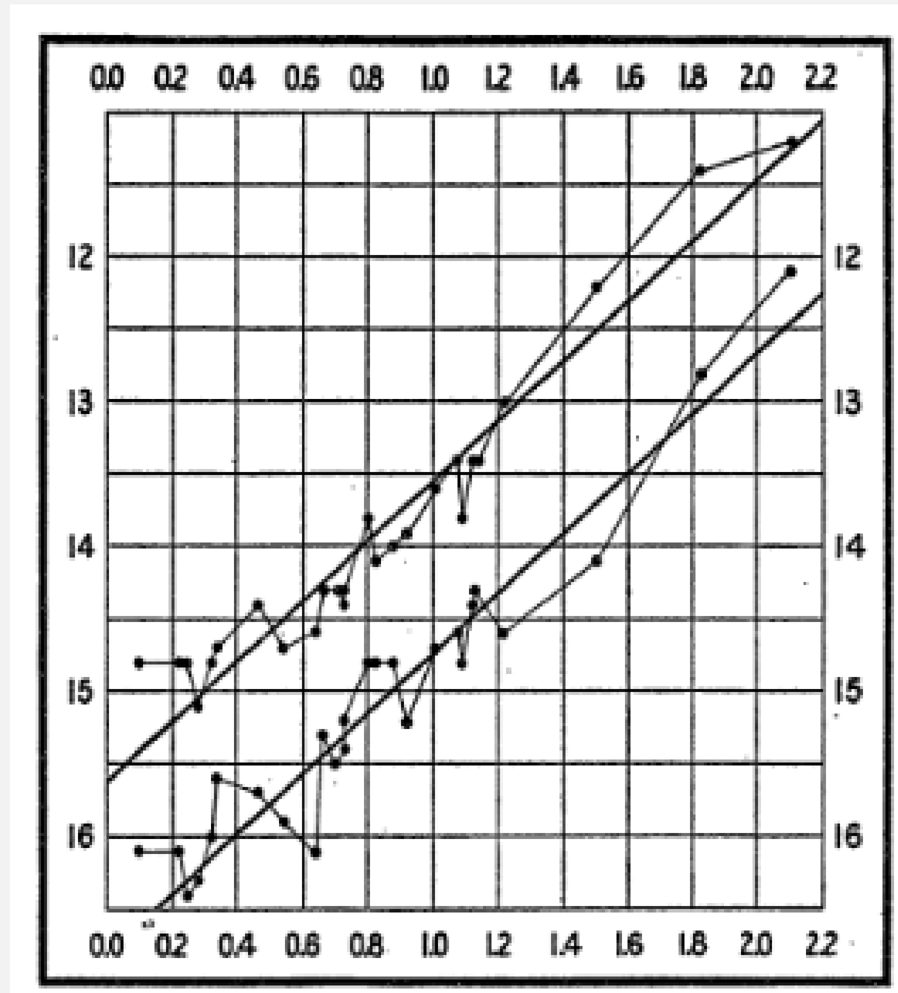
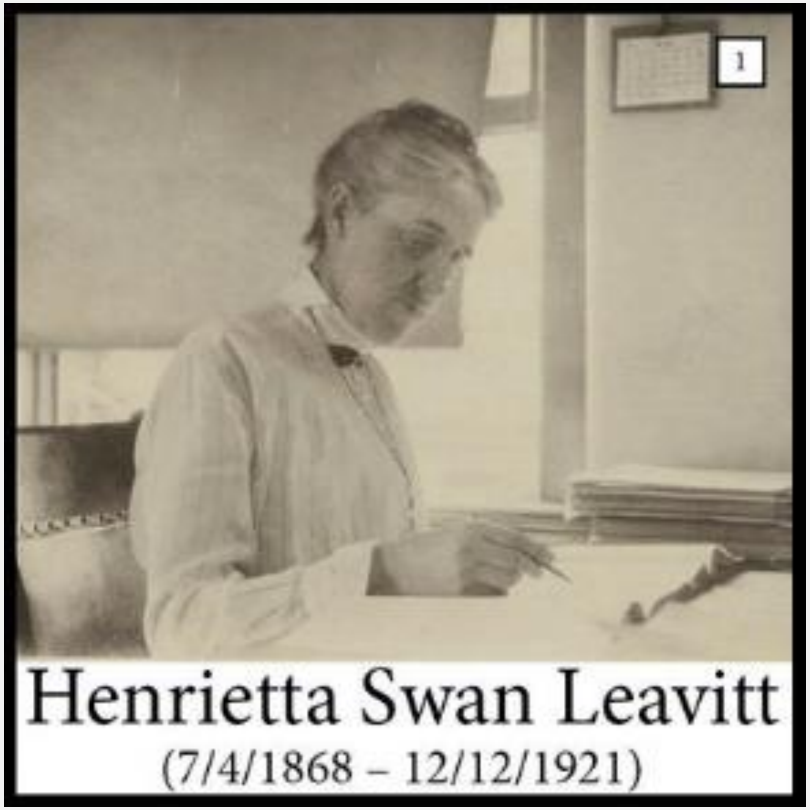
Henrietta S. Leavitt e la scoperta della relazione periodo – luminosità delle cefeidi: strumenti e tecniche

Paolo Paura – INAF-OACN

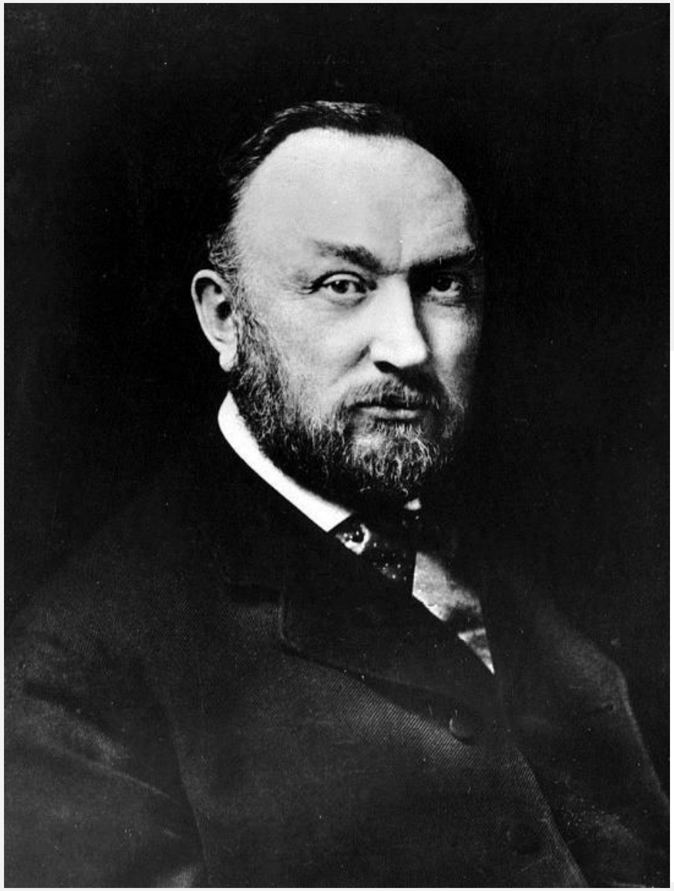
Astromeeting 14 dicembre 2022





Studi: Graduated Radcliffe College, Cambridge, Massachussetts, nel 1892

Harvard College Observatory, Cambridge, Massachussetts, nel 1893



Edward Charles Pickering (1846-1919)

Professor of Physics MIT : 1868
Harvard Director : 1876 - 1918

As Director of the Observatory he showed great administrative ability and secured a large financial support for his projects, the endowment growing from a few hundred thousand to a million dollars. Instead of venturing into the realm of speculative and picturesque astronomy, he was content to be what he called himself "a collector of astronomical facts," the interpretation of which he was perfectly willing to leave to the future. The posthumous value of the work of such men as Herschel and Argelander appealed especially to him and shaped the large investigations that he undertook, whose importance could not be completely revealed perhaps for centuries.

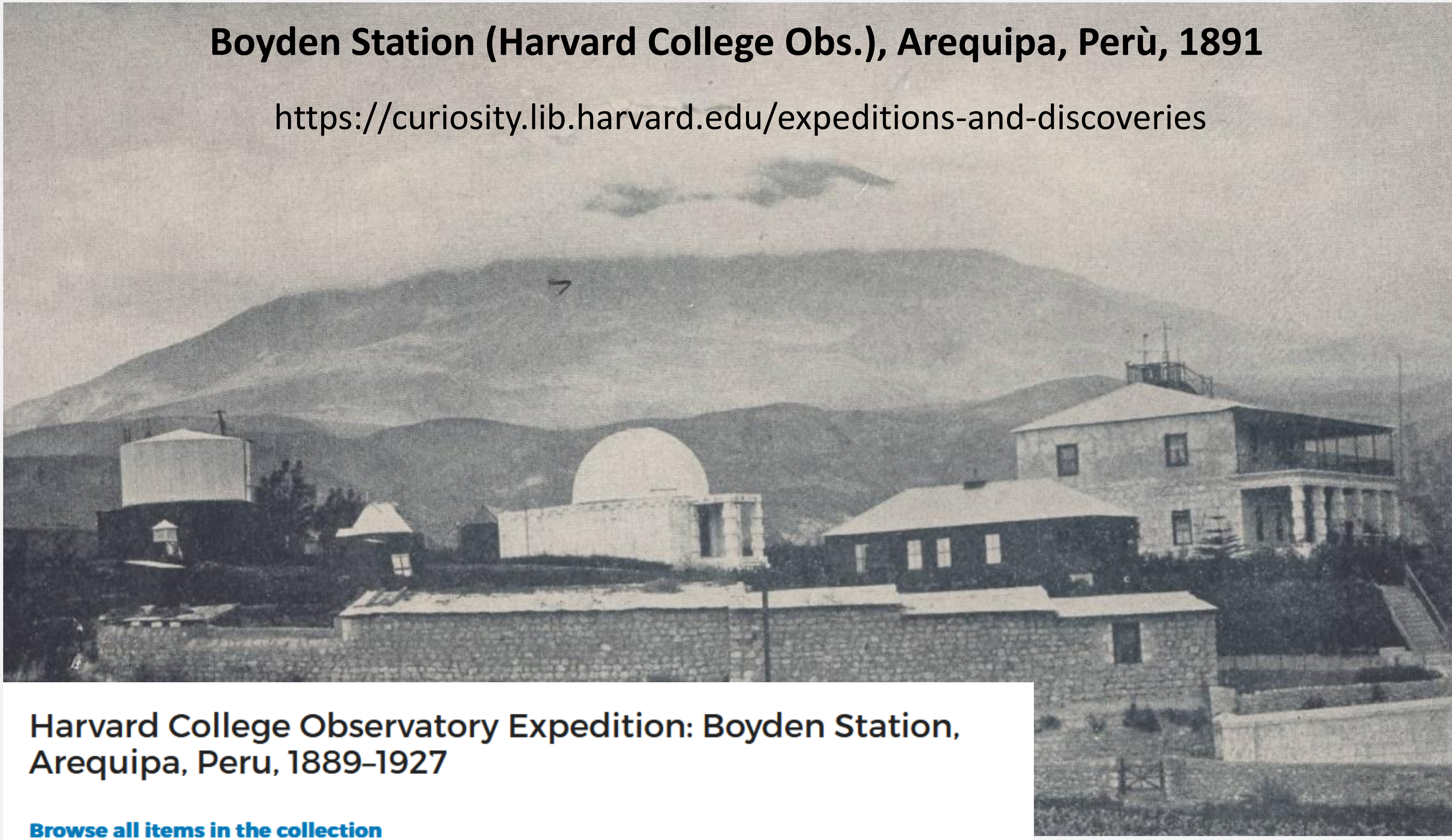
estratto da:

Edward Charles Pickering (1846-1919)
Author(s): Joel H. Metcalf
Source: *Proceedings of the American Academy of Arts and Sciences*, Vol. 57, No. 18 (Nov., 1922), pp. 502-506
Published by: American Academy of Arts & Sciences

Fu uno dei primi astronomi a sperimentare nel 1882 la fotografia astronomica a grande campo

Boyden Station (Harvard College Obs.), Arequipa, Perù, 1891

https://curiosity.lib.harvard.edu/expeditions-and-discoveries



Harvard College Observatory Expedition: Boyden Station, Arequipa, Peru, 1889–1927

Browse all items in the collection

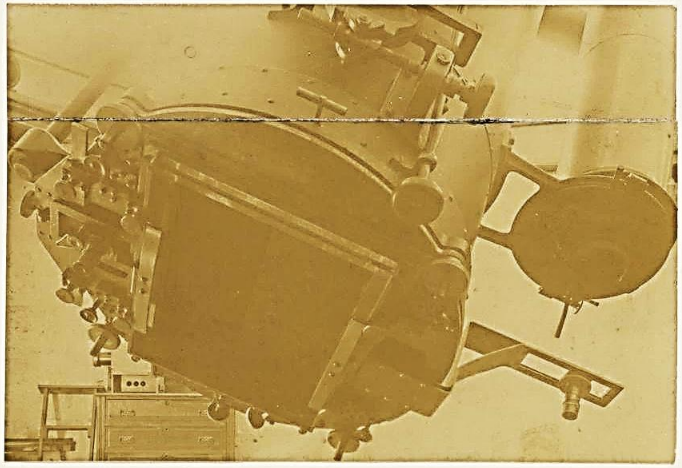
The Harvard College Observatory (HCO) appointed **Solon I. Bailey** to find a site for a new observatory in the southern hemisphere. The goal of the new observatory would be to perform photographic surveys of the sky not visible from HCO's northern latitude. In 1890, Bailey established the Boyden Station near

Ø = 600 mm, F = 3430 mm - f/5.6

(curiosity.lib.harvard.edu/expeditions-and-discoveries)

Arequipa, Perù

Harvard University, Harvard University Archives, W432705_1



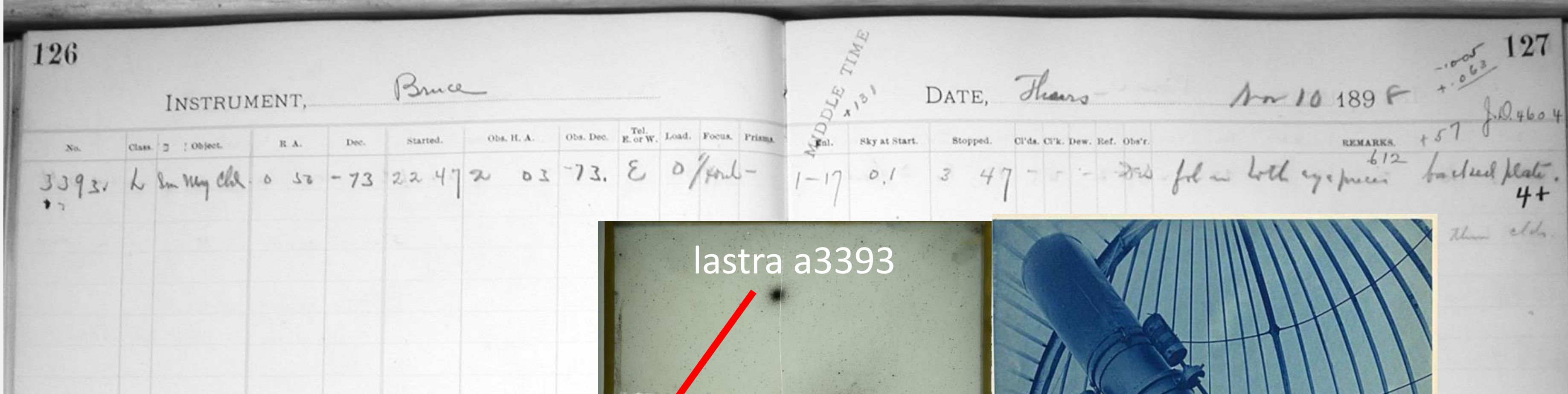
Plates 355 x 432 mm - F.O.V. 6º x 7º

Harvard University, Harvard University Archives, UAV_630_271_Album_3_mets

Harvard University, Harvard University Archives, W431784_1

Arequipa, Perù

Bache telescope (portrait lens)
Ø = 200 mm, F= 1118 mm - f/5.6
plates 200 x 254 mm - F.O.V. = 10^o x 13^o


126

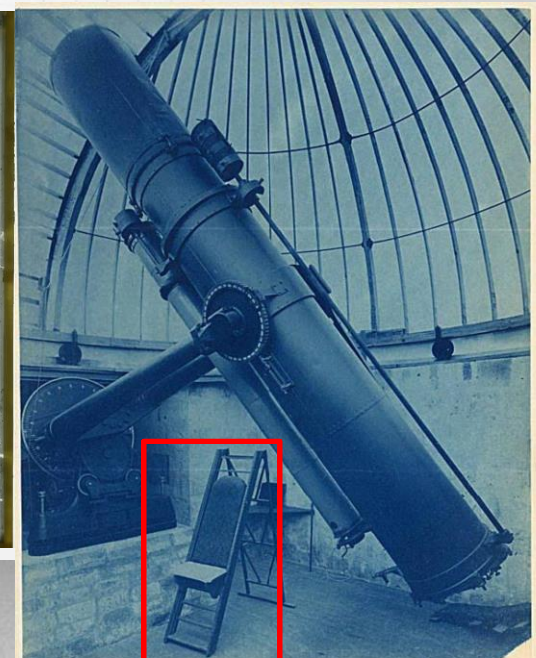
INSTRUMENT, Bruce

No.	Class.	Object.	R. A.	Dec.	Started.	Obs. H. A.	Obs. Dec.	Tel. E. or W.	Load.	Focus.	Prisma.
3393	L	Sm Mag Cld	0 58	-73	22 47	2 03	-73.	E	0/foul	-	

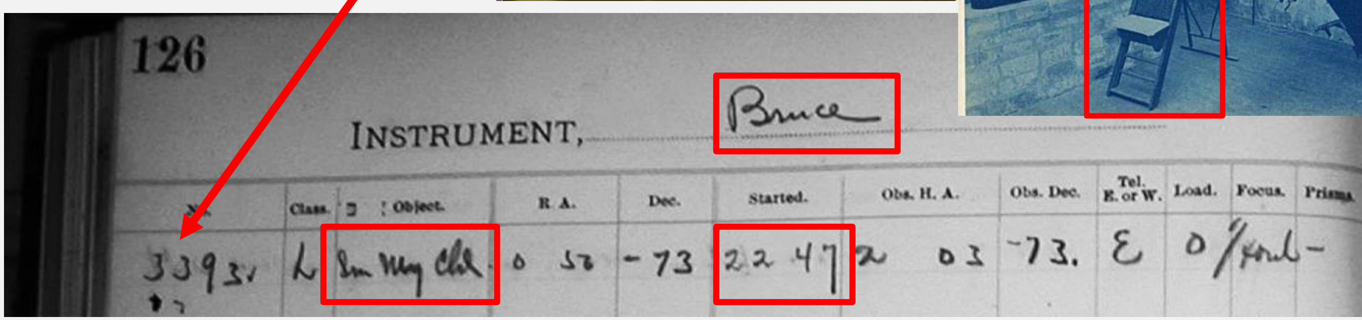
127

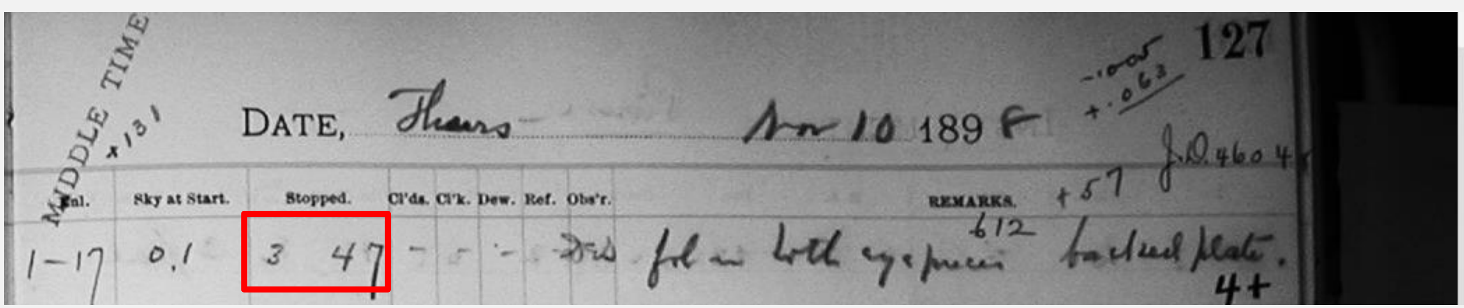
DATE, Thurs Nov 10 1898

Exposure Total.	Sky at Start.	Stopped.	Cl'ds.	Cl'k.	Dew.	Ref.	Obs'r.	REMARKS.
1-17	0.1	3 47	-	-	-		DFS	fol on both eye pieces backed plate. 4+



Logbooks delle osservazioni fotografiche ad Arequipa

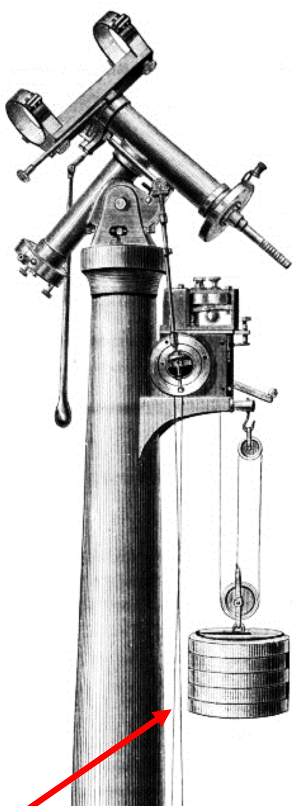




Motori equatoriali idonei alle lunghe esposizioni fotografiche

22 T. COOKE & SONS,

PORTABLE EQUATORIAL MOUNTINGS.



The work is very straining and fatiguing, because I have to expose each plate for two hours, controlling without intermission the driving clock by the guiding telescope. But this is only caused by the want of means to procure a larger lens and a better clock, and unfortunately there is little hope of obtaining them in Germany.

Heidelberg Observatory,
1892, September.

Estratto da: M. Wolf, Photographing Minor Planets,
Journal of the British Astronomical Association, 1892-93

Lowell Obs. 1930’s

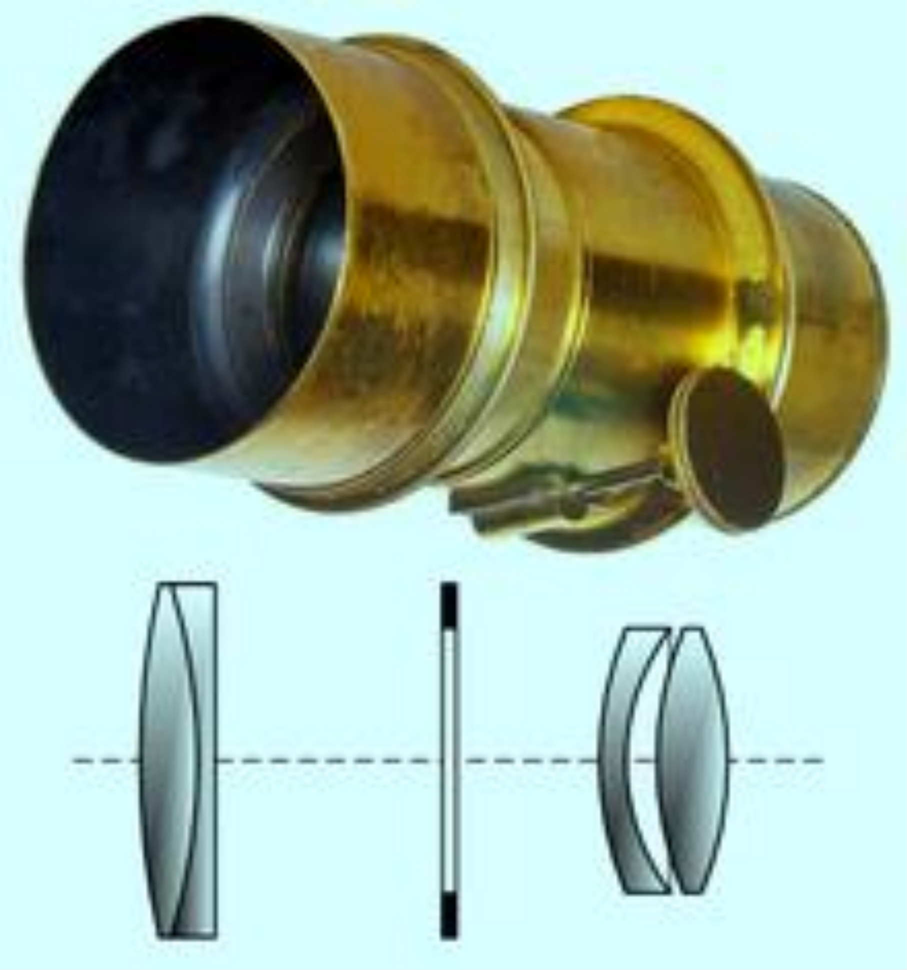
peso in caduta sostituito successivamente da motori elettrici

Lo stato dell'arte della fotografia astronomica

Dry plates – 1871
Sensibili al blu Δλ~ 4000 - 5000 Å
Max exp. = ore

Nascita della fotografia astronomica
di stelle e oggetti estesi diffusi

Lo sviluppo degli astrografi a lenti



Petzval *portrait lens* – 1840;
questi obiettivi fotografici a quattro lenti erano denominati “*doublets*”

I successivi sviluppi degli schemi ottici delle *portrait lenses*

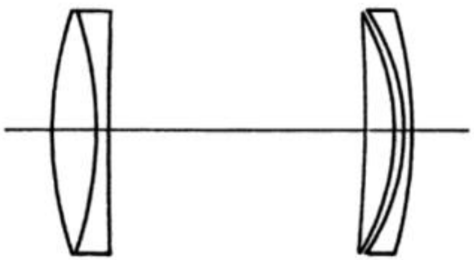


Figure 3.5. Dallmeyer's Patent Portrait lens.

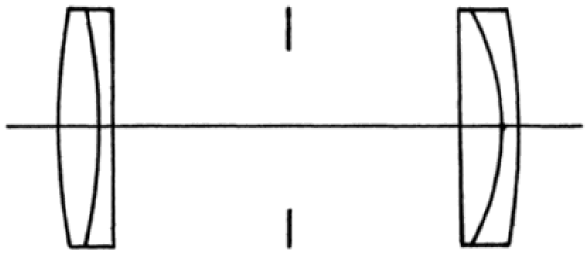


Figure 3.7. Voigtländer's portrait lens of 1878.

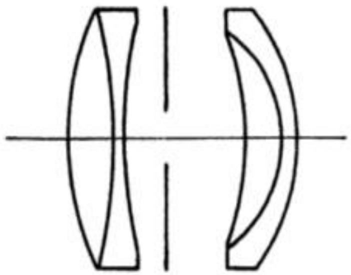


Figure 4.9. The Ross Doublet objective.

...

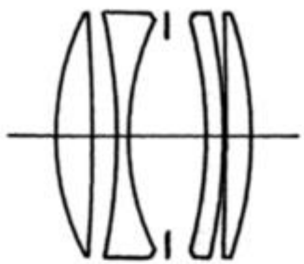
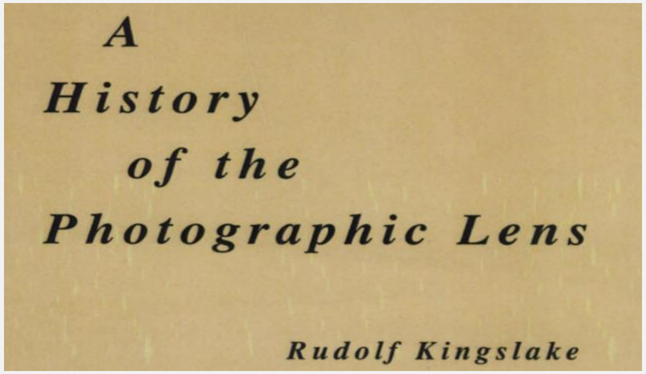
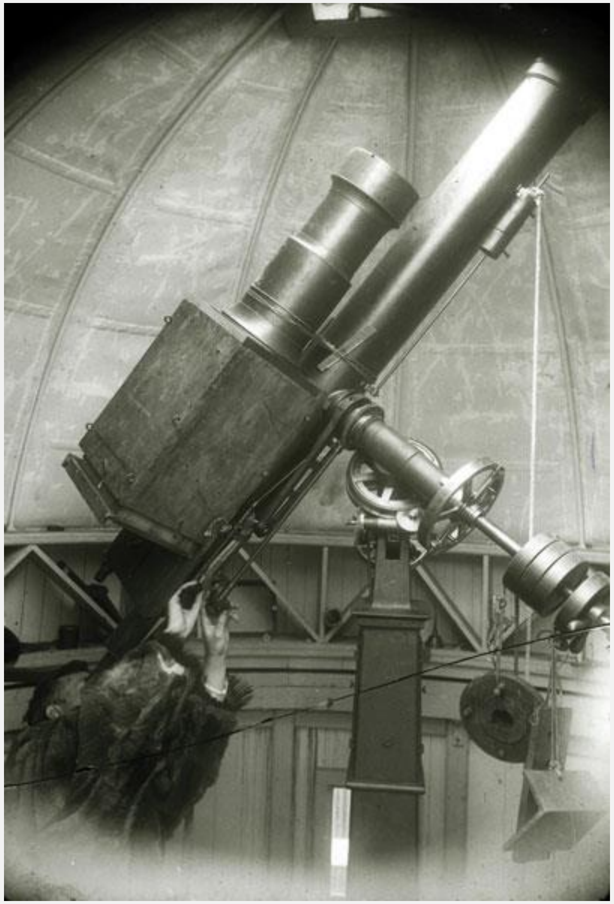


Figure 6.5. The Zeiss Unar.

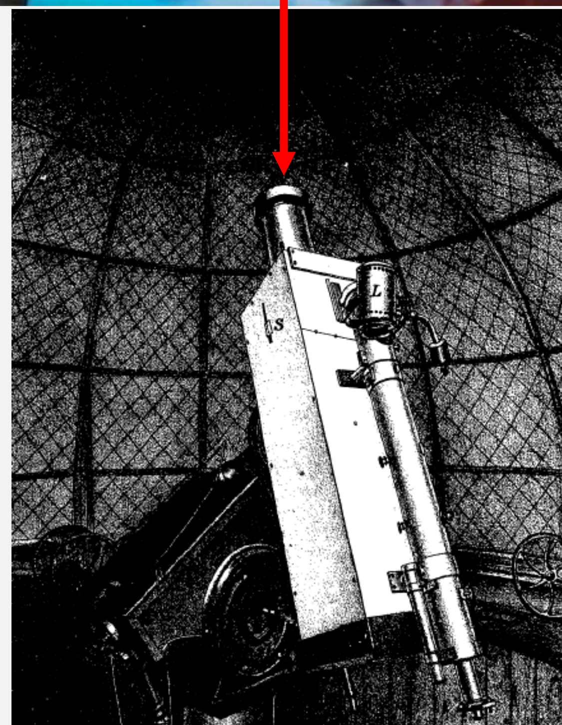
estratto da:



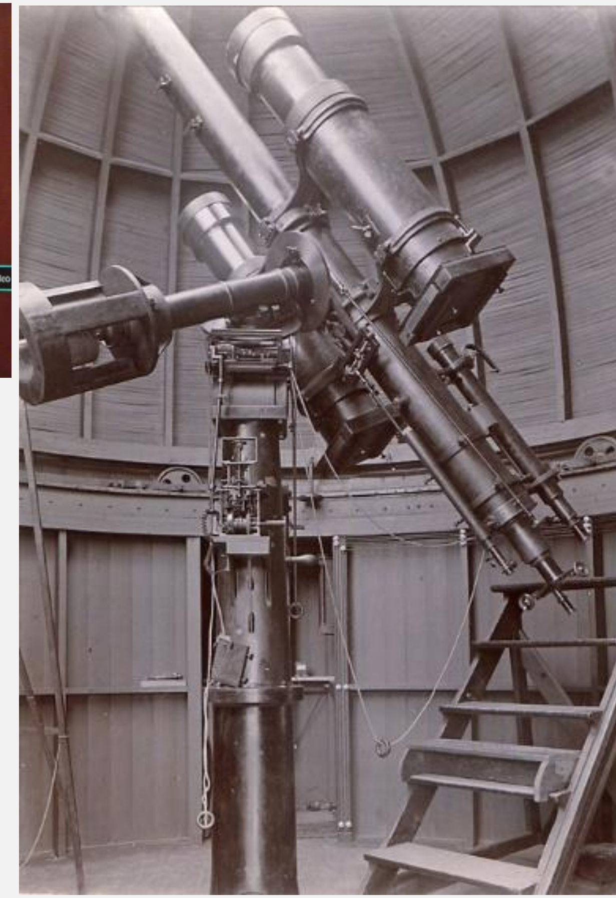
I primi utilizzi delle *portrait lenses* nella fotografia astronomica a grande campo



Willard lens Ø= 150 mm
Lick Obs.
(digitalcollections.library.ucsc.edu)



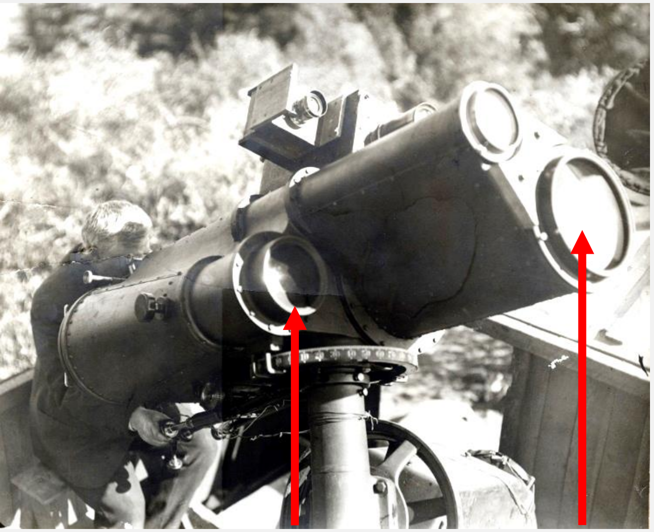
Ø = 150 mm, F = 1370 mm
F.O.V. = 6° x 6°
Cape of Good Hope Obs.



Max Wolf telescope Ø = 150 mm
F.O.V. = 12° x 8°
Heidelberg Obs.
(epsilon-lyrae.de)

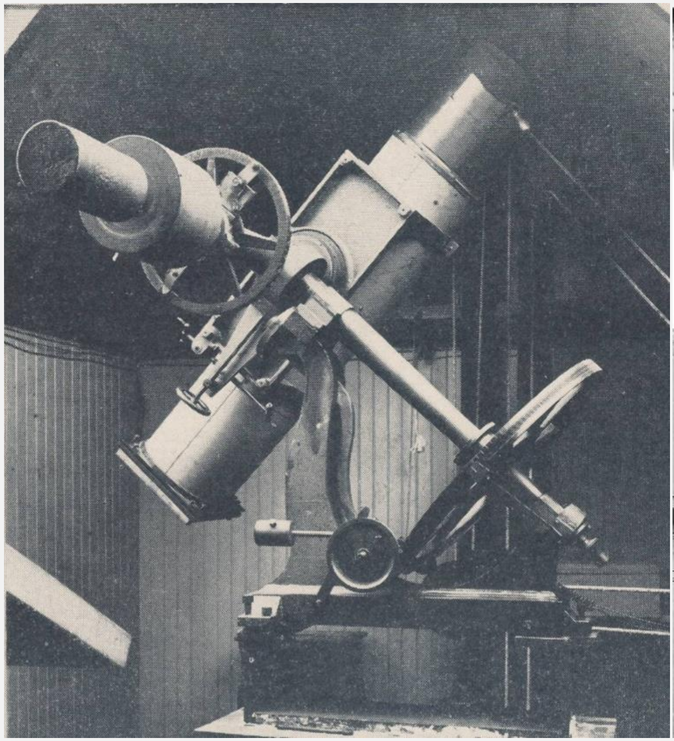
I primi astrografi

Doppio astrografo di Yerkes (Bruce telescope)



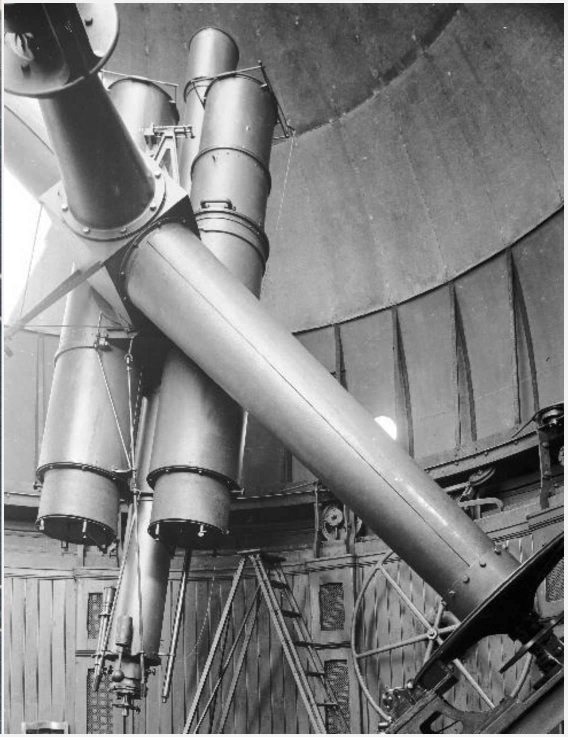
Ø = 250 mm ; F.O.V. 12° x 12°
Ø = 170 mm ; F.O.V. 12° x 11°
(Photoarchive.lib.uchicago.edu)

Astrografo Harvard Ø = 200 mm (Draper telescope)



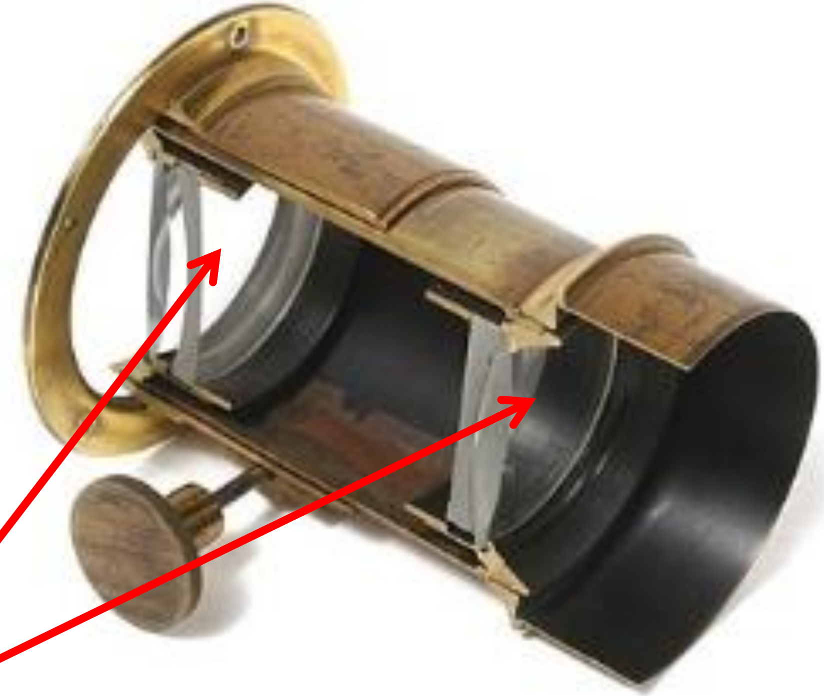
(library.cfa.harvard.edu/dasch-telescopes)

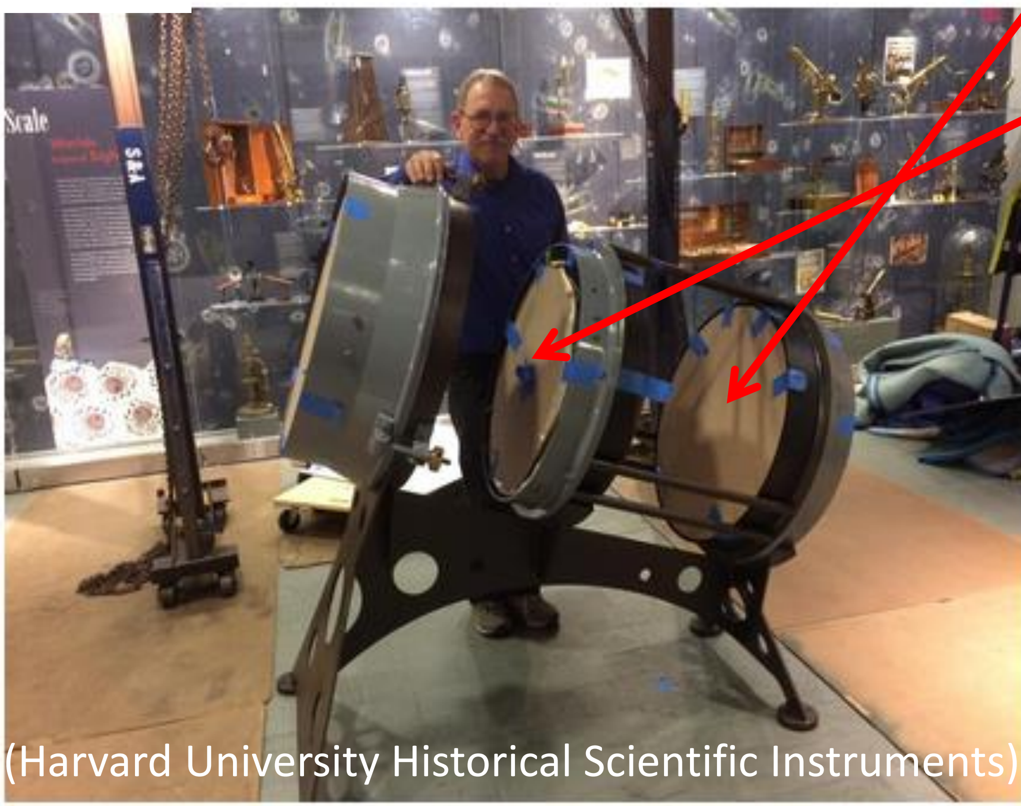
Doppio astrografo Heidelberg Ø = 400 mm (Bruce telescope)



(lsw.uni-heidelberg.de/projects/scanproject)

Bruce photographic telescope lenses and prism





(Harvard University Historical Scientific Instruments)

La scoperta di nuove variabili

Anno		**variabili note**
	1800	13
	1880	200
	1900	1000
	1950	11000

*Variable Stars of Short Period**.

In a recent communication to this Academy † the following classification of the variable stars was proposed :—

I. Temporary stars. Examples, Tycho Brahe's star of 1572, new star in Corona, 1866.

II. Stars undergoing great variations in light in periods of several months or years. Examples, *o Ceti* and *χ Cygni*.

III. Stars undergoing slight changes according to laws as yet unknown. Examples, *α Orionis* and *α Cassiopeiæ*.

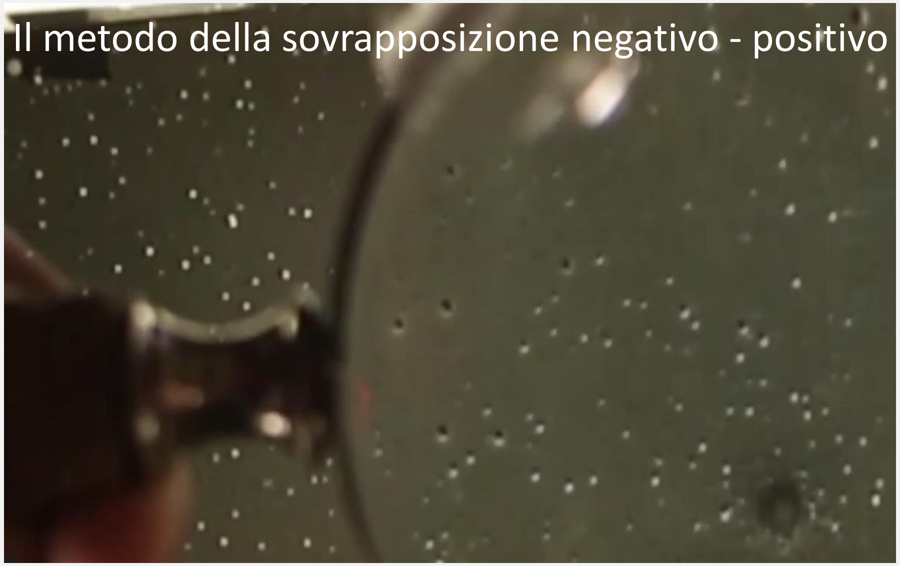
IV. Stars whose light is continually varying, but the changes are repeated with great regularity in a period not exceeding a few days. Examples, *β Lyræ* and *δ Cephei*.

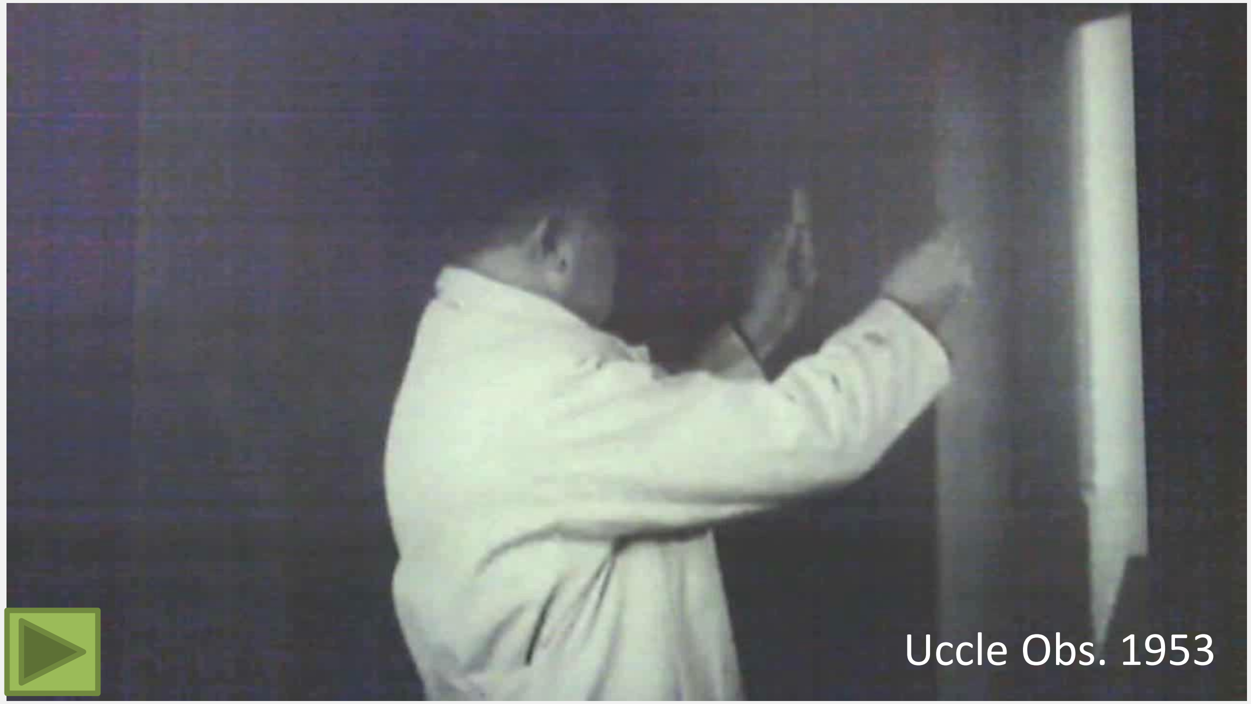
V. Stars which every few days undergo for a few hours a remarkable diminution in light, this phenomenon recurring with great regularity. Examples, *β Persei* and *S Cancri*.

A discussion was given, in the article referred to, of the stars of the last class. It was shown that in the case of *β Persei* at least, the observed variations could be very satisfactorily explained by the

E. Pickering, The Observatory, vol. 4, 1881

Strumenti e tecniche per la scoperta di nuove variabili





Leggìo dell’epoca per l’esame delle lastre fotografiche. Queste erano esaminate alla luce diffusa del cielo

Altri strumenti per la scoperta delle stelle variabili ma NON utilizzati ad Harvard

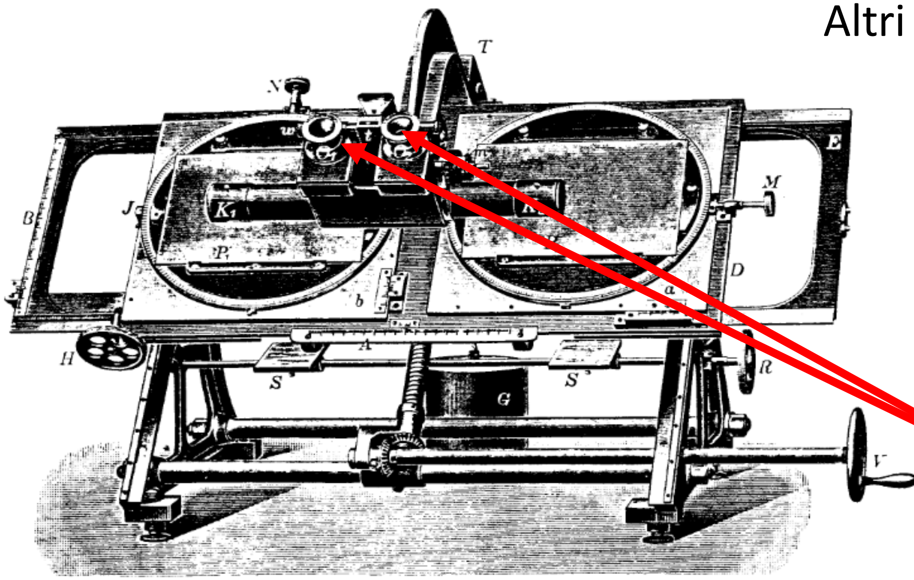
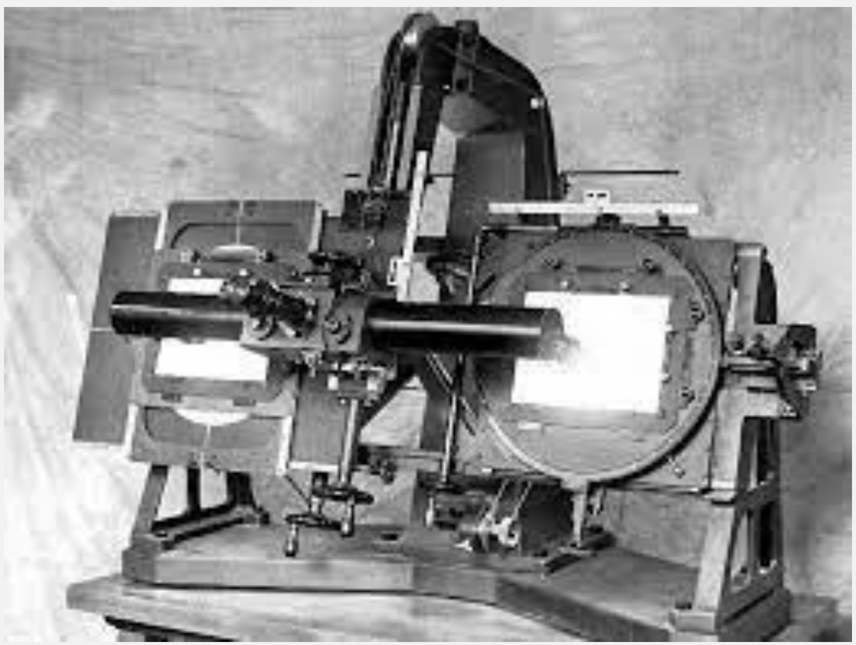


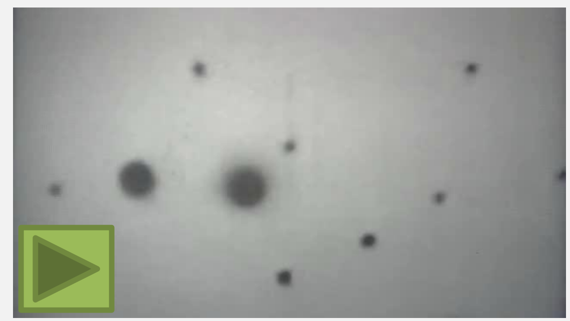
Figure 4. An early model of a stereocomparator. From *Zeitschrift für Instrumentenkunde*, 22, p. 76, 1902.

Women in the History of Variable Star Astronomy 11

Stereo comparator



Blink comparator o blink microscope



Variazioni astrometriche

Variazioni fotometriche

Lick Obs. 1950s(?)

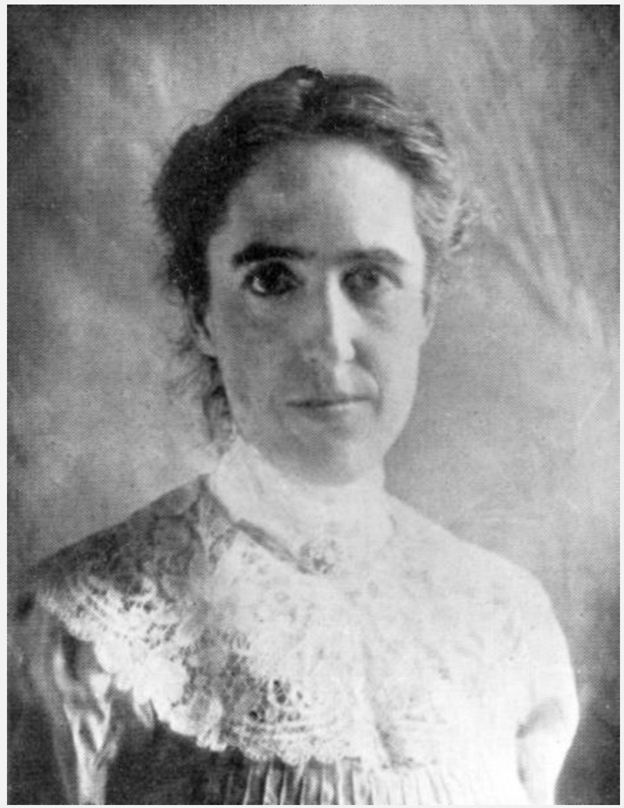
Henrietta Swan Leavitt ad Harvard

estratto da:

The measurement of starlight
Two centuries of
astronomical photometry

J. B. Hearnshaw

When Edward Pickering (1846–1919) came to Harvard as observatory director in 1877 he quickly decided to continue a vigorous programme of photometry

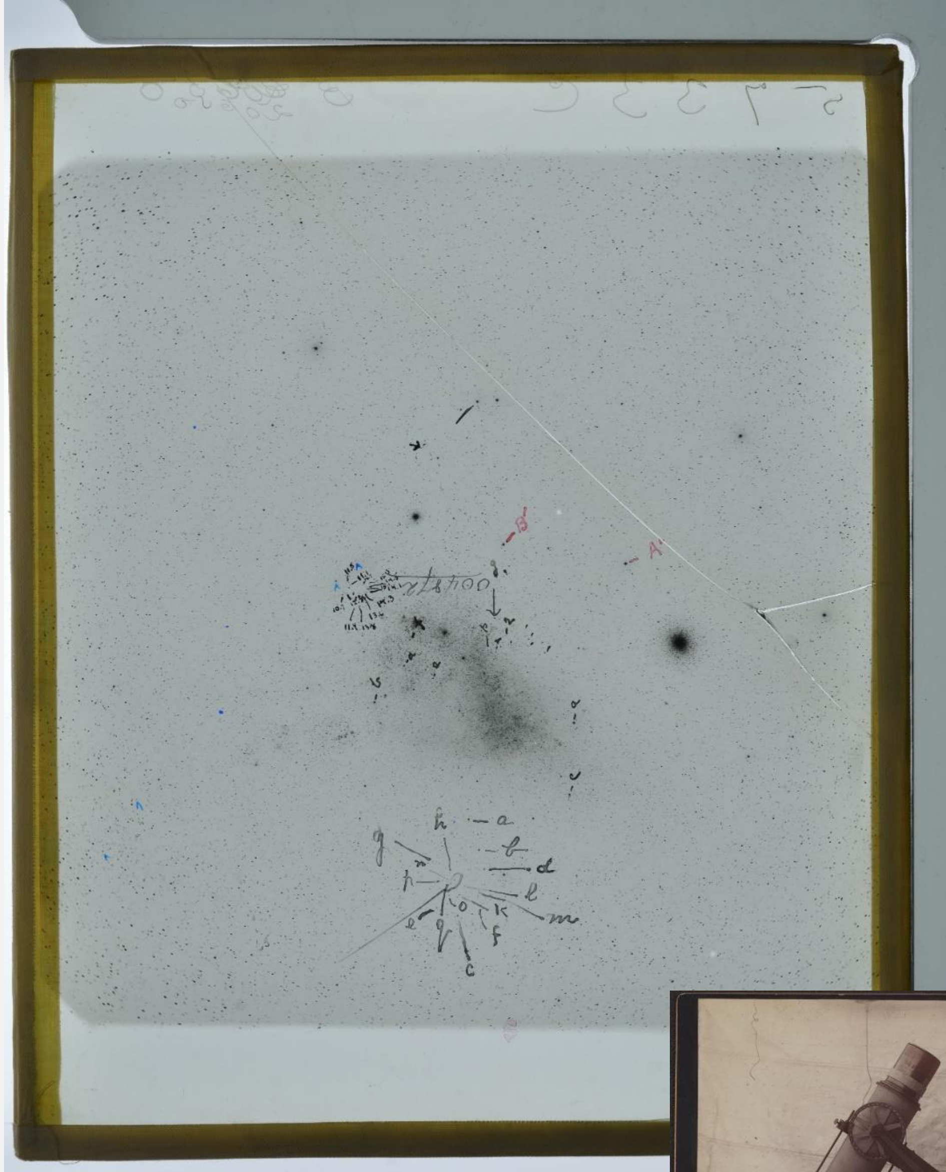


1892 - 1902 non staff Harvard
1902 - 1921 staff

Esame delle lastre fotografiche provenienti dagli astrografi ad Arequipa per la scoperta e lo studio delle stelle variabili

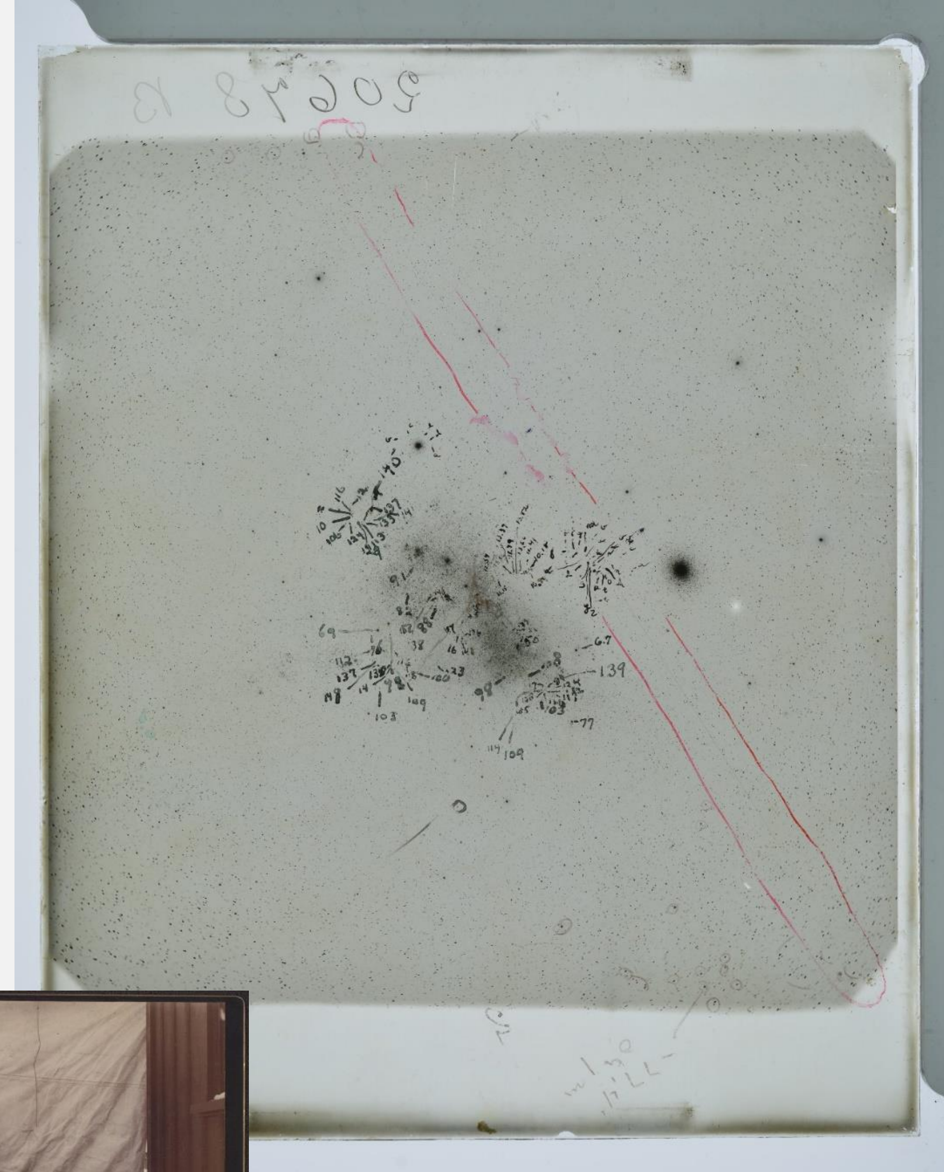
SMC - a 3393 – (355x432 mm) 300 min

SMC - a 6982 (355x432 mm) - 120 min



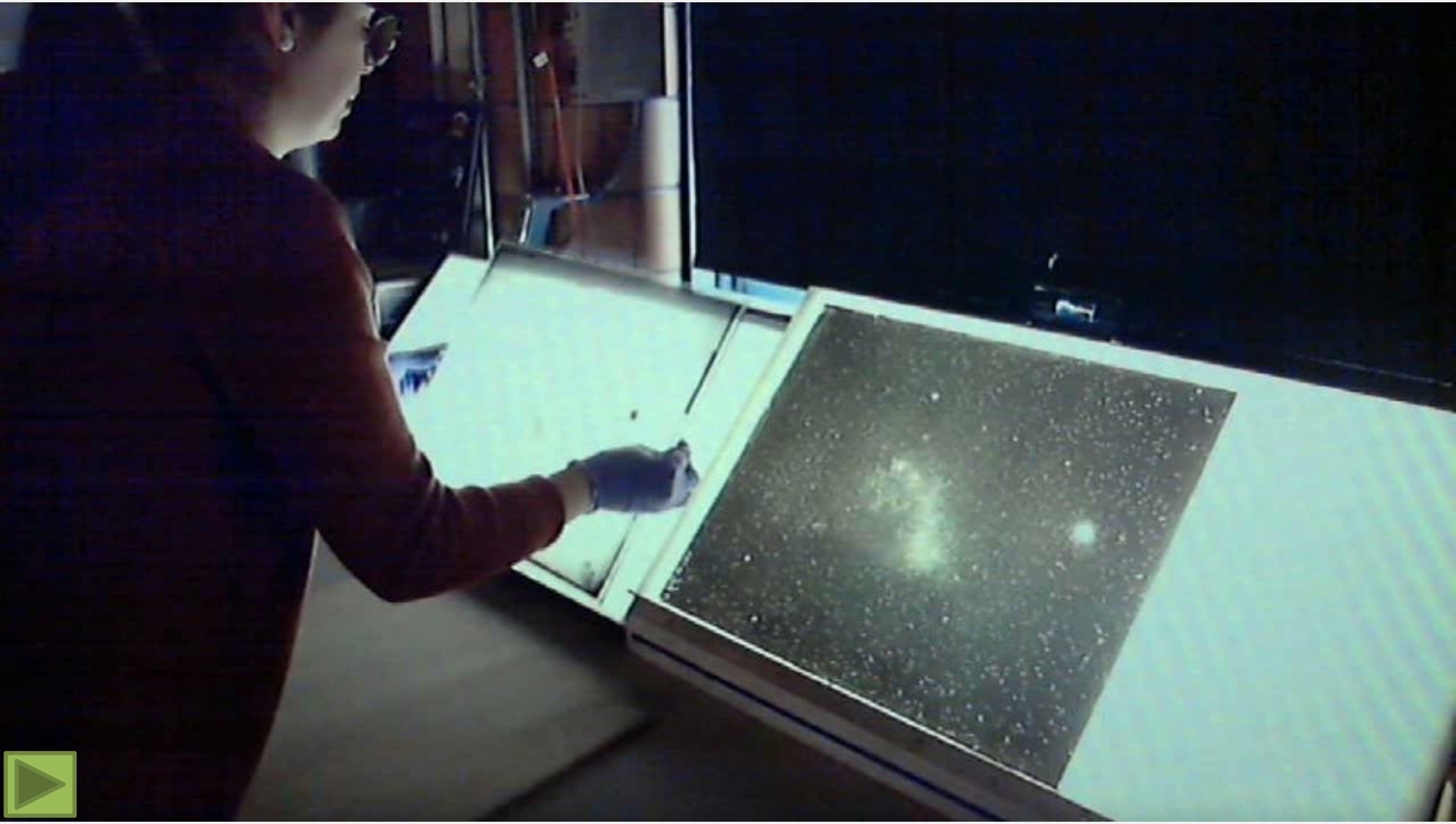
SMC - b20650 (200x254 mm)
240 min

Harvard University, Harvard University Archives, W431953_1



SMC - b20678 (200x254 mm)
270 min

La metodologia di ricerca e di studio fotometrico di nuove variabili



https://www.youtube.com/watch?v=eZpbknjj0c0

This image shows the bottom half of the two plates overlaid in Step 5 to give an idea of how the image even a few inches away could be shifted relative to each other. As can be seen in the red circles in this image, even though these plates are taken of stars in the same section of sky with the same telescope with the same settings only a week apart, the stars do not exactly line up when the two images are overlaid. This type of variation between plates is due to instrument effects, when the two plates are tilted even slightly differently in the telescope plate holder.

lastra b 20670 sovrapposta alla lastra b 20678

https://learninglab.si.edu/collections/henrietta-swan-leavitt-web-resources/qqXikk5s1yijR91U

Instrumental Effects on Astronomical Error 1880-1940

DESCRIPTION

Astronomers quantified their instrument limitations and error sources as much as possible, trying to account for and quantify even tiny sources of error. The use of a "fly spanker" - a small piece of glass with stars of example magnitudes; see image - to calibrate the magnitude (size) of a reference star on a photographic plate to take into account variations in exposure, weather, telescope settings, etc. is one example. Averages were often used to compensate for possible atmospheric effects which might have reduced starlight reaching the telescope for a non-variable star, e.g., a very fine haze not noticed by the observer, or a plate taken near the horizon. Multiple exposures of the same star would be measured, and the average of three measurements used as the official magnitude of record.

Instrumental effects caused by physical changes or defects in the setup could include:

- Mapping of the image of the curved sky to a flat glass plate, which distorted star shapes at the edges of the plate. Think of a globe versus a map of the Earth. If a star was too close to the edge of a plate, it was not used for measurement.

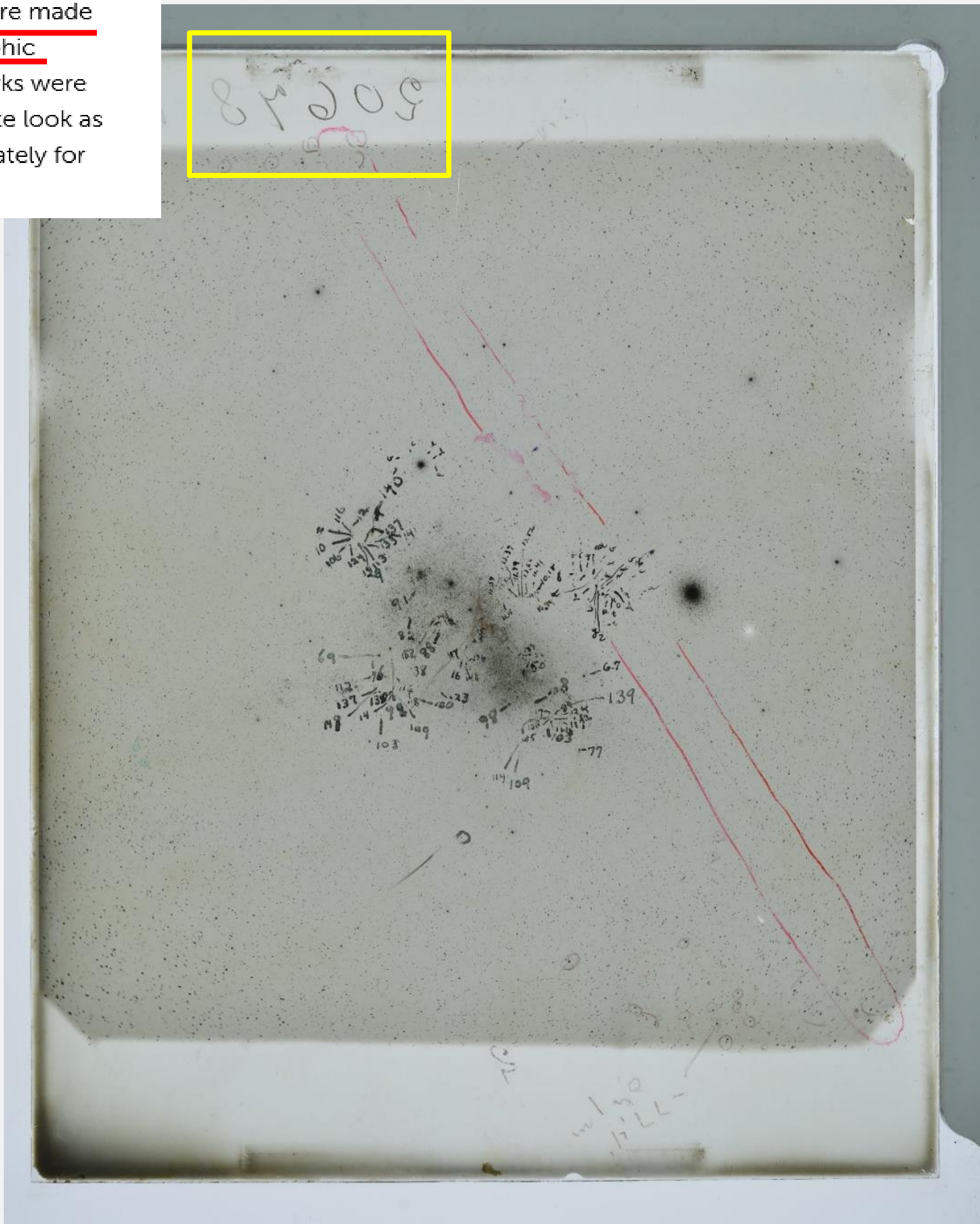
- Under- or over-exposure of a star – That star would not used for measurement, as when too close to the plate edge.

- If the plate angle relative to the telescope optics varied even by a fraction of a degree in the holding clamp, relative distance between stars on a plate would be shifted as in this example image. This effect was usually not an issue when overlapping small areas of the plates for study. Note that the offset grows larger the farther away from the aligned section.

Other possible equipment variations (e.g., perhaps the glass plate itself might not be exactly flat, the chemicals on plates might vary from batch to batch, possible imperfections in the optics might exist, and especially temperature changes which could cause expansion/contraction of equipment materials) were also noted and compensated for whenever possible.

DESCRIPTION

This Figure shows a detail from photographic plate **b20678** demonstrating Leavitt's method of examining variable stars. She labeled each star's dot with a letter, and then measured that star's magnitude. Marks were made on the back of the glass plates to avoid damaging the photographic emulsion on the front side. Plates were used many times, so marks were washed off the glass as needed. The remaining notes on this plate look as if it was used in several different analyses over the years. (Fortunately for historians, these were not completely cleaned!)



b20650
240 min
21-10-1897

Markings
Leavitt

No. B20650

Class, L

R. A. 0 52

Dec. −72.3

Quality, 4

Date, Oct 20 - 1897

Exposure, 240

S.m.c.

for Lantern slide

Reject for DASCH

This plate may have been used by Henrietta Leavitt for her 1908 paper on variables in the Magellanic Clouds (L.Smith, 2016)

DESCRIPTION

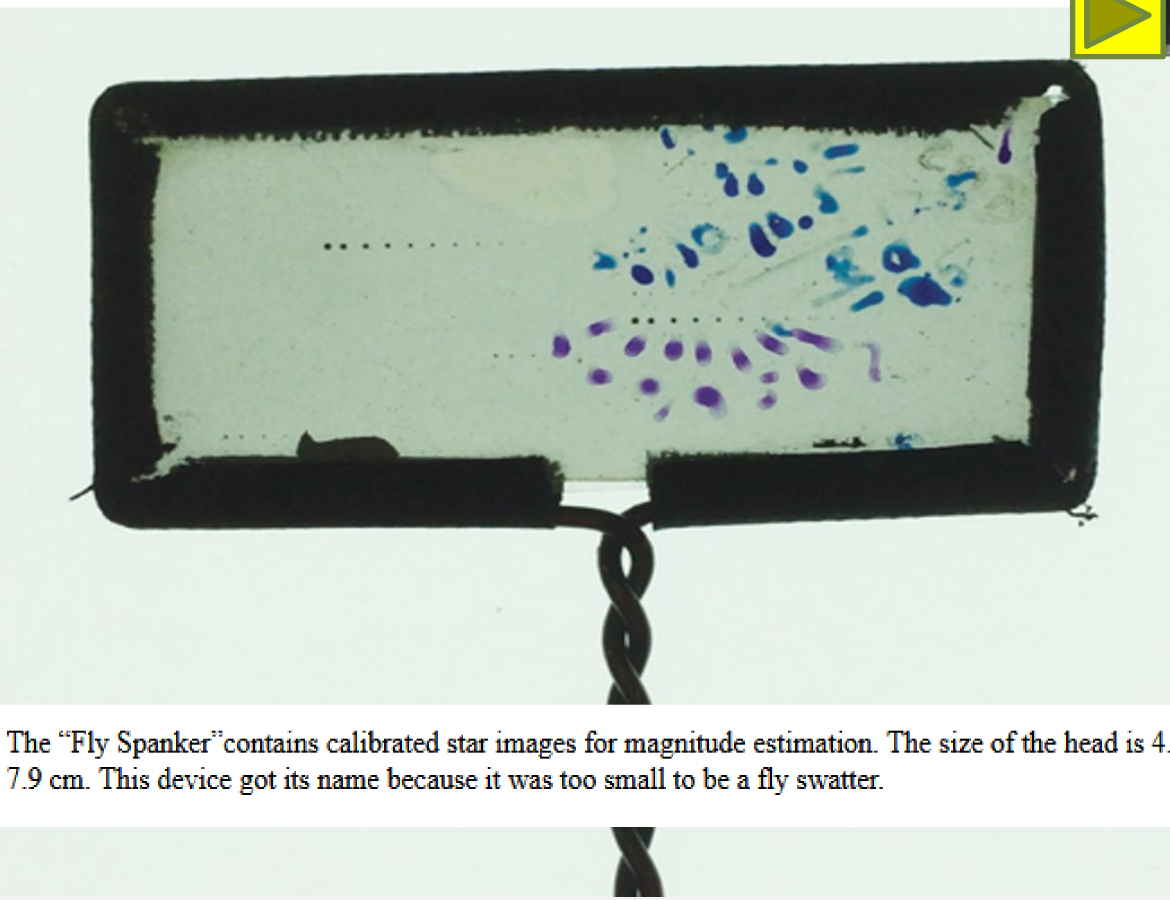
Since the exposure time often varied on photo plates, and even the plates could vary on the exact photochemical mixture used, Leavitt would use a "fly spanker" (so called because it was too small to be a fly swatter; see lower left) to calibrate the size of a reference star on each plate. This identified a standard conversion factor for that photo to a fixed magnitude photometric scale.

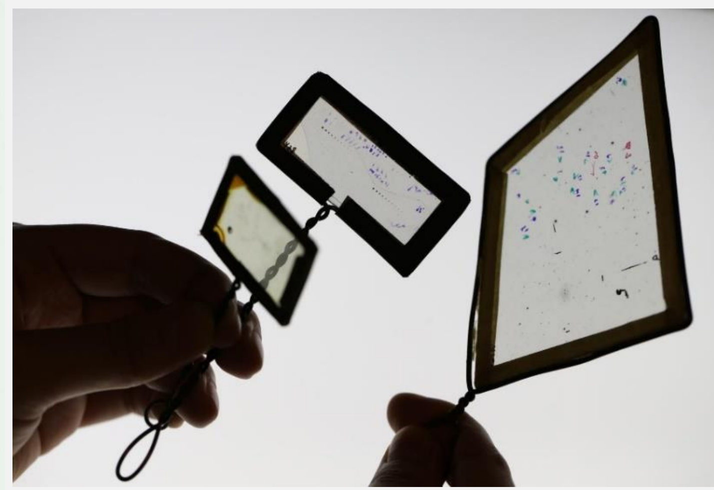
Thus, if a star with known magnitude 5 looks like a 7 in its exposure on a plate, the astronomer can compare all other stars on that plate to the known star to determine their standard magnitudes at that exposure.

Come si usavano i "fly spankers"

Photographic Glass Plate Collection
Harvard - Smithsonian Center for Astrophysics

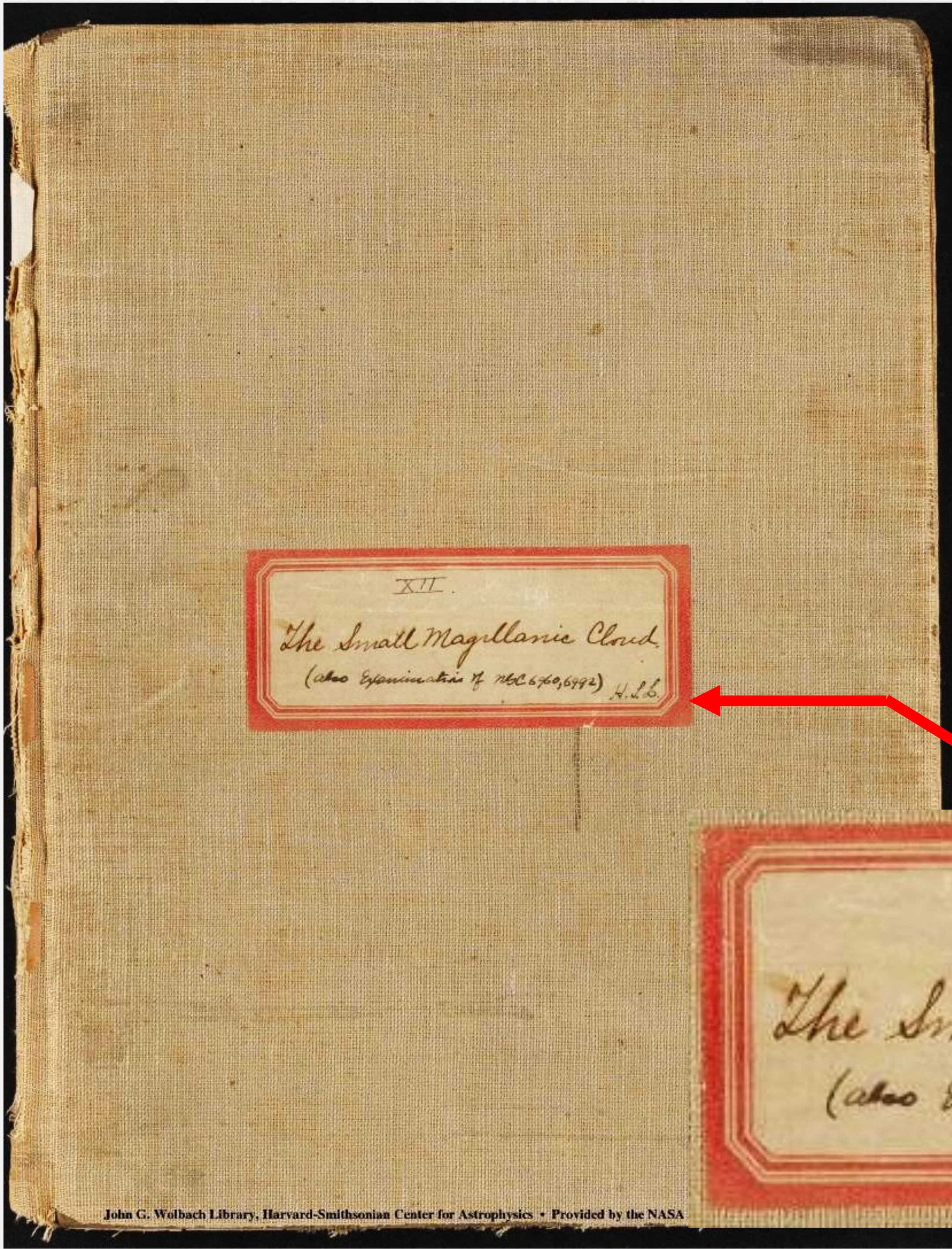
https://www.youtube.com/watch?v=rXv8KANr798





The "Fly Spanker" contains calibrated star images for magnitude estimation. The size of the head is 4.1 cm x 2.1 cm and the overall length of the head and handle is 7.9 cm. This device got its name because it was too small to be a fly swatter.

Notebooks delle variabili scoperte e stime delle loro magnitudini.

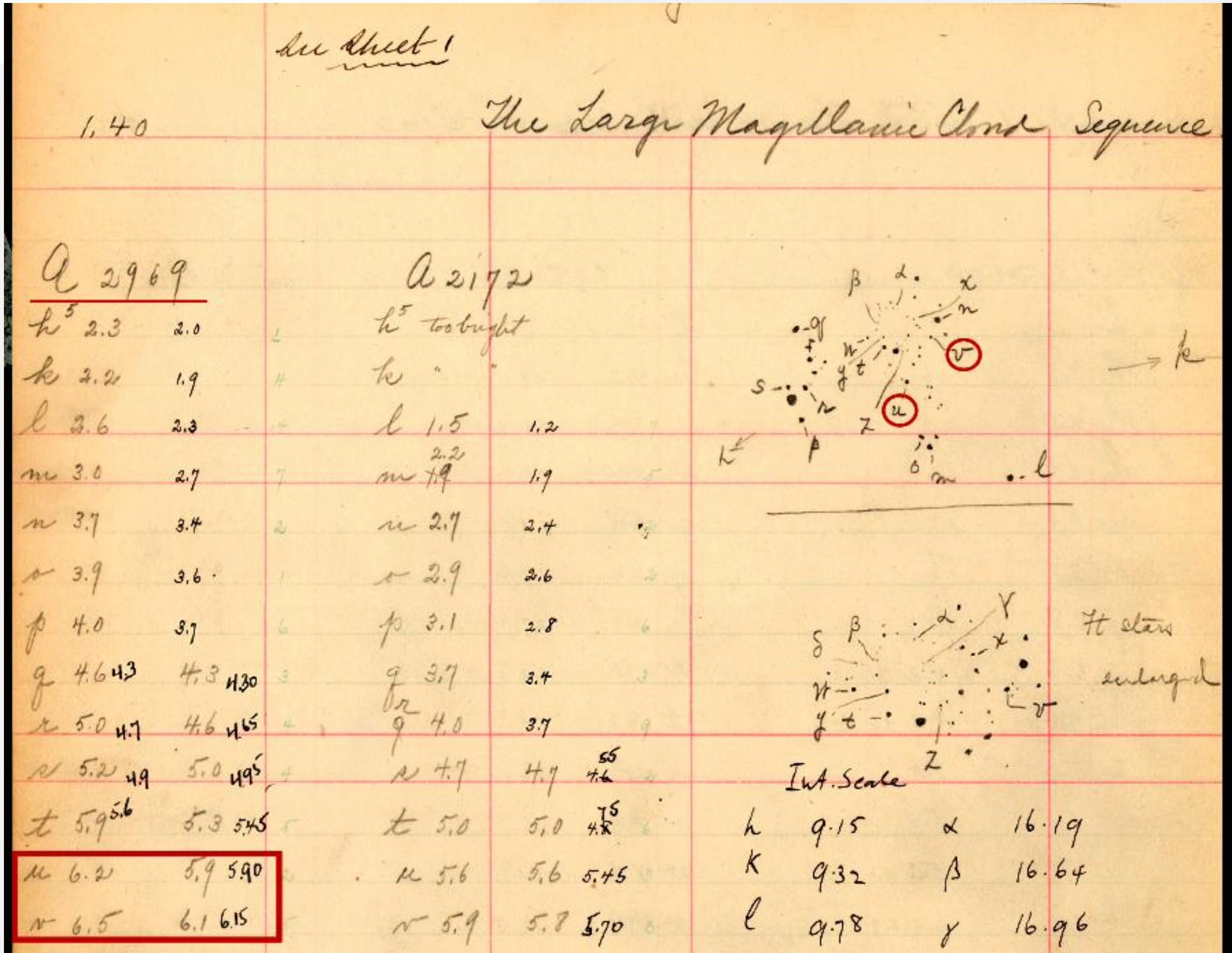


Iniziali di Henrietta Swan Leavitt

DESCRIPTION

On this same notebook page from Steps 2 and 3, shown more fully here, the column indicated by underlining "A2969" shows a list of the magnitudes determined for each labeled star in the chart with "u" and "v" circled.

The magnitudes for "u" and "v" are shown in the red rectangle. The star magnitudes were measured, using the diameter as an approximation, and then that measurement was calibrated to a standard scale using a reference star of known magnitude somewhere in the image. (See "fly spanker" resource.)



HARVARD COLLEGE OBSERVATORY.

CIRCULAR No. 96.

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843 NEW VARIABLE STARS IN THE SMALL MAGELLANIC CLOUD.

IN Circular No. 79, announcement was made of the discovery of 57 new variable stars in the Small Magellanic Cloud. In order to provide material for the study of their light curves, sixteen excellent photographs, having exposures of from two to four hours, were taken last autumn at Arequipa, with the 24-inch Bruce Telescope. These plates reached Cambridge in January, and an examination of them by Miss Leavitt led to the surprising discovery that hundreds of variable stars were present in this region, the small number found in her earlier examination being due to the

April 12, 1905

H.S. Leavitt scoprì durante la sua carriera circa 2400 stelle variabili

Harvard College Observatory.

Circular 115.

TWENTY-TWO NEW VARIABLE STARS IN CARINA.

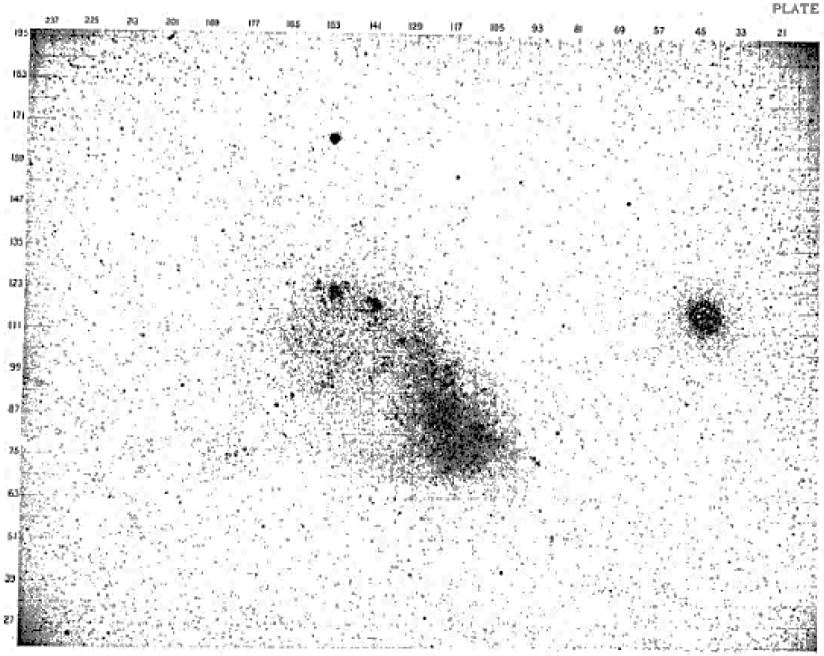
An interesting feature of the groups of variable stars which have been discovered during the past two years by Miss H. S. Leavitt is their distribution, as well as the large number of these objects. In comparing the number of variables found in different regions, the conditions under which they were discovered must be considered, or the results will be without value from this point of view. The method adopted in this research has been to compare the photographs, superposed as described in Circular 79, carefully but not exhaustively, using a two inch positive eye-piece. The time spent in the examination of a pair of plates, taken with the Bruce Telescope and covering an area of about 42 square degrees, varies from fifteen minutes to two hours, according to the number of stars in the region and the number of suspected variables marked. The ten variables found in Carina

May 4, 1906

1777 VARIABLES IN THE MAGELLANIC CLOUDS.

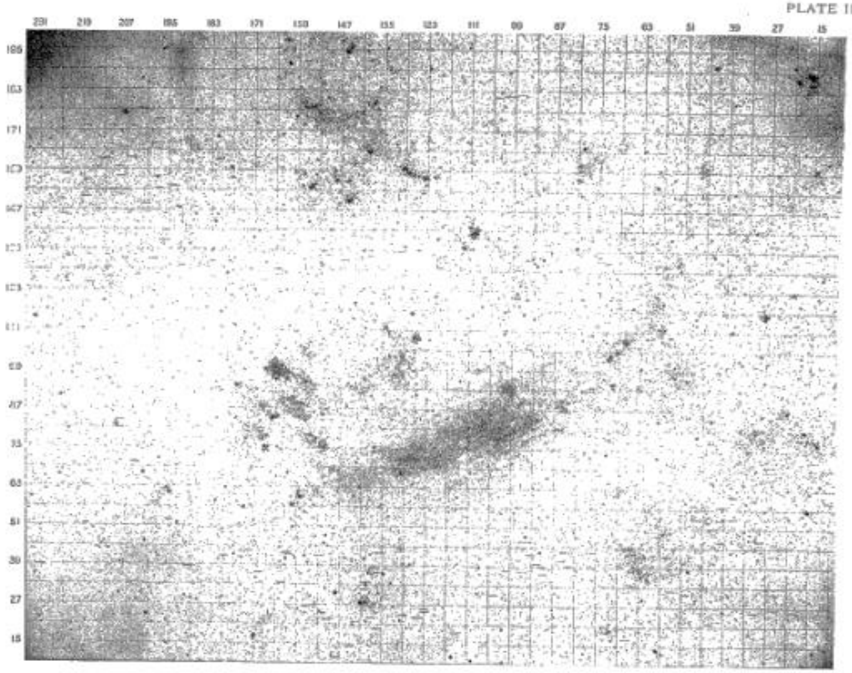
BY HENRIETTA S. LEAVITT.

PLATE I.



SMALL MAGELLANIC CLOUD.

PLATE II.



LARGE MAGELLANIC CLOUD.

Annals Harvard College, 1908

The variables appear to fall into three or four distinct groups. The majority of the light curves have a striking resemblance, in form, to those of cluster variables. As a rule, they are faint during the greater part of the time, the maxima being very brief, while the increase of light usually does not occupy more than from one-sixth to one-tenth of the entire period. It is worthy of notice that in Table VI the brighter variables have the longer periods. It is also noticeable that those having the longest periods appear to be as regular in their variations as those which pass through their changes in a day or two. This is especially striking in the case of

TABLE VI.

PERIODS OF VARIABLES IN THE SMALL MAGELLANIC CLOUD.

Harvard No.	Max.	Min.	Range.	Epoch.	Period.	Min. to Max.	Average Dev.	Earliest Observation.	No. Periods.	No. Plates.
					d.	d.				
818	13.6	14.7	1.1	4.0	10.336	1.7	.12	1890	566	44
821	11.2	12.1	0.9	97.	127.	49.	.06	1890	45	89
823	12.2	14.1	1.9	2.9	31.94	3.	.13	1890	184	56
824	11.4	12.8	1.4	4.	65.8	7.	.12	1889	94	83
827	13.4	14.3	0.9	11.6	13.47	6.	.11	1890	448	60
842	14.6	16.1	1.5	2.61	4.2897	0.6	.06	1896	843	26
1374	13.9	15.2	1.3	6.0	8.397	2.	.10	1893	574	42
1400	14.1	14.8	0.7	4.0	6.650	1.	.11	1893	724	42
1425	14.3	15.3	1.0	2.8	4.547	0.8	.09	1893	1042	33
1436	14.8	16.4	1.6	0.02	1.6637	0.3	.10	1893	2859	22
1446	14.8	16.4	1.6	1.38	1.7620	0.3	.09	1896	2052	21
1505	14.8	16.1	1.3	0.02	1.25336	0.2	.10	1896	2335	25
1506	15.1	16.3	1.2	1.08	1.87502	0.3	.09	1896	1560	23
1646	14.4	15.4	1.0	4.30	5.311	0.7	.06	1896	681	24
1649	14.3	15.2	0.9	5.05	5.323	0.7	.10	1893	894	32
1742	14.3	15.5	1.2	0.95	4.9866	0.7	.07	1893	954	28

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Harvard College Observatory.

Circular 173.

PERIODS OF 25 VARIABLE STARS IN THE SMALL MAGELLANIC CLOUD.

The following statement regarding the periods of 25 variable stars in the Small Magellanic Cloud has been prepared by Miss Leavitt.

Fifty-nine of the variables in the Small Magellanic Cloud were measured in 1904, using a provisional scale of magnitudes, and the periods of seventeen of them were published in H.A. 60, No. 4, Table VI. They resemble the variables found in globular clusters, diminishing slowly in brightness, remaining near minimum for the greater part of the time, and increasing very rapidly to a brief maximum. Table I gives all the periods which have been determined thus far, 25 in number, arranged in the order of their length. The first five columns contain the Harvard Number, the brightness at maximum and at minimum as read from the light curve, the epoch expressed in days following J.D. 2,410,000, and the length of the period expressed in days. The Harvard Numbers in the first column are placed in Italics, when the period has not been published hitherto. A remarkable relation between the brightness of these variables and the length of their periods will be noticed. In H.A. 60, No. 4, attention was called to the fact that the brighter variables

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have the longer periods, but at that time it was felt that the number was too small to warrant the drawing of general conclusions. The periods of 8 additional variables which have been determined since that time, however, conform to the same law.

TABLE I.

PERIODS OF VARIABLE STARS IN THE SMALL MAGELLANIC CLOUD.

H.	Max.	Min.	Epoch.	Period.	Res. *M*.	Res. *m*.	H.	Max.	Min.	Epoch.	Period.	Res. *M*.	Res. *m*.
			d.	d.						d.	d.		
1505	14.8	16.1	0.02	1.25336	−0.6	−0.5	1400	14.1	14.8	4.0	6.650	+0.2	−0.3
1436	14.8	16.4	0.02	1.6637	−0.3	+0.1	*1355*	14.0	14.8	4.8	7.483	+0.2	−0.2
1446	14.8	16.4	1.38	1.7620	−0.3	+0.1	1374	13.9	15.2	6.0	8.397	+0.2	−0.3
1506	15.1	16.3	1.08	1.87502	+0.1	+0.1	818	13.6	14.7	4.0	10.336	0.0	0.0
1413	14.7	15.6	0.35	2.17352	−0.2	−0.5	*1610*	13.4	14.6	11.0	11.645	0.0	0.0
1460	14.4	15.7	0.00	2.913	−0.3	−0.1	*1365*	13.8	14.8	9.6	12.417	+0.4	+0.2
1422	14.7	15.9	0.6	3.501	+0.2	+0.2	*1351*	13.4	14.4	4.0	13.08	+0.1	−0.1
842	14.6	16.1	2.61	4.2897	+0.3	+0.6	827	13.4	14.3	11.6	13.47	+0.1	−0.2
1425	14.3	15.3	2.8	4.547	0.0	−0.1	*822*	13.0	14.6	13.0	16.75	−0.1	+0.3
1742	14.3	15.5	0.95	4.9866	+0.1	+0.2	823	12.2	14.1	2.9	31.94	−0.3	+0.4
1646	14.4	15.4	4.30	5.311	+0.3	+0.1	824	11.4	12.8	4.	65.8	−0.4	−0.2
1649	14.3	15.2	5.05	5.323	+0.2	−0.1	821	11.2	12.1	97.	127.0	−0.1	−0.4
1492	13.8	14.8	0.6	6.2926	−0.2	−0.4							

The relation is shown graphically in Figure 1, in which the abscissas are equal to the periods, expressed in days, and the ordinates are equal to the corresponding magnitudes at maxima and at minima. The two resulting curves, one for maxima and one for minima, are surprisingly smooth, and of remarkable form. In Figure 2, the abscissas are equal to the logarithms of the periods, and the ordinates to the corresponding magnitudes, as in Figure 1. A straight line can readily be drawn among each of the two series of points corresponding to maxima and minima, thus showing that there is a simple relation between the brightness of the variables and their periods. The logarithm of the period increases by about 0.48 for each increase of one magnitude in brightness. The residuals of the maximum and minimum of each star from the lines in Figure 2 are given in the sixth and seventh columns of Table I. It is possible that the deviations from a straight line may become smaller when an absolute scale of magnitudes is used, and they may even indicate the corrections that need to be applied to the provisional scale. It should be noticed that the average range, for bright and faint

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variables alike, is about 1.2 magnitudes. Since the variables are probably at nearly the same distance from the Earth, their periods are apparently associated with their actual emission of light, as determined by their mass, density, and surface brightness.

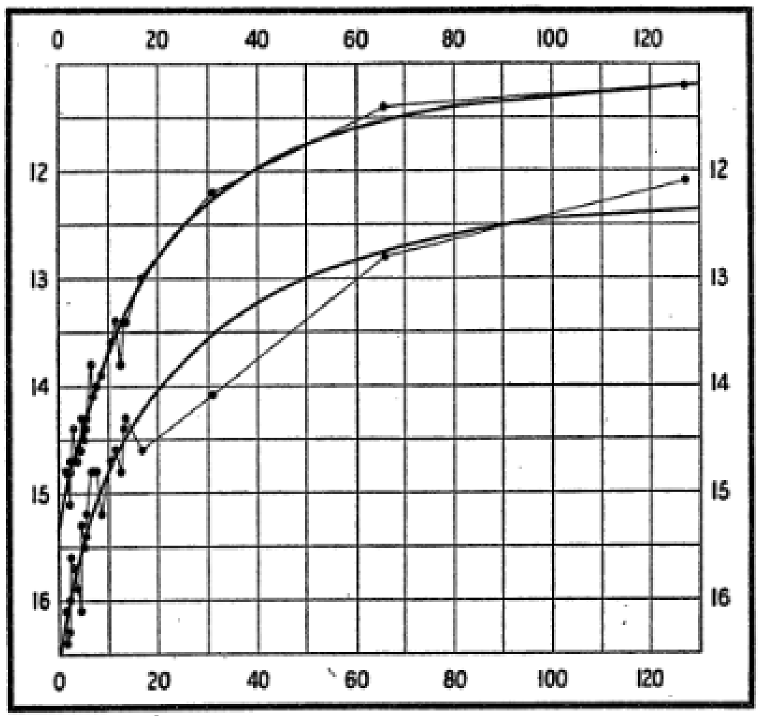


Fig. 1.

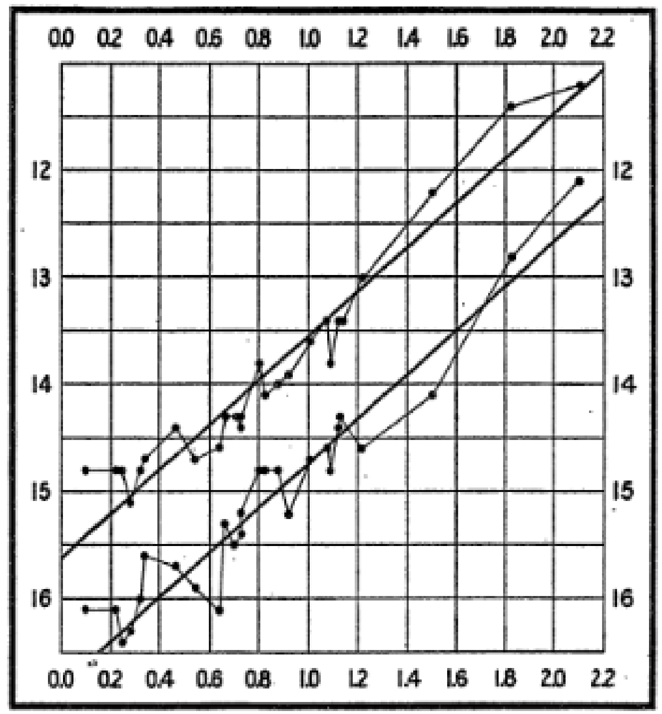


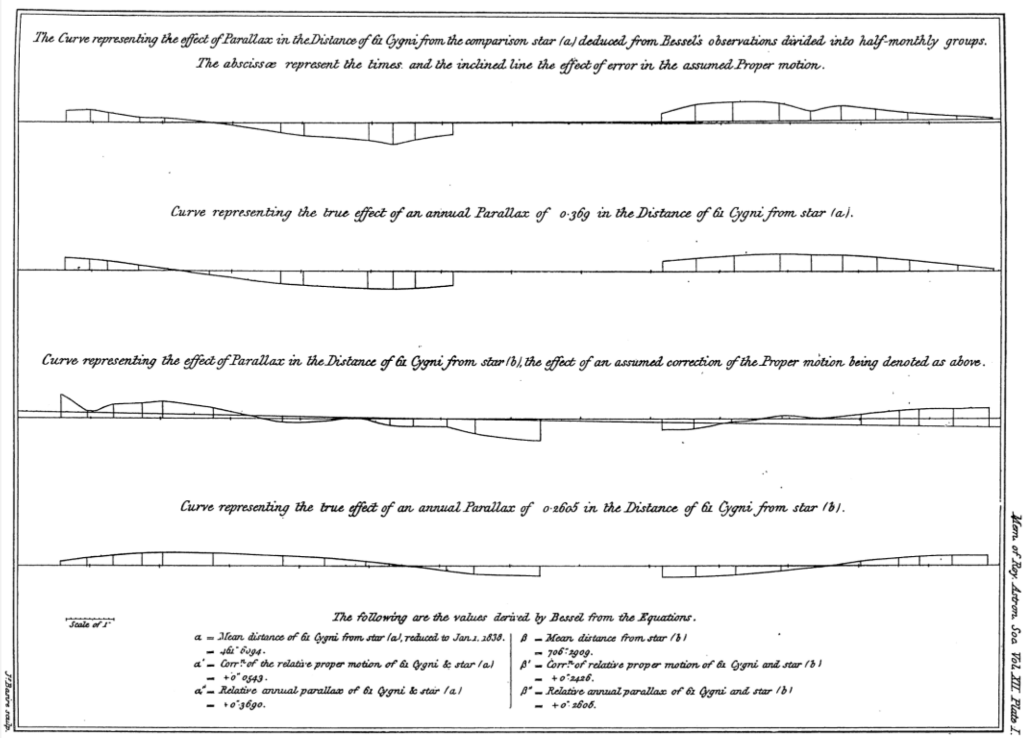
Fig. 2.

Le cefeidi come candele standard

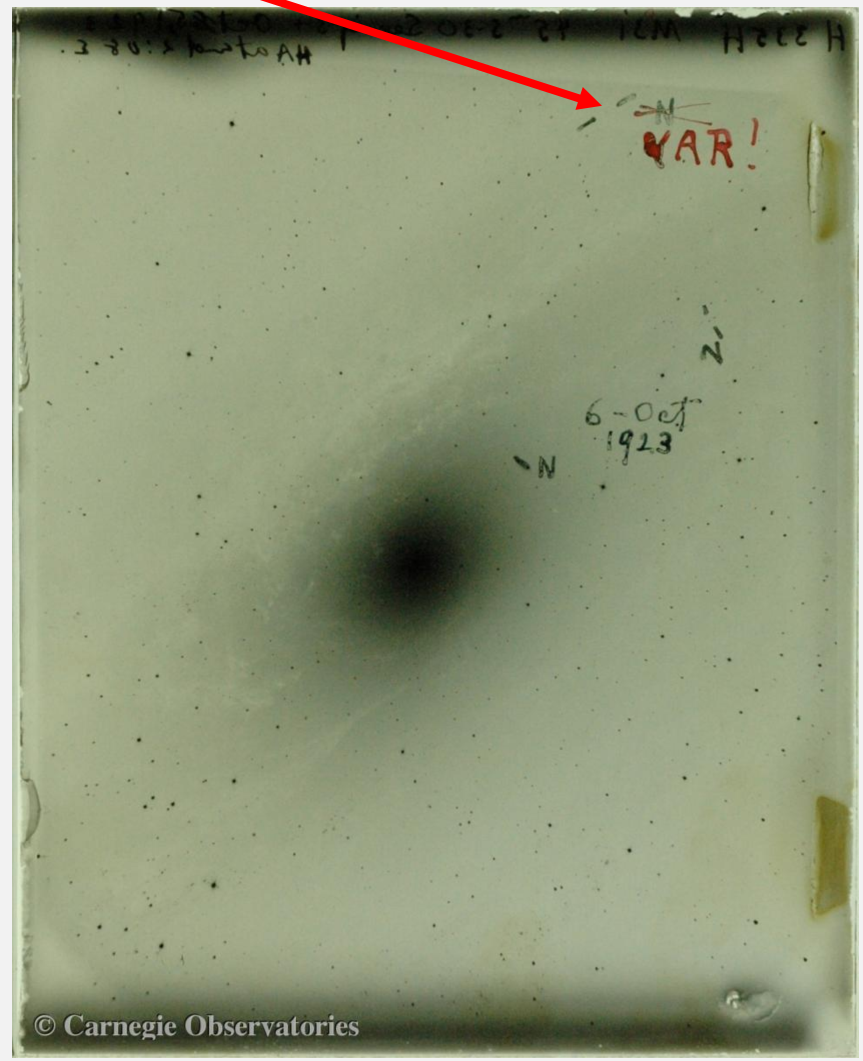
- **Le prime calibrazioni della relazione P-L (E. Hertzsprung, H. Shapley …)**

cefeide in M 31 (E. Hubble, 1923)

Parallasse annua della 61 Cygni (F.W. Bessel, 1838)



The first and third curves are Main's plots of Bessel's observed shifts of 61 Cygni with respect to comparison stars "a" and "b." The second and fourth curves are their predicted counterparts. Compare these curves with those of Wilhelm Struve for Vega, on the opposite page. From the "Memoirs" of the Royal Astronomical Society.



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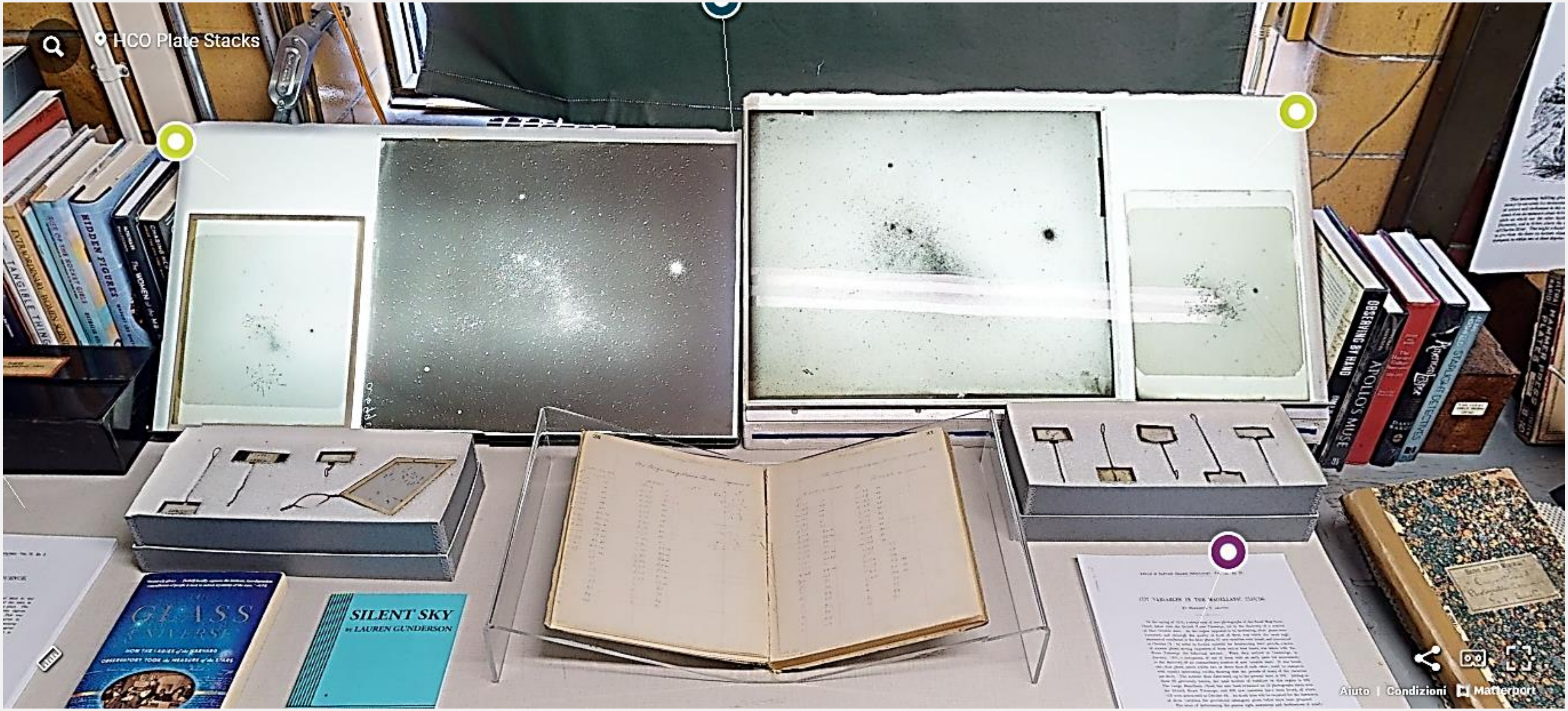

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