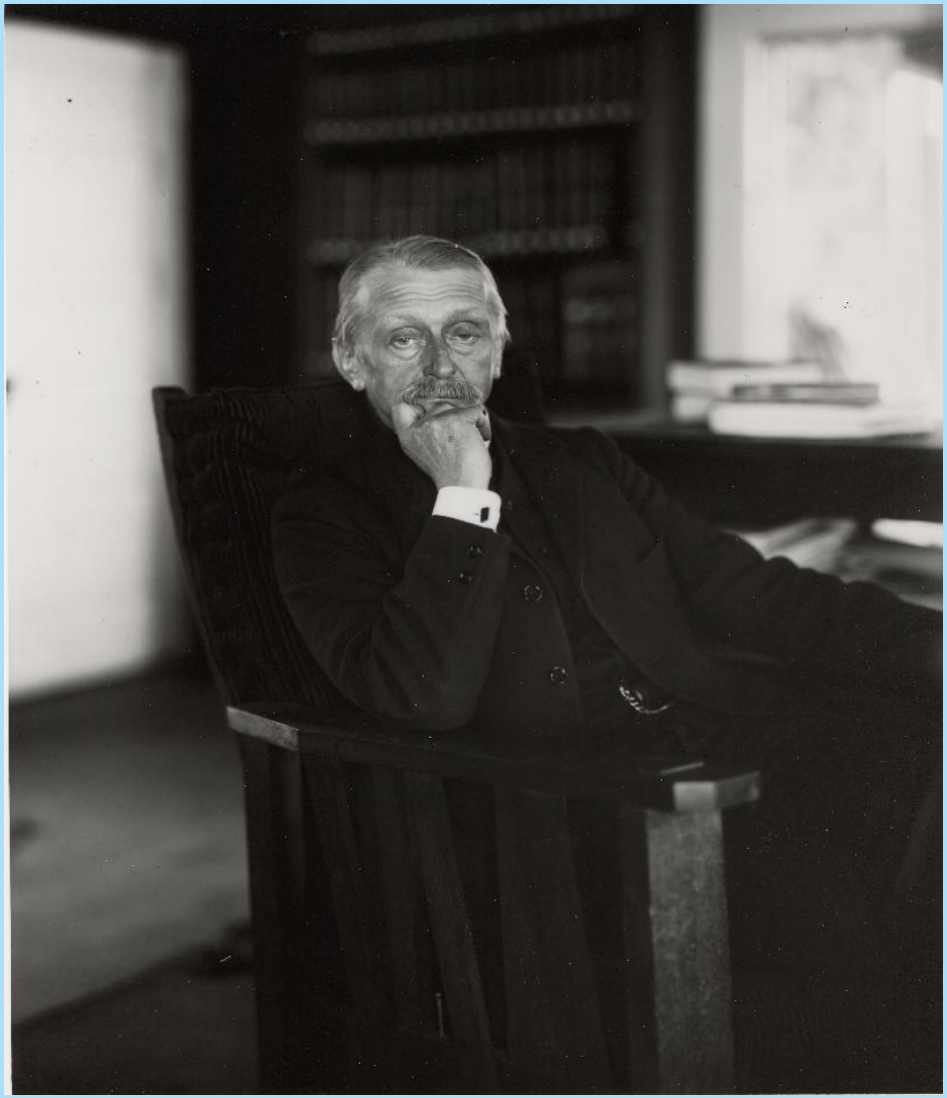


- He devised the Plan of Selected Areas after discussion with many colleagues.
- Eventually it became 220 areas in the 'Systematic Plan' (+46 in the 'Special Plan').
- All measurable properties of stars should be determined.





- In St. Louis he met George E. Hale of the Mount Wilson Observatory
- Kapteyn was appointed staff associate for three months/year.
- He went to Mt. Wilson each year from 1908 to 1914.

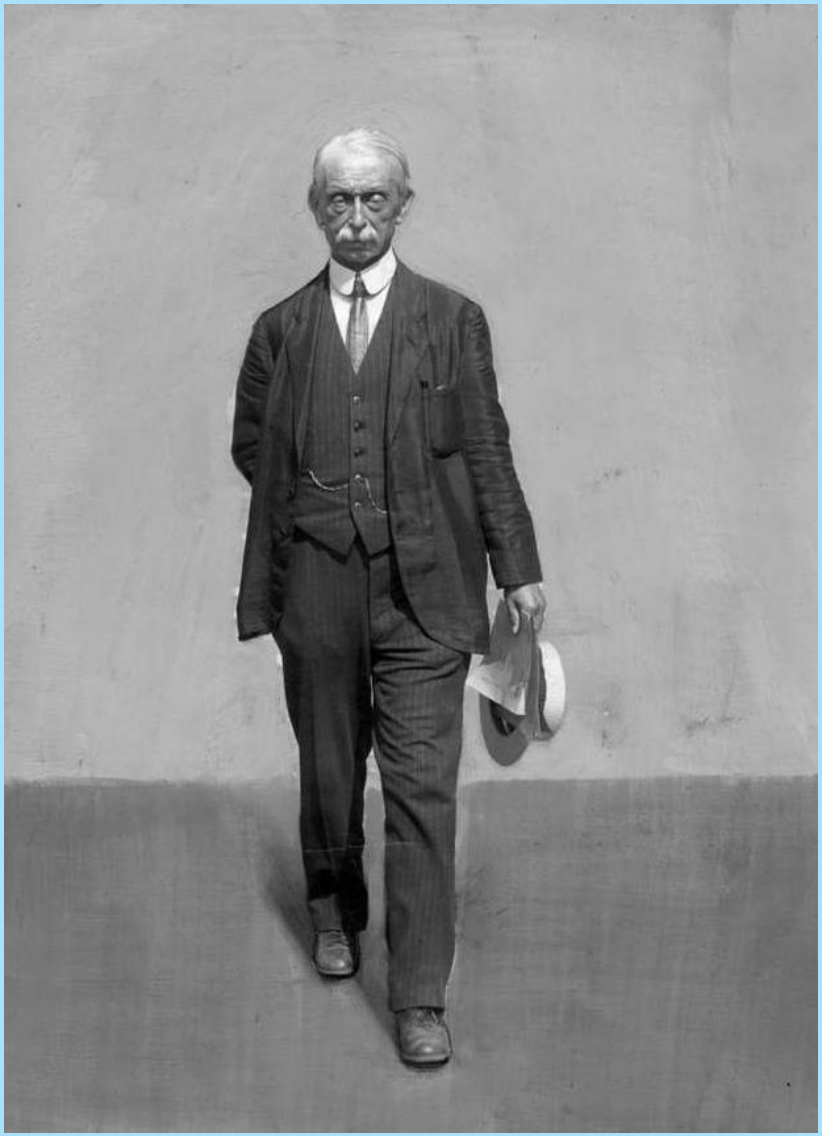


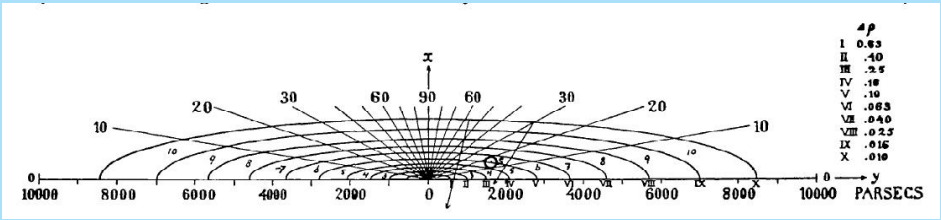
- Hale adopted the Plan as the prime program for his new Mount Wilson 60-inch.
- The star counts in the Selected Areas project did come along well.
  - Harvard-Groningen with Pickering (1918/23/24): all sky down to mag. 16 .
  - Mt. Wilson-Groningen with Seares (1930): north down to mag. 19.
- Supplemented with radial velocity studies by Adams (MtW).

JACOBUS CORNELIUS KAPTEYN

(Fotografie door ALBERT KAPTEYN)

- The problem Kapteyn worried about very much was that of extinction or absorption by interstellar dust.
- He deduced it would produce reddening and found (1909) a reasonable ~ 0.3 mag/kpc (also van Rhijn's PhD thesis).
- Could be due to correlation color-absolute magnitude.
- Shapley showed (1916) space was transparent towards M13.





- In the end he produced the Kapteyn Universe, which had the Sun close to the center.
- He did derive a correct vertical distribution.
- Using velocities he laid the foundations for studies of galactic dynamics.
- First determination of local mass density.

- Kapteyn introduced the concept of the astronomical laboratory.
- This was listed by Baillaud, first IAU president in Rome in 1922 as one of the three most important recent developments.
- The other two were astronomical photography and giant telescopes.
- This was quoted by de Sitter, but rather overinterpreted.

- After retirement, Kapteyn became parttime adjunct-director in Leiden.
- The Kapteyns first stayed with their daughter in Amsterdam and bought a house in Hilversum.

- Kapteyn never lived there; after a prolonged illness he died in Amsterdam on June 18, 1922.

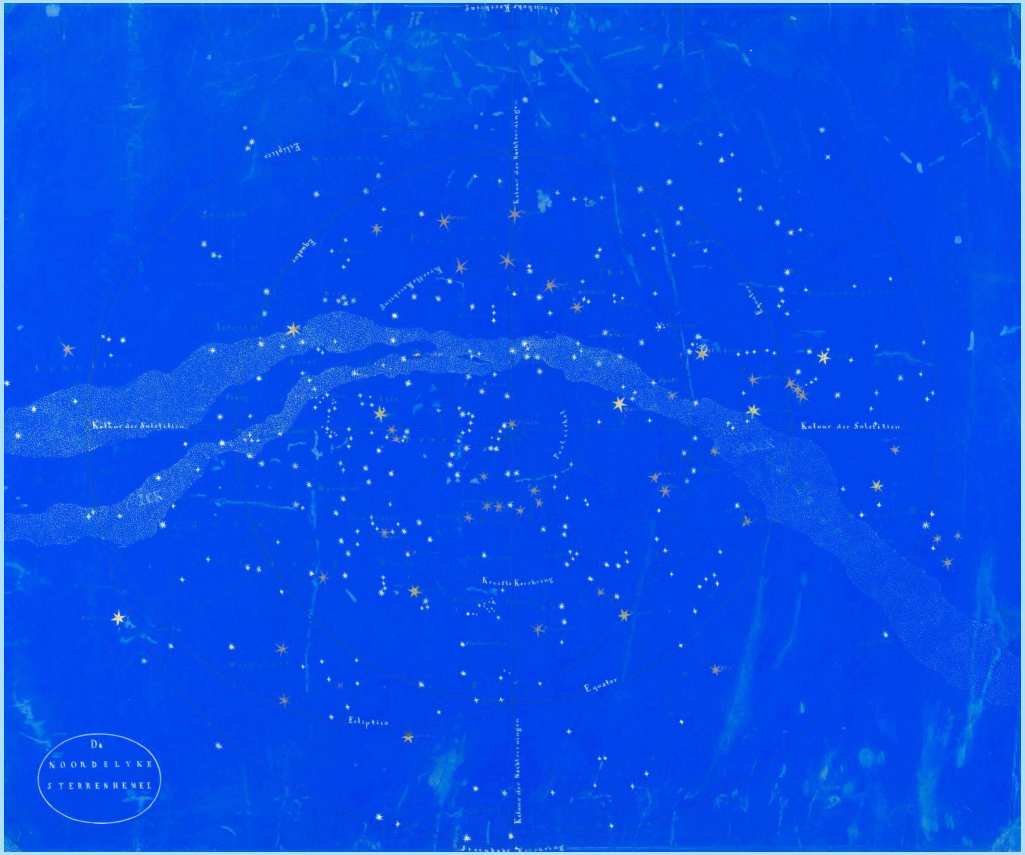
Born investigator of the heavens?

(Misconceptions about Kapteyn)

Accidental astronomer?

- It is usually stated that Kapteyn by accident entered astronomy.
- Adriaan van Maanen[2] in his obituary:
  - *'... his doctoral thesis was in physics: "Onderzoek der Trillende Platte Vliezen".*
    Just at this time, however, the position of observer at the Leiden Observatory was vacant, and Kapteyn applied for and obtained the position.
    By this accidental circumstance astronomy secured the privilege of counting Kapteyn as one of its workers and before long as one of its foremost leaders.'
- Or Sir James Jeans[3]:
  - *'It would appear that during his student days Kapteyn was not particularly attracted to astronomy, ...'*

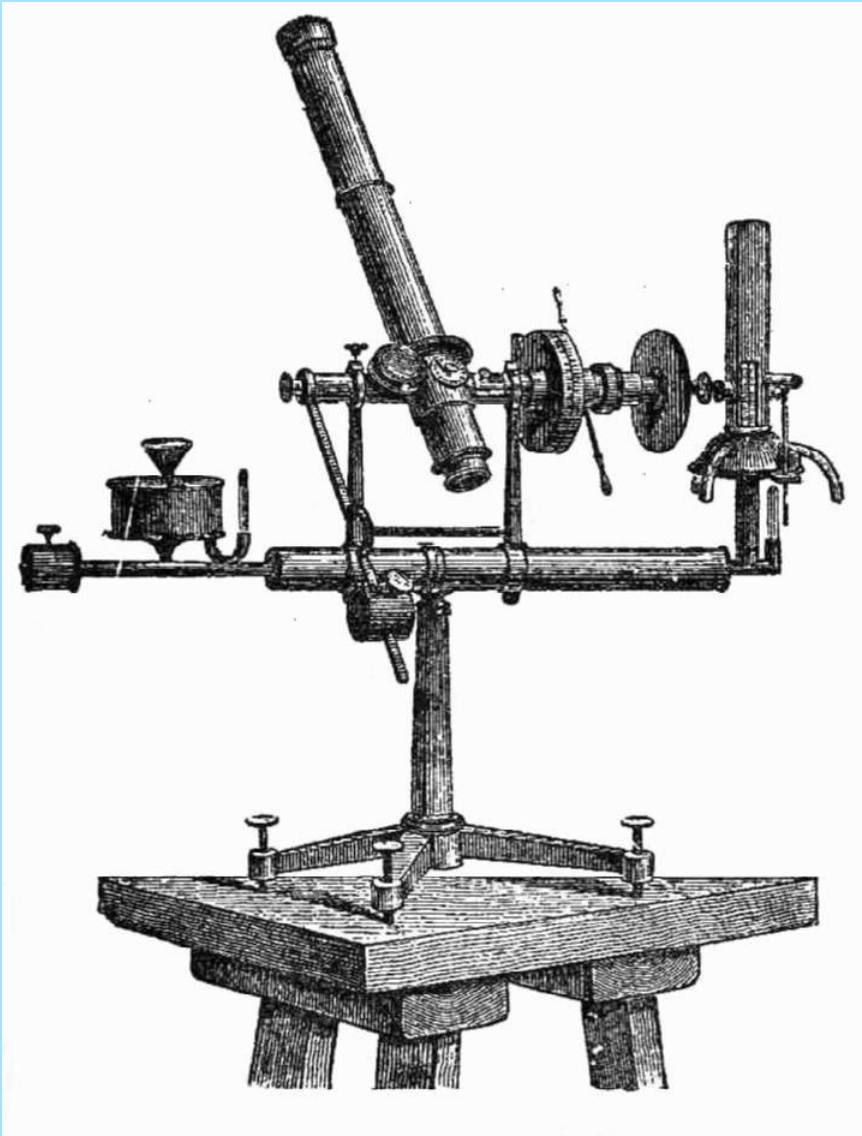
[2] Astrophysical Journal 56, 145-153 (1922).
[3] Monthly Notices Royal Astronomical Society 83, 250 (1923).



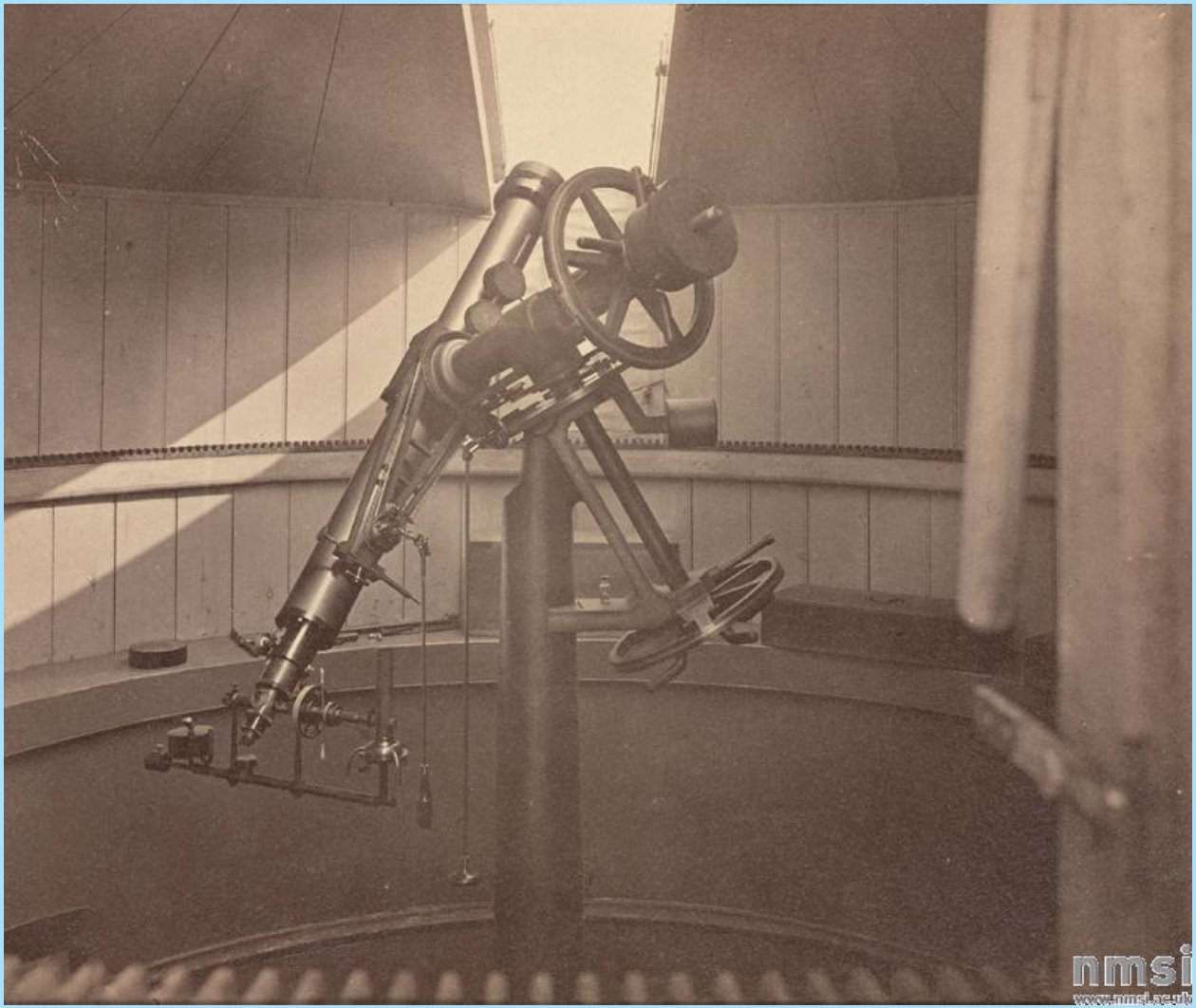
- There is evidence that Kapteyn as a child already had a special interest in astronomy.
- As a boy of 14 he made a starmap after his older sister had given him a star globe.
- HHK says:
- *'When his father noted how seriously he studied the stars, he bought a large telescope for him, that was erected in the attic room and with which he very diligently observed the stars.'*

- Various sources, including a brochure of the boarding school, mention that 'Benno' had an 'observatory'.

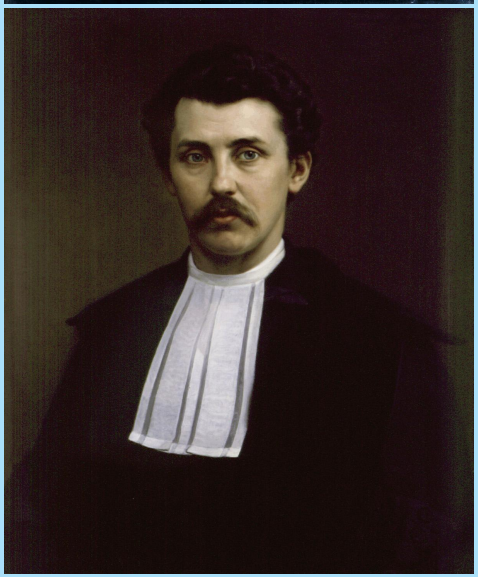
- His PhD thesis had 18 'Stellingen' (propositions); no less than 7 of these are on astronomy.
- For example:
  - *'XV. The average proper motion of stars of different magnitude is not inversely proportional to their distance.'*
- He must have read about this or hypothesized about it and probably tried it on real data.
  - *'X. The best photometer is that of Zöllner.'*
- So he knew what a Zöllner photometer was and might even have used one.



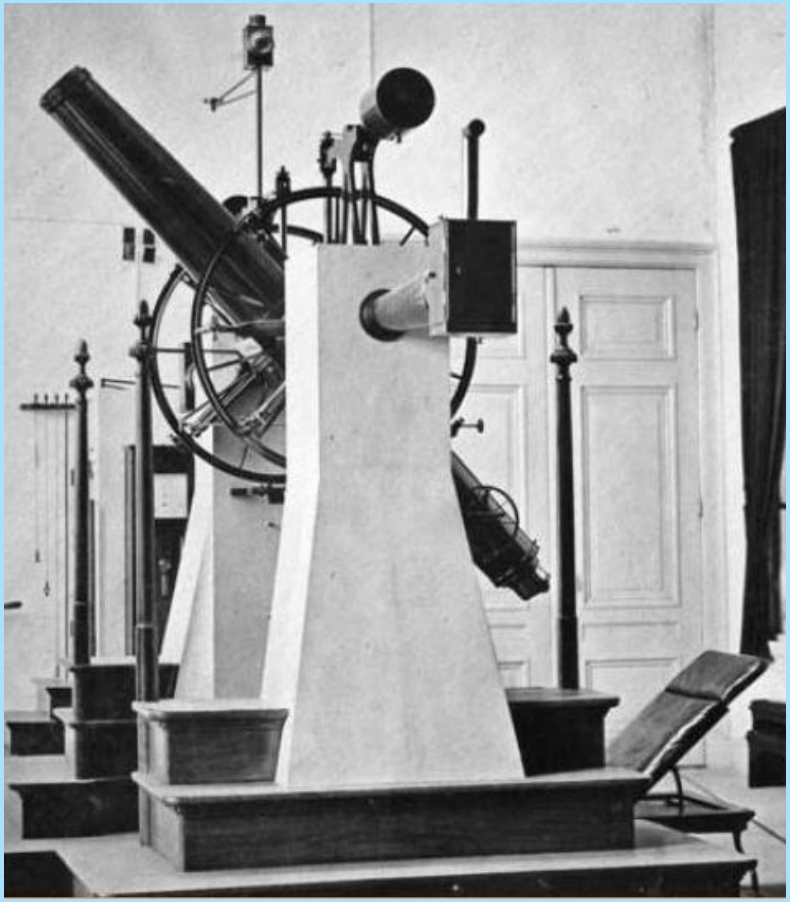
- The photometer was developed in 1858 by J.K.F. Zöllner and widely used from the 1860s onwards.
- It projected the light of a Bunsen burner through an adjustable set of polarizing plates.
- Utrecht Observatory had one, probably already at Kapteyn's time.



- A Zöllner photometer on the telescope at Pulkovo Observatory.



- Buys Ballot was first responsible for astronomy teaching and supervised one astronomical thesis (1871).
- In 1856 J.A.C. Oudemans was appointed, but he left to Dutch Indies (as geographer) in 1857.
- Eventually M. Hoek was appointed for astronomy teaching (1859).
- He was mostly interested in ether experiments and had no PhD students.
- He also had a poor health and died in 1873.
- Oudemans came back as professor of astronomy in 1875.

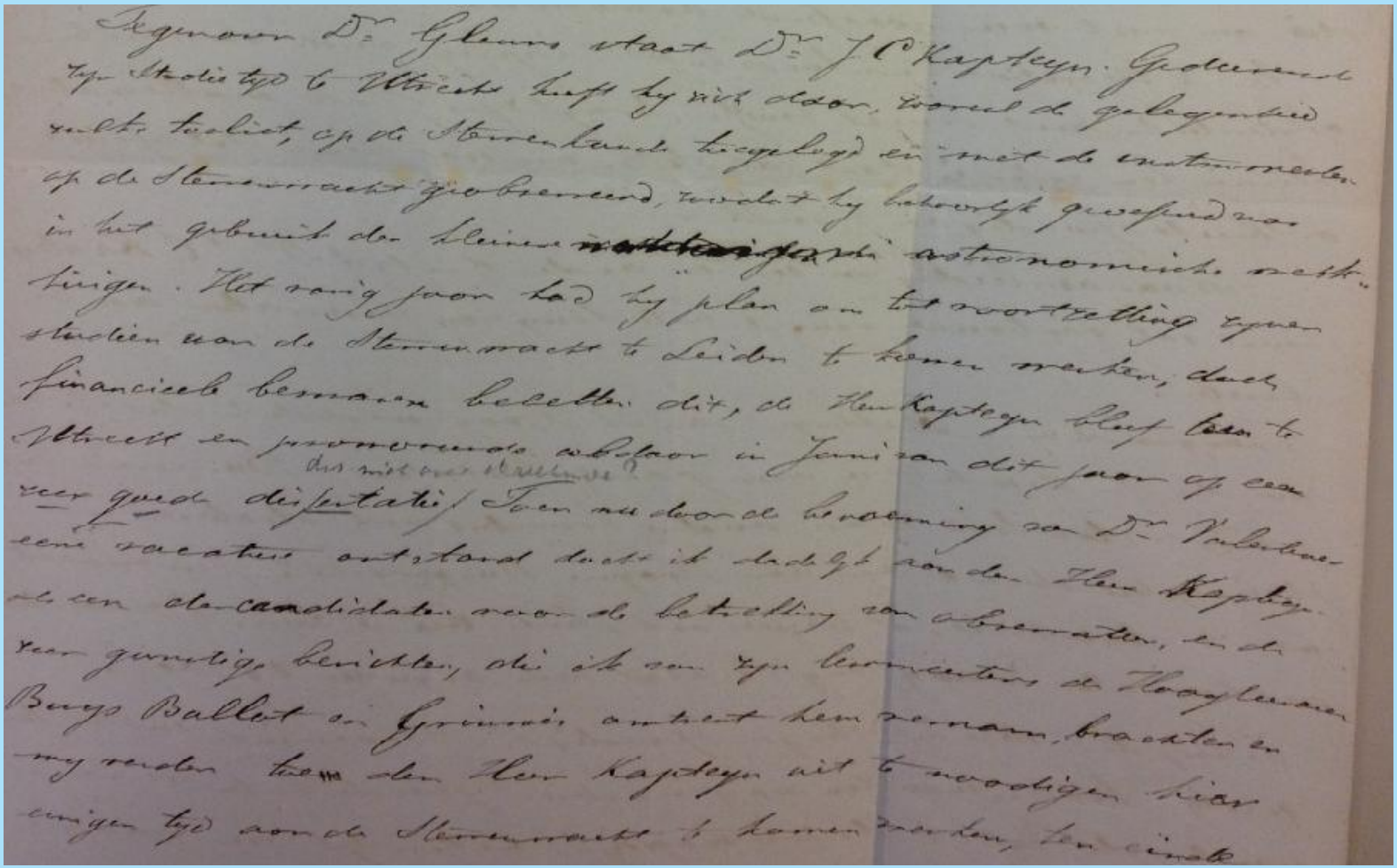


- So, Kapteyn had no option for an astronomy thesis in Utrecht.
- How did he get appointed in Leiden?
- The 'Sterrewacht' had H.G. van de Sande Bakhuyzen as director, and K.W. Valentiner and E.F. van de Sande Bakhuyzen as 'observator'.
- In 1875 Valentiner became director in Mannheim, creating a vacancy in Leiden.

- The course of events is as follows:
  - June 22, 1875. Van de Sande Bakhuyzen informs curators that Valentiner will be leaving.
  - July 28, 1875. Curators write that Minister awaits his proposals.
  - August 10, 1875. Van de Sande Bakhuyzen proposes that his brother become first and J.C. Kapteyn second observator.
  - September 29, 1875. Curators write that Minister has given honorable discharge to Valentiner and appoints the two observators as requested.
- Apparently not much happened between August 10 and September 29.

- From van de Sande Bakhuyzen's letter to Leiden University Curators of August 10, 1875:
  - *'... Dr. J.C. Kapteyn has been working for some time at my request at the Observatory, so that what he accomplishes here would make it possible to form an opinion on his suitability for the duties of an observator at the Observatory. As a result of the experience I had with him, I believe I can decide that, although he is not capable yet in all cases to perform the tasks that can be demanded from an observator, this will be the case in not too long a period, so that from the various candidates that are considered for this position, he should be recommended as the best.'*
- Apparently there were more candicates and Kapteyn had been on trial on a temporary basis.

- There is an unusual exchange of letters *directly* between the Minister and van de Sande Bakhuyzen.
- September 21, 1875. The Minister suggests that maybe Dr. W. Gleuns should be considered as well for the position.
- After all, Gleuns had been involved in calculations for van de Sande Bakhuyzen and was looking for a job.
- Curators have proposed Kapteyn without argumentation, *'which for a nomination like this is really very little'*.
- September 22, 1875. Van de Sande Bakhuyzen writes back immediately.
- Draft unreadable, but original in National Archives.



Piet van der Kruit

The Born Investigator of the Heavens

- Van de Sande Bakhuyzen strongly opposes Gleuns as being a mathematician with no affiliation to astronomy.
- From September 22, 1875 letter:
  - *'Vis-a-vis Dr. Gleuns we have Dr. Kapteyn. During his studies in Utrecht he has, as much as opportunities allowed, devoted himself to astronomy and has observed with instruments at the observatory so that he obtained consideable familiarity with the use of astronomical apparatus. Last year he took up the plan to continue his studies at the Observatory in Leiden, but financial considerations prevented this. Mr. Kapteyn did stay in Utrecht and obtained his degree there in June of this year with a very good thesis.'*
- So, Kapteyn had earlier contacted van de Sande Bakhuyzen and even tried to do an astronomical PhD thesis in Leiden.

- Van de Sande Bakhuyzen continues:
  - *'When the appointment of Dr. Valentiner created a vacancy, I immediately thought of Mr. Kapteyn as one of the candidates for the position of observator and the very positive words I received from his professors Buys Ballot and Grinwis about him made me decide to invite Mr. Kapteyn to work at the Observatory in order to decide to what extent he was a suitable candidate for the position of observator. Mr. Kapteyn accepted this offer and worked here for about 3 months, during which time he has completely confirmed the favorable expectations I initially had of him. Although he is not yet familiar with all the observing techniques he will have to perform, he has shown not the be second to any more experienced astronomer.'*
- Van de Sande Bakhuyzen had invited Kapteyn to come to Leiden for a trial period.

- Kapteyn had an interest in astronomy from a young age onward.
- Kapteyn did as much astronomy as possible in Utrecht, but could not do a PhD thesis there.
- Kapteyn tried to move to Leiden to do a thesis, but was prohibited by finances.
- Van de Sande Bakhuyzen thought of Kapteyn, when Valentiner left.
- Kapteyn actually worked on trial basis in Leiden for a few months.
- Kapteyn certainly did not enter astronomy 'by accident'.

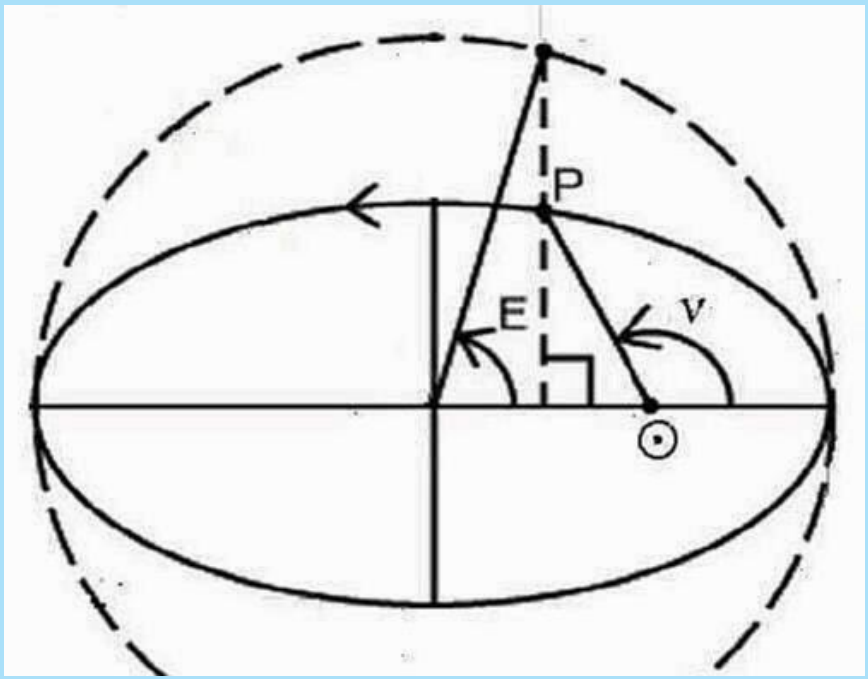
First Groningen years

- It is often implied that Kapteyn, after going to Groningen, produced little original, astronomical work.
- Again Adriaan van Maanen:
  - *'Lack of an opportunity for observational work was, however, keenly felt by Kapteyn during the early years of his professorship, and he requested Professor H.G. van de Sande Bakhuyzen to let him use the meridian circle of Leiden Observatory during his vacations. The request was granted and Kapteyn planned a careful program for the observation of stellar parallax.'*
- But that was only 1885 (while appointed 1878).
- Other obituaries also leave the impression nothing worth mentioning was accomplished in this interval.

- From the HHK biography:
  - *'Kapteyn suffered under the impossibility to bring his scientific plans to reality and was always looking for things to do with his hands or his head. He collaborated in those days with his brother Willem, the mathematician from Utrecht.'*
  - *'He was also busy with meteorologic studies and he traveled to Worms and to Paris in order to do research on the growth of trees in relation to the climatic circumstances.'*
  - *'But all this did not satisfy him. It was only child's play and he wanted to do something much greater and he knew he was able to do that. Then, suddenly the solution came and it gave a entirely new direction to his life.'*

1. Kepler's equation

Solve for E in $M = E - e \sin E$.



- For orbits in the Solar System:

$$M = \frac{2\pi}{P}(t - T_\circ),$$

$$\tan\left(\frac{E}{2}\right) = \sqrt{\frac{1-e}{1+e}} \tan\left(\frac{\nu}{2}\right)$$

- This was very time consuming.
- But important not to loose newly discovered asteroids and comets.

UEBER DAS KEPLER'SCHE PROBLEM.

VON PROFESSOR J. C. KAPTEYN.

In diesem Aufsatze wird eine Reihe entwickelt für die Lösung des Kepler'schen Problems, die für alle Planetenbahnen, auch die am meisten excentrischen, ausserordentlich convergent ist. Diese Convergenz ist so gross, dass eine *directe* Berechnung der excentrischen Anomalie, mit Zuhülfenahme einer mässig grossen Tafel eben so bequem, oder sogar noch etwas bequemer wird, als nach den gebräuchlichen Näherungsverfahren. Aber auch abgesehen von der Frage, in wiefern diese Lösung für den Praxis zu empfehlen ist, möchte die Reihe vielleicht nicht ohne Interesse sein.

Es sei M die mittlere, E die excentrische Anomalie, e die Excentricität, $\Delta E = E - M$,

$$R = \frac{e \sin M}{1 - e \cos M}, \quad T = \frac{e \cos M}{1 - e \cos M}.$$

Die erwähnte Reihe wird dann erhalten, wenn man $E - M$ entwickelt nach den steigenden Potenzen entweder von cotang M oder von T. Das Ergebniss der ersten Entwickelungsart wird man in die folgende Form bringen können—

$$\begin{aligned}(1)\ E - M = \alpha &+ \cot g M \left[-\frac{1}{6}\alpha^4 + \frac{11}{120}\alpha^6 - \frac{337}{5040}\alpha^8 + \frac{16711}{362880}\alpha^{10} - \frac{1279301}{39916800}\alpha^{12} + \frac{138693707}{6227020800}\alpha^{14} - \ldots \right] \\ &+ \cot^3 M \left[+\frac{1}{12}\alpha^7 - \frac{13}{120}\alpha^9 + \frac{7517}{60480}\alpha^{11} - \frac{228199}{1814400}\alpha^{13} + \frac{9528949}{79833600}\alpha^{15} - \ldots \right] \\ &+ \cot^5 M \left[-\frac{1}{18}\alpha^{10} + \frac{101}{864}\alpha^{12} - \frac{166549}{907200}\alpha^{14} + \ldots \right] \\ &+ \cot^7 M \left[+\frac{55}{1296}\alpha^{13} - \frac{403}{3240}\alpha^{15} + \ldots \right] \\ &+ \ldots\end{aligned}$$

WO—

$$(2) \qquad \alpha = R \cos \alpha$$

Es ist daher α immer kleiner (in absoluten Werth) als $\frac{e \sin M}{1 - e \cos M}$.

In eine Reihe entwickelt ergiebt sich für α—

$$(3) \qquad \alpha = R - \frac{1}{2}R^3 + \frac{13}{24}R^5 - \frac{541}{720}R^7 + \frac{9509}{8064}R^9 - \frac{7231801}{3628800}R^{11} + \ldots$$

Wird dieser Werth für α in (1) eingeführt, so ist die erhaltene Reihe in Wirklichkeit nicht verschieden von einer Reihe, die schon von Keill

- Kapteyn proposed a new series expansion.
- He published it in *Copernicus* in 1883.
- However, gain was modest (if there was any gain at all).

2. Higher order sine functions.

- His older brother Willem Kapteyn also studied in Utrecht under Grinwis (but thesis on vibrating plates).
- Appointed same day professor of mathematics in Utrecht.
- Together they extensively studied higher order sine functions.
- That was more Willem's interest, so Jacobus' contribution probably small.
- Ironic: Kapteyn series useful for Kepler's equation.

Regular sine functions.

$$\sin x = \sum_{n-0}^{\infty} \frac{(-1)^n x^{2n+1}}{(2n+1)!} = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \ldots.$$

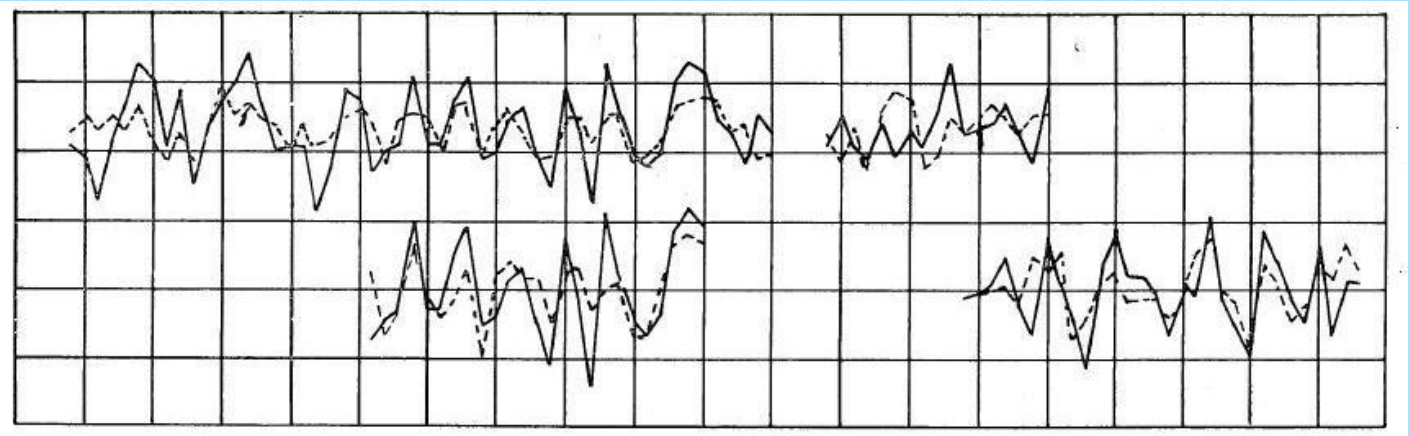
$$\cos x = \sum_{n-0}^{\infty} \frac{(-1)^n x^{2n}}{(2n)!} = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots.$$

Higher order sine functions.

$$\varphi_\mu(x) = \sum_{n=0}^{\infty} \frac{x^{kn+\mu}}{(kn+\mu)!} = \frac{x^\mu}{\mu!} + \frac{x^{\mu+k}}{(\mu+k)!} + \ldots.$$

$$\psi_\mu(x) = \sum_{n=0}^{\infty} \frac{(-1)^n x^{kn+\mu}}{(kn+\mu)!} = \frac{x^\mu}{\mu!} - \frac{x^{\mu+k}}{(\mu+k)!} + \ldots.$$

3. Tree rings.



1770 1880

- He looked for meteorological equivalents of Saros cycles.
- However, meteorological records were very too sparse and too recent, so he used tree rings to extend time sequence.
- He did find a correlation with number of wet days and periodicity of 12.4 years (unrelated to solar cycle).
- First published in 1909 in *Pasadena Star News*.

4. Absolute declinations.

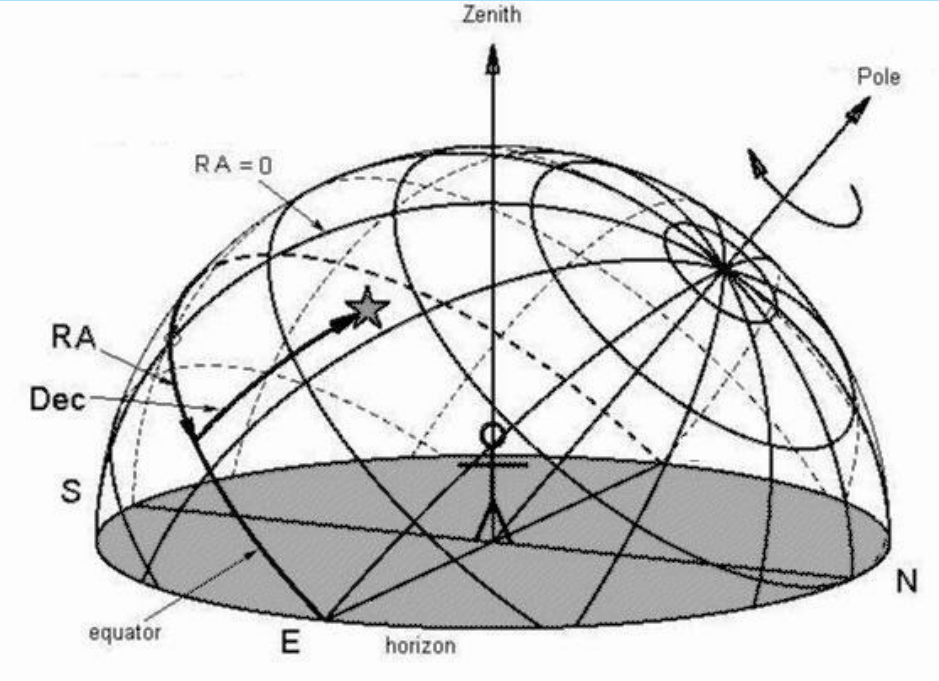
- Declinations (and polar height) were very inaccurate.
- Due to unknown amounts of flexure in the telescope and refraction ('bending') of light in the atmosphere.
- Another *Copernicus* paper in 1883:

UEBER EINE METHODE DIE POLHÖHE MÖGLICHST FREI VON SYSTEMATISCHEN FEHLERN ZU BESTIMMEN.

Von Professor J. C. KAPTEYN.

I. *Einleitung.*

Es ist eine sehr bekannte Sache, dass zwischen den Resultaten für die Declinationen der Fundamentalsterne, welche an verschiedenen, auch der best ausgestatteten Sternwarten, erhalten werden, Unterschiede bestehen, die weit ausser den Grenzen liegen, welche man, in Rücksicht auf die Uebereinstimmung der einzelnen, an der nämlichen Sternwarte angestellten Beobachtungen, erwarten müsste. Diese Erscheinung ist vermuthlich dem Zusammenwirken mehrerer Ursachen zuzuschreiben, und es verdienen hier wahrscheinlich das Mangelhafte unserer Kenntniss der Strahlenbrechung und der Biegung des Rohres und der Kreise in erster Linie genannt zu werden. Besonders auch in den letzten Jahren

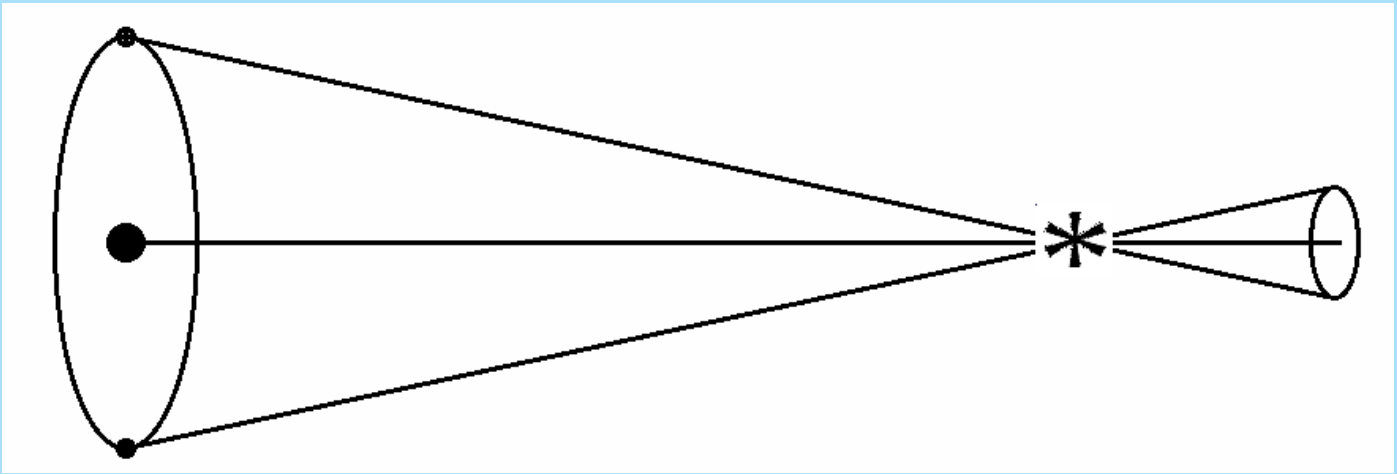


- Classical method; Measure declination (Decl) and right ascension (RA) from altitude and time of meridian passage.
- Height (altitude) of the pole from altitude of two passages of circumpolar stars.

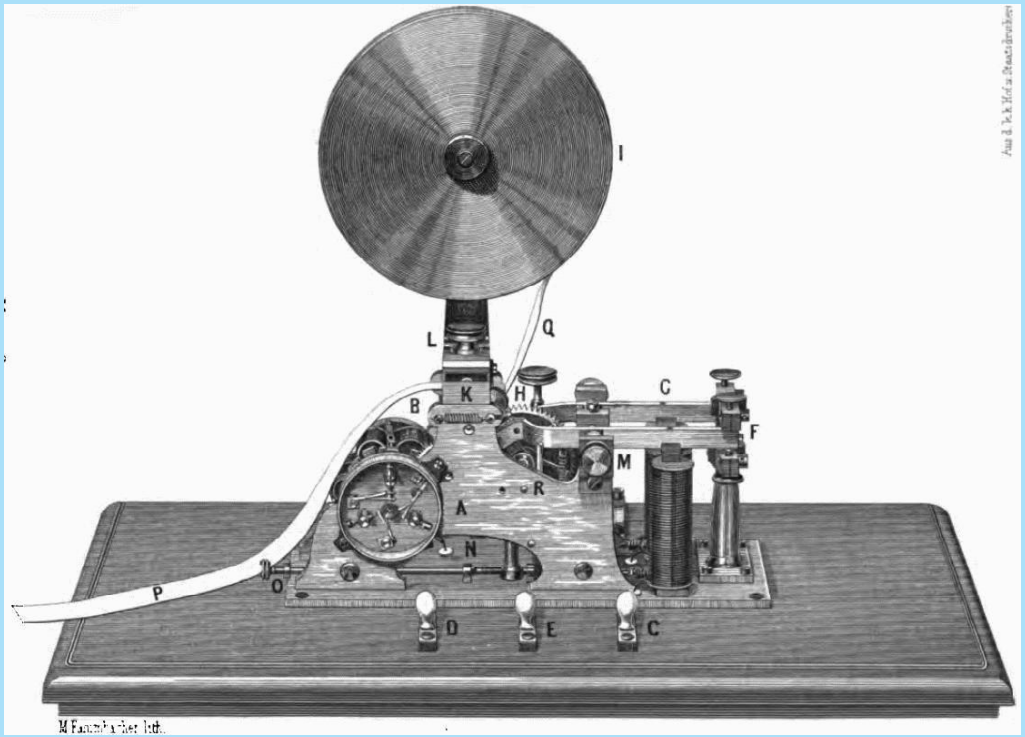
- Kapteyn's method involved measuring only azimuths and timing of prime vertical passage or altitude differences of two stars with roughly same altitude at the meridian.

- Van de Sande Bakhuyzen allowed Kapteyn test the idea with the Universal Instrument at Leiden.
- This was during the summer of 1882.
- The method was shown to work and paper was published in 1883.

5. Trigoniometric parallaxes.



- Kapteyn started a program to measure annual parallaxes by differential meridian timing measurements.
- This was felt to be too difficult.
- If parallax is 0.1 arcsec and its declination 50°, then parallax corresponds to time difference of 0.02 seconds of time.



- So you need extremely accurate timings.
- Only possible with many repeated measurements.
- Kapteyn used a 'Registrir-Apparat' or strip recorder on the Leiden meridian circle (spring 1885, Christmas 1885 & 1886, and spring 1887).

- He selected 15 stars with high proper motion that may be not too distant.
- Results published in Astronomische Nachtichten (preliminary) in 1889 and in Annalen van de Sterrewacht te Leiden in 1891.

Star	$p_{\rm Kapteyn}$ milli-arcsec	HD	$p_{\rm modern}$ milli-arcsec	Remarks
BB VII 81 (pr.)	74 ± 27	79210	172.06 ± 6.31	Flare star; binary
		79211	156.45 ± 8.58	Flare star; binary
θ Ursa. Maj.	52 ± 26	82328	74.19 ± 0.16	Spectroscopic binary
BB VII 85	64 ± 22	84031	54.89 ± 0.92	Variable star
20 Leon. Min.	62 ± 29	86728	66.46 ± 0.32	High proper-motion star
BB VII 89	176 ± 24	88230	205.21 ± 0.34	Flare star
BB VII 94	101 ± 26	90508	43.65 ± 0.43	High proper-motion star
BB VII 95	38 ± 27	91347	26.48 ± 0.59	High proper-motion star
Lal. 20670	-6 ± 28	92855	26.84 ± 0.50	Star in double system
BB VII 104	428 ± 30	95735	392.64 ± 0.67	Flare star
BB VII 105	168 ± 27	–	206.27 ± 1.00	High proper-motion star
BB VII 110	30 ± 27	101177	43.01 ± 0.73	Spectroscopic binary
BB VII 111	16 ± 32	102158	20.29 ± 0.70	Star in double system
BB VII 112	139 ± 26	103095	109.99 ± 0.41	High proper-motion star
BB VII 114	-28 ± 42	104556	17.5 ± 0.51	High proper-motion star
BB VII 119	56 ± 34	105631	40.77 ± 0.66	High proper-motion star

This really is very, very good!!

Cape Photographic Durchmusterung

- The usual view is that Kapteyn one day read a paper by David Gill, who was planning a southern photographic Durchmusterung from the Cape, and that this made him decide impulsively to offer his help, and that this, for Gill, came completely out of the blue.
- Henriette Hertzsprung-Kapteyn:
  - *'During the Christmas holidays of 1885 he read in Leiden in an astronomical journal an article by David Gill, Her Majesty's astronomer at Cape of Good Hope, about a major project he wanted to undertake. He was planning to produce a catalog of the stars in the southern hemisphere down to magnitude 10 and using photographic methods.'*
  - *'Instantly, the thought occurred to Kapteyn: 'Here is my chance!'. He immediately wrote to Gill and offered to collaborate with him.'*

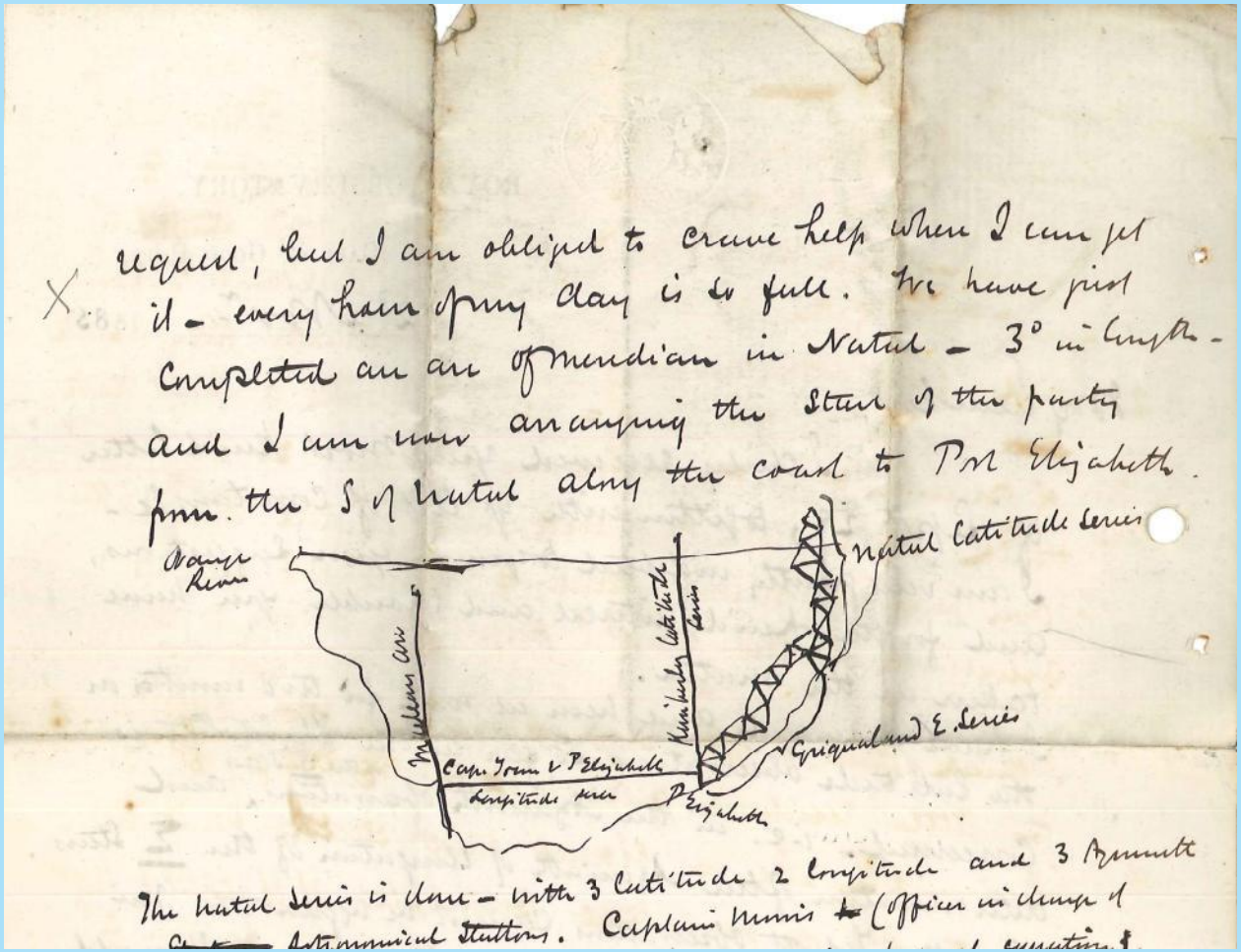
- Gill had photographic plates taken of the Great Comet of 1882.
- He noted the large number of stars on these photographs.
- He decided that this would be a quick way of making a southern Durchmusterung.
- But he did not have the manpower to measure plates.

Actually:

- On April 30, 1884 Kapteyn had written to Gill and sent him his *Copernicus* paper on polar height and Gill answered on September 12, 1884.
- Kapteyn asked Gill to work together on a project to measure the altitude of the pole from the Cape.
- Gill agreed and Kapteyn sent a list of suitable stars on December 10, 1884 and Gill answered on January 18, 1885 (18 pages) laying out an observing strategy.
- The Annual reports of the Royal Observatory at Cape of Good Hope mentions ongoing observations between 1885 and 1890.
- No real publication has resulted, but they corresponded and collaborated well before the CPD.

- Gill early on discusses his plans for a Durchmusterung with Kapteyn.
- On April 3, 1885:
  - *'I shall, I hope, write you next mail on some other points. Meanwhile I send you some of our first attempts in producing a photographic Durchmusterung of the southern Heavens. I hope to improve very greatly on this attempt. If you have any suggestions to give me on the best plans of measurement I shall be glad and grateful to have them. An accuracy of $\pm 0''.2$ would be ample.'*

- On May 15, 1885:
  - *'We have now nearly 200 pictures towards a photographic Durchmusterung, each about 6° on the side. The plans of measurement & reduction I am still considering, and should greatly value your suggestions. I have not yet decided whether to adopt a system of position angles and distances or rectangular coordinates. I should be glad if you could think this matter over as to which presents the simplest method for converting measures into RA & Decl. with an accuracy of 0!.2 on the great circle.'*
- These is all really very close to solliciting Kapteyn's help.

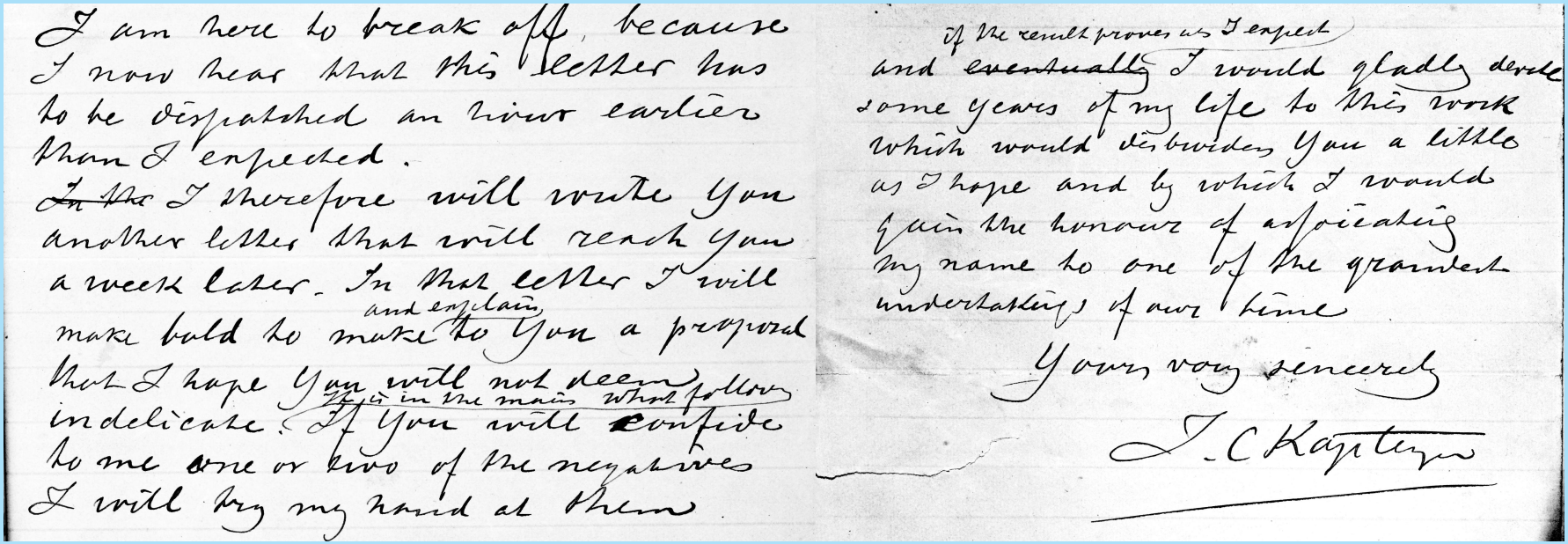


request, but I am obliged to crave help when I can get it - every hour of my day is so full. We have just completed an arc of meridian in Natal - 3° in length - and I am now accompanying the staff of the party from the S of Natal along the coast to P.E. Elizabeth.

The Natal series is done - with 3 Latitudes 2 Longitudes and 3 Azimuth Astronomical Stations. Captain Morris (Officer in charge of

- Gill on November 2, 1885:
  - *'I would ask you a a great favour, to enter all your alterations, corrections and suggestions in red ink upon the lists I sent you, and return them to me. I will then send you a clean copy of the finally adopted list. It may seem to you absurd to make such a request, but I am obliged to crave help where I can get it – every hour of the day is so full.'*
  - *'So do not think I am neglecting astronomy. I am only rather overbusy at present, and would ask you to assist me in the way I propose.'*

- Kapteyn took the bait on December 16, 1885:



I am here to break off, because I now hear that this letter has to be dispatched an hour earlier than I expected.
~~In the~~ I therefore will write You another letter that will reach You a week later. In that letter I will make bold to make to You and explain a proposal that I hope You will not deem indelicate. It is in the main what follows If You will confide to me one or two of the negatives I will try my hand at them

if the result proves as I expect
and eventually I would gladly devote some years of my life to this work which would distinguish You a little as I hope and by which I would gain the honour of associating my name to one of the grandest undertakings of our time

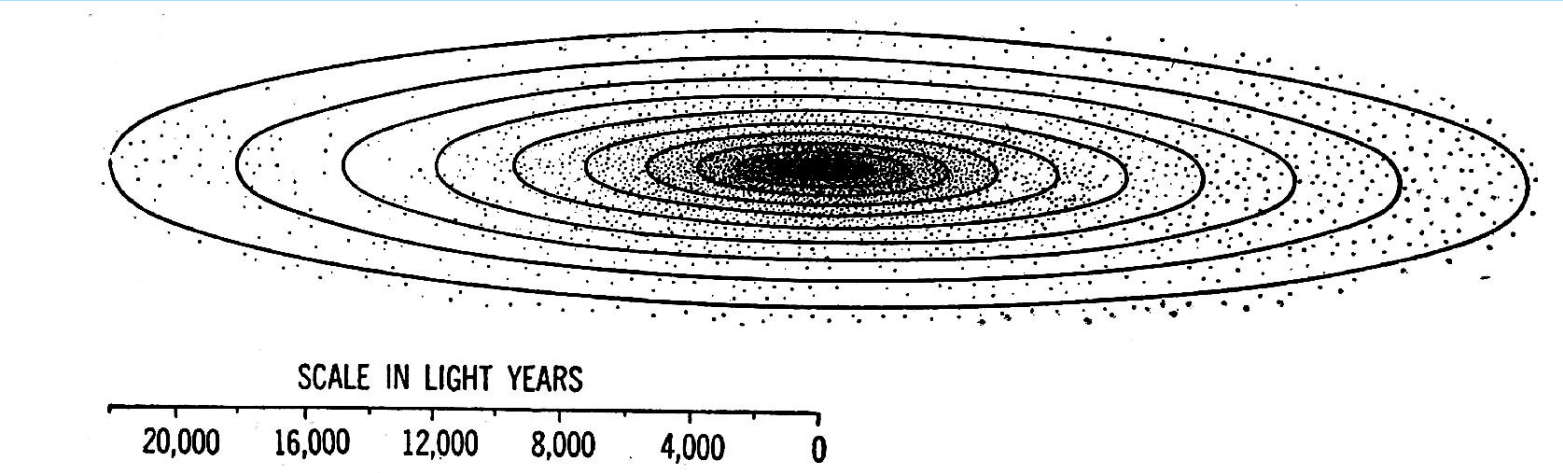
Yours very sincerely

J. C. Kapteyn

- Kapteyn wrote:
  - *'If you will confide to me one or two of the negatives I will try my hand at them, and, if the result proves as I expect, I would gladly devote some years of my life to this work, which would disburden you a little, as I hope, and by which I would gain the honour of associating my name with one of the grandest undertakings of our time.'*
- This was written in a hurry and he promises to write more very soon.
- He asked van de Sande Bakhuyzen for advice, who tried to discourage Kapteyn.

- Kapteyn wrote Gill again on December 23, 1885:
  - *'Now, after your success in Stellar photography, and especially after your letter in which you tell me "I am obliged to crave help where I can get it," it has occurred to me that by measuring and reducing your photographs I could contribute very effectually towards the success of an enormous and eminently useful undertaking.'*
- Kapteyn's astronomical work on absolute declinations and polar altitudes was the key in establishing collaboration with Gill.
- Gill then succeeded in enlisting Kapteyn for his photographic Durchmusterung.

The Kapteyn Universe



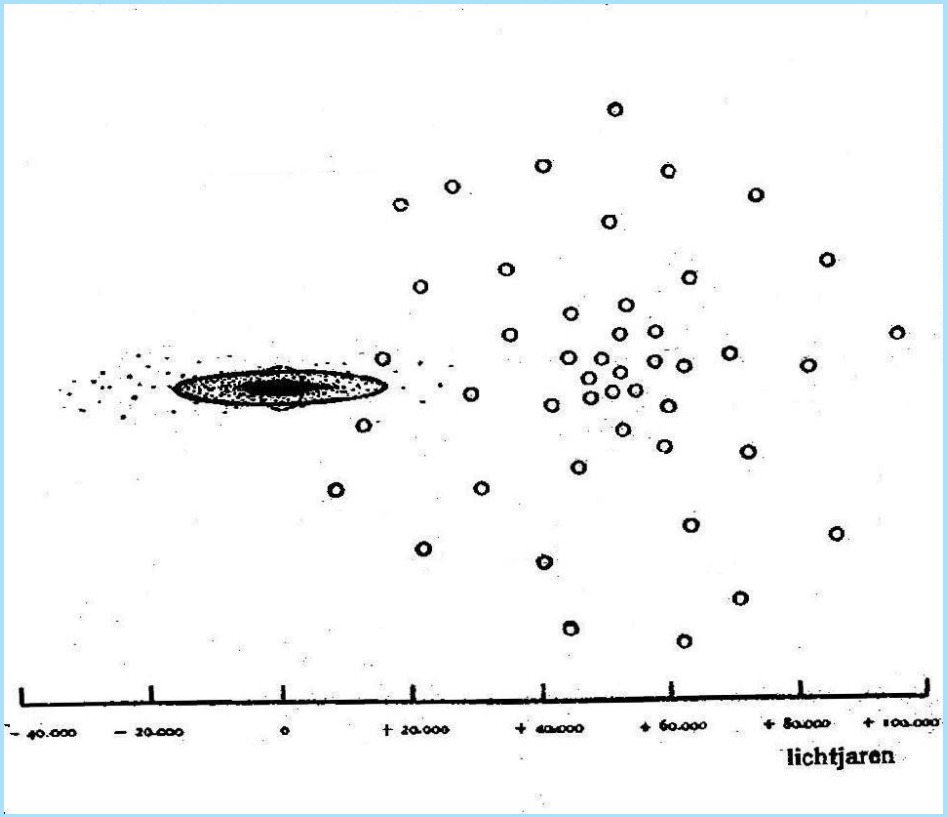
The Kapteyn Universe (coined by Jeans) was presented in two papers in 1920 and 1922:

- **On the Distribution of the Stars in Space Especially in the High Galactic Latitudes** by Kapteyn and van Rhijn.[4]
- **First Attempt at a Theory of the Arrangement and Motion of the Sidereal System** by Kapteyn.[5]

[4] Ap.J. 52, 23-38, 1920; also Contr. Mt. Wilson Obs., No. 188.
[5] Ap.J. 55, 302- 328, 1922; also Contr. Mt. Wilson Obs., No. 230.

- Kapteyn and van Rhijn (1920) presented a model for the distribution of stars in space.
- Kapteyn (1922) presented a model for its dynamics ('mechanics').

- Vertical dynamics based on random motions: correct.
- Horizontal based on rotation + random motions: incorrect.



(Figure from de Sitter, attributed to Oort.)

- This contrasted with Harlow Shapley's globular cluster distribution
- Kapteyn had neglected interstellar absorption; system had diameter of $\sim$ 15 kpc.
- But Shapley's distances too large also because of absorption; center at $\sim$ 20 kpc.
- Often seen as winner-loser:
  - Kapteyn's Universe was wrong because of his unfounded neglect of interstellar extinction, in contrast to Harlow Shapley's brilliant work on globular clusters.

- Jan Hendrik Oort's 1926 acceptance lecture as 'privaat-docent' in Leiden: *Non-light-emitting matter in the Stellar System*.[a]
- Assumption of absorption in space the 'least contrived' solution to Shapley – Kapteyn disagreement.

Jan and Mieke Oort after thesis defense.

[a] Openbare les: *'Niet-lichtgevende materie in het sterrenstelsel'*.

- Oort found differential rotation and the Oort constants in 1928.
- Improved Kapteyn's analysis to derive the Oort limit in 1932.

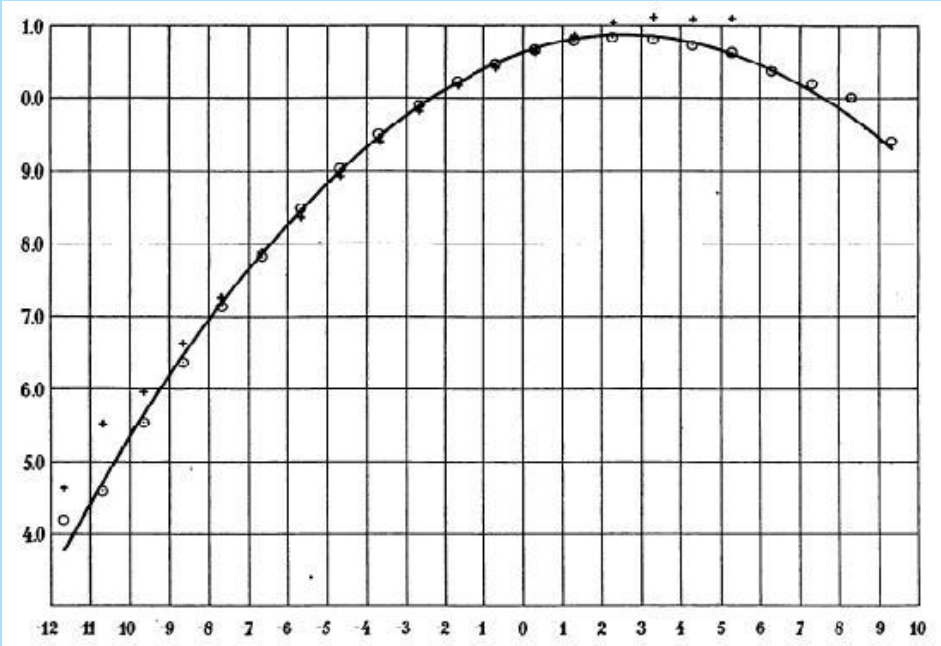
What would have happened had Kapteyn lived an extra 10 years?

- Kapteyn worried very much about extinction, and wrote four papers on this (1 in A.J. and 3 in Ap.J.)
- In 1904 George Comstock had deduced from the star ratio that absorption was very strong.
- He deduced 0.18 mag per unit distance (corresponds to parallax of $0''.1$), or 18 mag/kpc.
- Kapteyn agreed there was extinction.
- From luminosity curve as a function of distance he found much less than Comstock.
- Sun in special position (local minimum) if Comstock were right.
- In 1909 Kapteyn proposed that scattering means reddening.
- Deduced 0.003 mag per unit distance in photographic band.
- Actually not too bad compared to present.

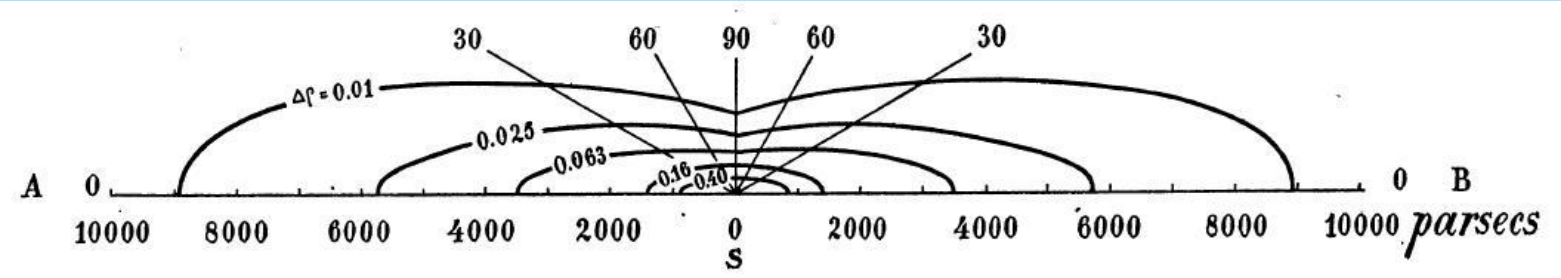
- The turning point came with Shapley's 1916 work on M13.
- If Kapteyn were correct, the stars should be 2.5 magnitudes redder than observed.
- Shapley concluded that space was transparent.
- This was widely accepted as the final word.

- Kapteyn & van Rhijn (1920):
  'Now that, after so many years of preparation, our data seem at last to be sufficient for the purpose, we have been unable to restrain our curiosity and have resolved to carry through completely a small part of the work ...'

- First determined the luminosity curve.



Kapteyn hated the 'ugly' term parsec, but did adopt it and redefined absolute magnitude to distance of 1 pc.



- Kapteyn & van Rhijn (1920):
- Solved counts for star density as function of distance from Sun.
- Performed this process for latitudes 0°, 30°, 60° and 90°.
- Resulting system had radius of 9 kpc, but based on extrapolations..

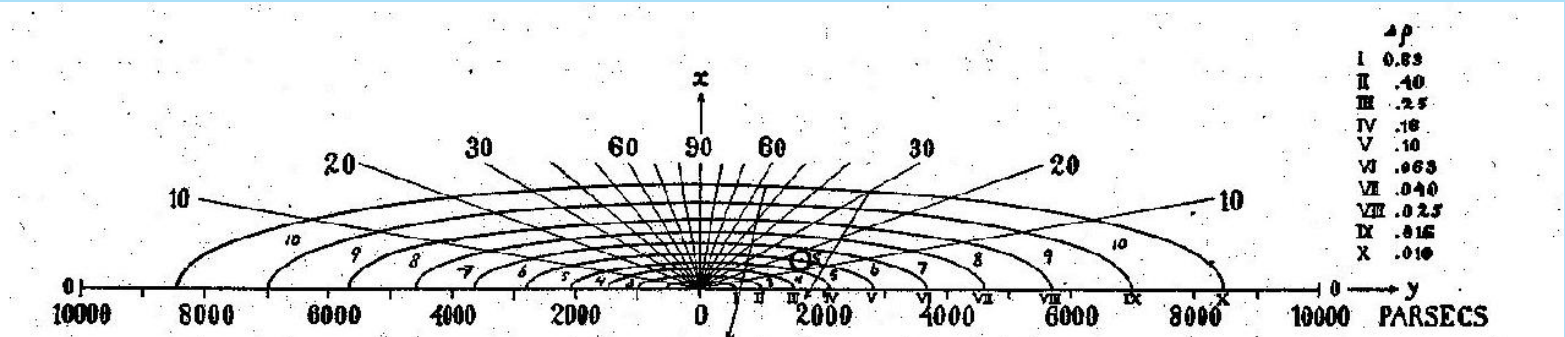


FIG. 1

- Kapteyn's (1922): *'First attempt at a theory of the arrangement and motion of the Sidereal System'*:
- First he fitted ellipsoids and then calculated gravitational potential.
- In the vertical direction assumed hydrostatic equilibrium with velocity dispersion 12 km/s.
- *'Mass of dark matter in the Universe' ... 'cannot be excessive'*.
- Fit Kapteyn data with isothermal sheet: $z_\circ = 650$ pc.
- Modern: $z_\circ \sim 700$ pc and velocity dispersion about 17 km/s.

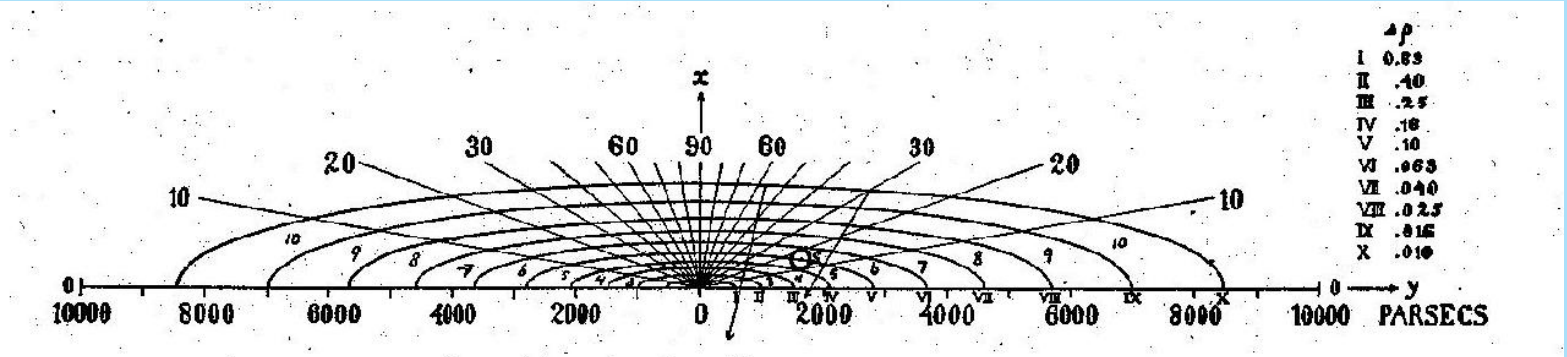


FIG. 1

- Kapteyn (1922) in the horizontal direction.
- Add centrifugal force: between 0.5 and 1.5 kpc from center rotation of 20 km/s required.
- That meant that the rotation was seen in the Star Streams!
- Sun cannot be in center; chose 650 pc radial displacement.
- From (son-in-law) Ejnar Hertzsprung from distribution of Cepheids: vertical displacement 38 pc.

- Kapteyn's Universe was a consistent, dynamical system.
- It explained both the distribution and the motions.
- What was wrong were two parts:
  1. Transparency of space – Observational evidence was Shapley's colors of M13 stars.
  2. Star Streams versus velocity ellipsoid – Observational evidence was very different make-up in terms of spectral types.
- Kapteyn constructed his model just before retirement and died soon afterwards,
- Important developments occurred only a few years later.
- He left Dutch astronomy in the hands of protégé's like van Rhijn in Groningen and de Sitter and Hertzsprung (and later Oort) in Leiden.

The Kapteyn Astronomical Laboratory and the Mt. Wilson Kapteyn Cottage.

THE END