HISTORY OF THE DISCOVERY OF MIRA STARS

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Abstract

This year we celebrate the 400th anniversary of Fabricius' discovery of Mira, "The Wonderful," in 1596. But was he the first? Within the first century following Fabricius, four Mira-type variables were discovered, and in all cases it has been found that the stars were suspected of being novae long before their "official" discovery in the Western World. Three of the four had been recorded as novae in early Chinese or Korean records. By 1896, 251 Mira-type variables had been discovered, most of them after the beginning of photographic experimentation. Now in the year of the fourth centennial, over 6000 Miras are known. Because of their ease of discovery relative to stars of small amplitude, no new Mira stars reaching naked-eye visibility have been discovered since 1899. The history of the discovery of Mira-type variables illustrates that (1) some new discoveries are re-discoveries of objects previously assumed to be novae; and (2) apparently logical deductions that early observations of a guest star correspond to a later discovered Mira-type may nevertheless be wrong.

1. Mira, the Wonder Star

David Fabricius (1564–1617), an amateur astronomer and native of Friesland, The Netherlands, is recognized as the first to have discovered a long period variable in 1596, later called o (omicron) Ceti by Johann Bayer in 1603. Fabricius (Wolf 1877) observed the star from August 3, when he had used it as a comparison star for the determination of the position of the planet he assumed to be Mercury (later identified by Argelander, 1869, as more probably Jupiter), until August 21, when it had increased from magnitude 3 to magnitude 2. In September it faded, disappearing entirely by October (Clerke 1902). At the time Fabricius assumed the star was a nova. However, he observed it to reappear on February 15, 1609. Although Pingré saw it October 14, 1631, the star was practically forgotten until Johann Fokkens Holwarda (1618–1651), also of Friesland, rediscovered it in 1638 and determined its period as eleven months. Johannes Hevelius of Danzig (1611–1687) also observed the star on November 7, 1639, and in 1642 named it Mira, "The Wonderful." Fabricius unfortunately did not live to enjoy this appreciation for his discovery. Fabricius, a minister, had been murdered by a peasant whom he had cited from the pulpit as having stolen one of the minister's geese (Poggendorff 1863)!

Speculation arose as to whether or not Mira had been observed before the time of Fabricius' discovery. Müller and Hartwig (1920, **2**, 449) indicate that Hipparchus in about 134 BC had observed o Ceti. The catalogue of Hipparchus is unfortunately lost. The only extant publication of Hipparchus is a commentary on the observations of the risings and settings of stars observed by Aratus (315–245 BC) and Eudoxus (408–355 BC). In a German translation, Manitius (1894) identifies some of the stars by their Bayer designations, including three references to o Ceti as observed by Aratus. Did

Hipparchus actually discover Mira as a supposed nova in 134 BC; or did he infer a nova from Aratus' earlier description of the star; or is Manitius' identification at fault?

Mira is not contained in the Catalogue of Ptolemy (Baily 1843). In general, Ptolemy took the magnitudes in the *Almagest* from Hipparchus, but updated the positions. This implies that Ptolemy did not include o Ceti in his catalogue simply because it was invisible at the time of his observations. Neither is it included in Baily's transcriptions of the Ulugh Beigh and Tycho catalogues. It is, of course, included in that of Hevelius (Baily, p. 202, no. 523) where it is described as "Nova in colo Ceti," magnitude 2½. Gore (1900) indicated that o Ceti is not included in the catalogue of Al Sufi (AD 903–986); either it was faint when Al Sufi was observing stars in Cetus, or he was observing only stars in Ptolemy's catalogue.

Ho Peng Yoke (1962) compiled a list of ancient and medieval Chinese and Korean observations of comets and novae through 1600. He cites a "guest star" of July 134 BC, the year of Hipparchus' observation, but this one is in Scorpius, not Cetus (see also Humboldt 1850). He does cite two other guest stars in Cetus, December 25, 1070, and 23 November (mistakenly transcribed by Ho Peng Yoke as 28 November) 1592. For the first of these (1070), the positions given by Stephenson (1976) and by Hsi Tsê-tsung (1958) disagree by 5° (see Figure 1) and are 10–15° from the position of Mira. However, Mira is within the designated Chinese constellation. Likewise, Stephenson's position for the 1592 event is about 15° SW of Mira. Nevertheless, Clark and Stephenson (1977) indicate that both of these events may actually represent early observations of Mira, though they seem to favor an interpretation as supernova for the 1592 event. The positions of both the "guest stars" of 1070 and 1592 as given by Stephenson are compared as follows with the position of Mira for 1950:

1070	$02^h\,40^m + 05°$	Hsi Tsê-tsung	$02^h\,40^m + 10°$
1592	$01^h\,20^m - 10°$		
Mira	$02^h\,17^m - 03°$		

For these two guest stars, Ho Peng Yoke gives only the Chinese configuration within which they appeared, Thien-Chün (1077) and Thien-Tshang (1592). It is not clear just how the coordinates by Stephenson and Hsi Tsê-Tsung were determined; Stephenson's appear to be simply close to the mid-points of the Chinese asterisms within which the guest stars were reported to occur. The mere statement that a star was observed within a stated configuration could not necessarily define its position even within fifteen degrees. (For example, the constellation Leo is shown on two Ho Peng Yoke maps; the lines joining the star images of the Chinese constellation Hsein-Yuan span about 30 degrees.) The declinations given by Stephenson and by Hsi Tsê-tsung differ on the average by about three degrees, but range up to 15°. Under such circumstances, neither of the two events in Cetus could be entirely ruled out as possible apparitions of Mira.

In the case of the 1070 event, too long a time has elapsed (over 500 epochs) to test if the observation satisfies Mira's period. The inferred position is slightly closer to Mira's than that ascribed to the 1592 event. However, the latter is only three or four years prior to Fabricius' discovery. Hence it seemed that a check of the maximum phases might confirm or rule out the possibility that the 1592 guest star was indeed Mira. Table 1 lists numerous observations and instantaneous periods derived for Mira, together with the dates of maxima and O-C values based on an average period. The questioned Ho Peng Yoke initial date and final date when the brightness had declined are included. In view of the range in instantaneous periods and the adoption of an average period over the entire span of the tabulated observations of Mira, there would remain a distinct possibility that the 1592 date could represent Mira.

Ho Peng Yoke states that the guest star of 1592 was visible on November 28, 1592,

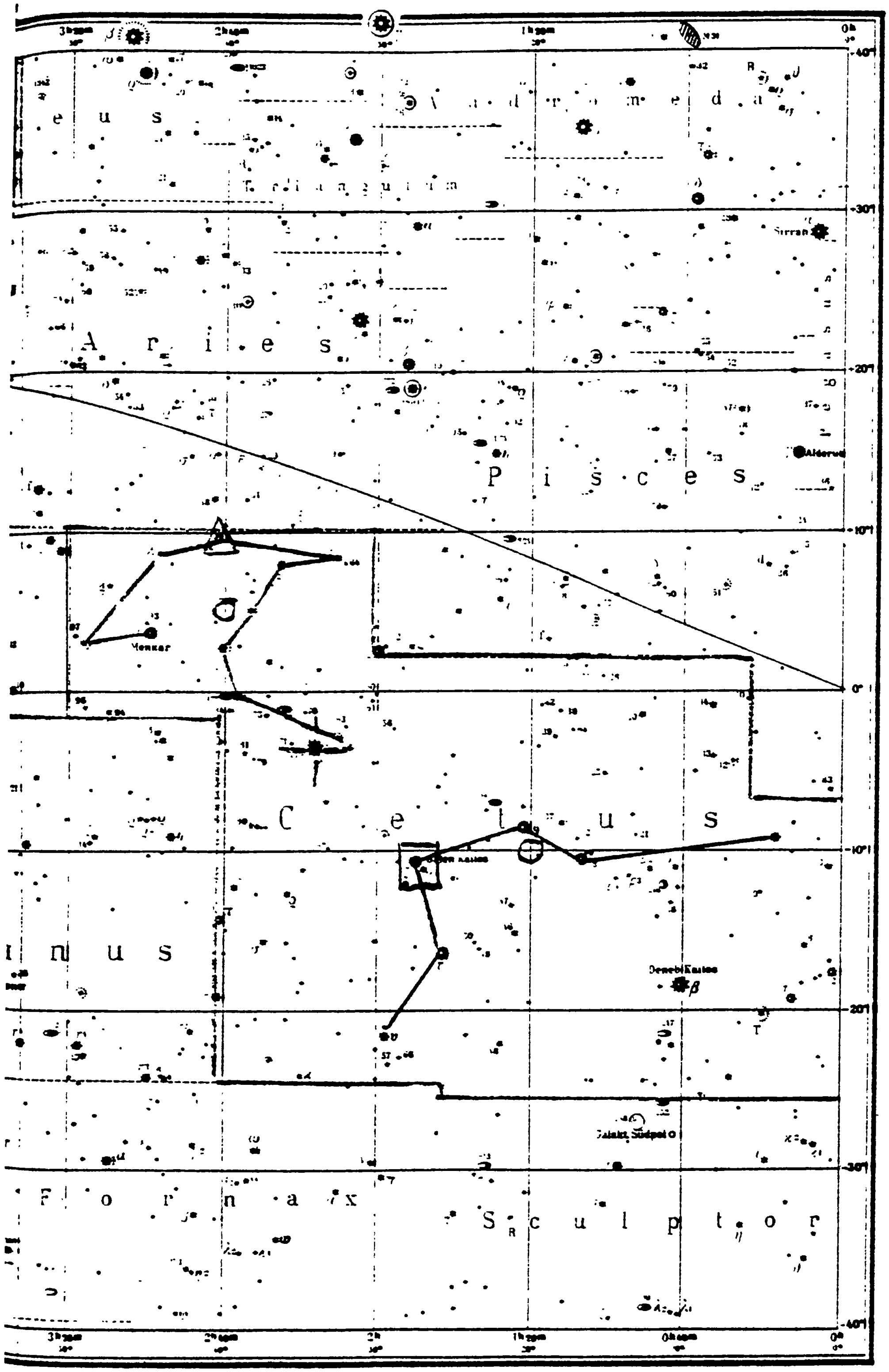

Figure 1. Copy of part of Chart III of the Schurig-Götz Himmels-Atlas (Schaifers 1960) on which the constellation Cetus is outlined, and the two Chinese constellations, Thien-Chün (upper left) and Thien-Tshang (lower right), are defined by the lines joining specific stars. The position of Mira is indicated by a cross. The open circles show the coordinates assigned by Stephenson, and the triangle shows the position for the 1070 object assigned by Hsi. The square gives the more exact Korean position of the 1592 nova (Huang 1988), proving that this star is not Mira.

and that its size *diminished* on February 20, 1594. This would indicate that the latter observation represented the beginning of the decline toward minimum. The interval of 449 days, or 15 months, led Clark and Stephenson (1977) to classify the event of 1592 as a slow supernova. If so, this star could not be Mira. However, the object could not have been observed throughout a whole year, as it would have been too close to the sun for a few months around springtime. In that interval, a minimum could have occurred between the first and last observations. The 15 months' interval of the observations might then correspond to the end of the 1592 rising light curve and the

Table 1. Maxima and pre-discovery observations of Mira Ceti.

Year	*Period*	*J.D.*	*Epoch*	*O-C* (331.691^d)	*Observers/Authors*
134 BC					Hipparchus
1070 AD		*2112225*			Chinese
*1592?**		*2302853*	*- 75*	*+ 69*	*Korean*
*1594?**		*2303310*	*- 73*	*+192 med*	
1596		2304202	- 71	+ 90	Fabricius
		to 4220		+108	
		*4231**		*+119 med*	
		*4261**		*+149 n.s.*	
1603					Bayer
1609		2308781	-57	+24	Fabricius
1631		2317057	-32	+ 8	Pingré
1638	11 Mo.	2319686	-24	-16	Holwarda
1639		2320003	-23	-31	Hevelius
1660	**329.8**	**2327663**	**0**	**0**	***Prager***
1667	334	2329977	+ 7	- 8	Boulliau
1670		2331272	11	-40	Hevelius
1698	333.2	2341271	41	+ 9	*Prager*
1729	328.6	2352918	76	+46	"
1752	332.8	2361162	101	- 2	"
1799	331.0	2378454	153	+42	"
1840	328.2**	2393389	198	+51	"
1847	334.1	2395988	206	- 3	"
1865	329.5	2402330	225	+38	"
1867		2403298	228	+ 9	Secchi
1887	335.4	2410569	250	- 17	*Prager*
1898	332.1	2414566	262	0	"
1902	331.69	2415575	265	+14	*Müller and Hartwig*
1913	329.2	2419873	278	0	*Prager*
1927	331.8	2425151	294	- 29	"
1946	331.48	2432158	315	+12	*Kukarkin and Parenago* 1948
1954	331.62	2434814	323	+15	*Kukarkin and Parenago* 1951
1964	331.65	2438457	334	+ 9	*Kukarkin* et al. 1969
1981	331.96	2444839	353	+89	*Kholopov* et al.

* Italics for 1592–1594 indicate that previous identifications of the guest star as Mira were questionable and have been disproved. Other italics simply indicate observations fainter than maximum.

** Prager gives the period as 322.8, but comparison with Argelander (1869) indicates that this is a typo for 328.2.

beginning of the decline in 1594. I asked Yale astronomer John Lee, a native of China, if in Ho Peng Yoke's transcriptions of the Korean records there could be any inconsistencies in conversions from the Chinese calendar to the Georgian, and if more precise positions of the guest star were available. He found that there could be no transcription error for 1594, but that conceivably for 1592 one could read 1593, making the apparent duration of maximum a reasonable 84 days, or about 25% of the period.

The period of Mira has been somewhat variable (see Table 1), hence a computation of phases to see if these older observations do indeed correspond to Mira might (again) not necessarily constitute certain confirmation, though indication of agreement of both position and period would be more promising. The average period for the interval 1596 through 1981, consistent with the range of published periods at different epochs, is 331.691 days. Table 1 gives the years, published periods, Julian dates of approximate maxima and the number of epochs computed from the maximum of 1660 with the residuals (Observed minus Computed maxima) based on the period of 331.691 days. Observers of some of the maxima are indicated in the final column. The names given in italics are authors of general catalogues: Prager (1934), Müller and Hartwig (1922), Kukarkin *et al.* (1948, 1958, 1969), and Kholopov *et al.* (1985). Ho Peng Yoke (1962) is the source for the Korean observations.

As the earliest epoch for which both Argelander (1869) and Prager (1934) reported a period is for 1660, that Julian date is retained as the zero epoch for testing the period of 331.691 days between 1592 and 1981. The entire span of the O-C values for maximum brightness from 1596 is 148 days, or 45% of the period. From 1609 through 1964, the span amounts to 91 days, or 27% of the period, which is consistent with the width of individual cycles at about one magnitude below maximum. At the two extremities, the O-C values for the assumed constant period deviate appreciably, indicating, as is well known, that one period is not strictly valid for the entire span of the observations (see Figure 2). In Table 2, the (O-C) values are summarized for the average period, and for the early and late epochs for periods more closely representing those observations, 330.122 and 333.695 days, respectively. The span of values indicated as percentage of the period is then obviously decreased to 13 to 21 percent of the period. The dispersions are due to a combination of numerous causes: sufficiently detailed light curves of the individual cycles are not always available, so that the time of actual maximum light is not well determined, only that the star had been observed at the indicated time; and the overall period tested is not strictly applicable at the given epoch (note the variability of instantaneous published periods cited in Table 1).

The brightnesses at maximum and minimum vary appreciably from cycle to cycle. Pannekoek (1961) says Mira reached first magnitude in 1779, but at other times only fourth magnitude; Chandler (1888) states that the maxima vary from 1.7 to 5.6 and the minima from 8 to 9.5; while Prager (1934) gives maxima of 2.0–4.9v, and minima of

Table 2. Span of O - C as percentage of period.

Epochs		*Period*	*Span of O - C*			*% Period*
from	*to*	*days*	*from*	*to*	*= days*	
- 71	+353	331.691	-40	+108	148	45
- 71	+ 11	330.122	-67	+ 3	70	21
+ 41	+278	331.691	-17	+51	68	21
+294	+353	333.695	+ 7	+49	42	13

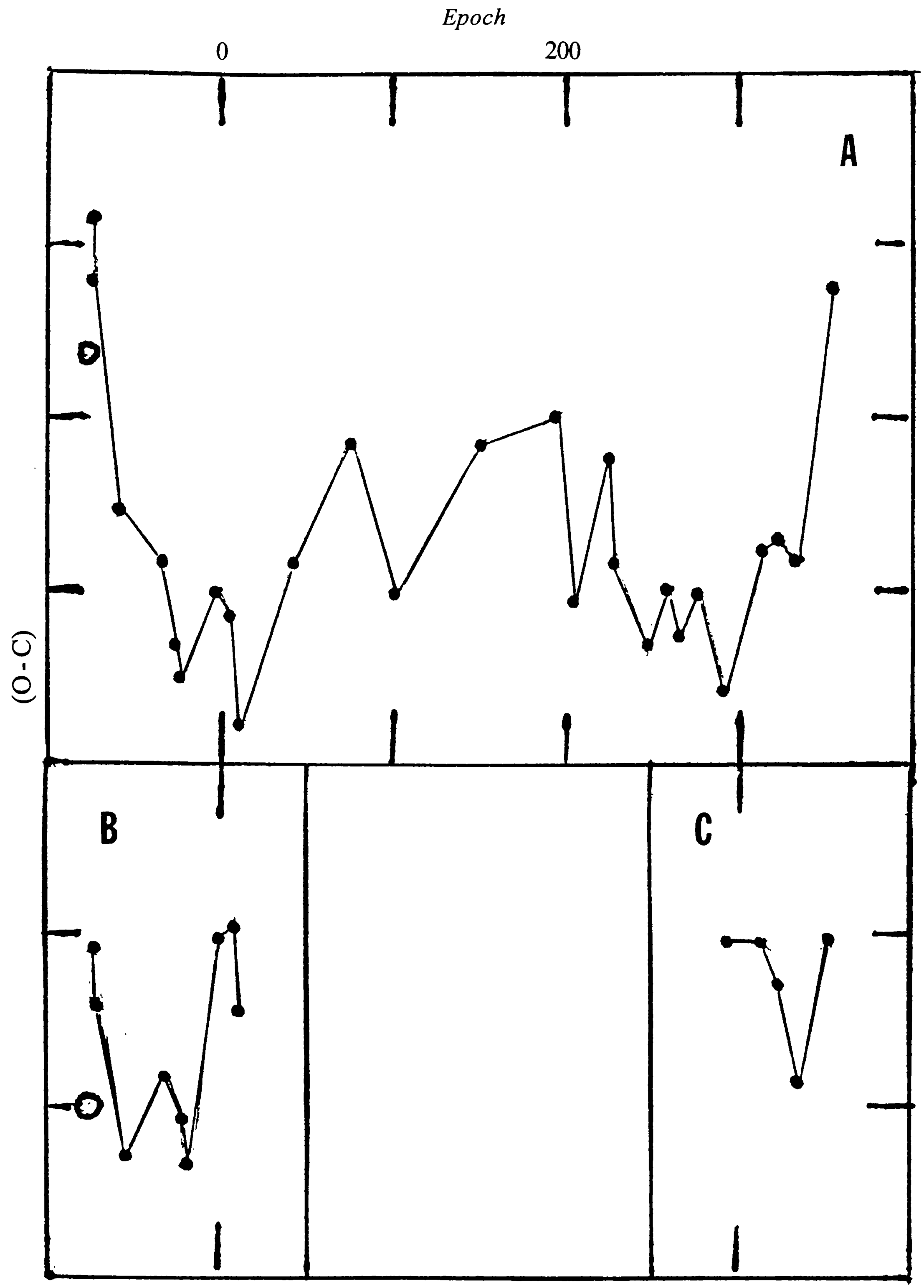

Figure 2. O-C values (A) for an average period for Mira of 331.691 days; (B) for 330.122 days for early epochs; and (C) for 333.695 days for late epochs. Ordinate markers at 50-day intervals, abscissae at 100-day intervals. The open circles give the O-C for the discovery date of the nova of 1592, spuriously suggesting that it might be a pre-Fabricius observation of Mira.

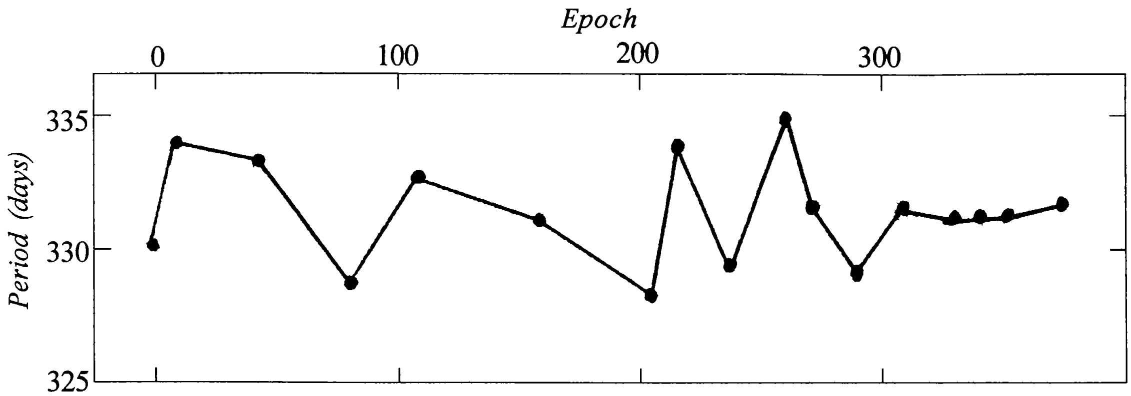

Figure 3. Changing published periods for Mira as a function of epoch.

8.6–10.1. The current *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985) gives the total range from 2.0 to 10.1v.

Figure 3 shows how previously determined periods appeared to vary from epoch to epoch. These had been determined largely from observed intervals between maxima. More recently, Fischer (1968) determined that the period appears more nearly constant when intervals between successive points of beginning of steepest ascending light curve (called "eruption points") are used to determine the period of Mira, the durations of maxima in different cycles not being the same.

The combined results, from Ho Peng Yoke's quoted observations of brightness, and within the uncertainties of position, appeared adequate to assure that the 1592 guest star could indeed be a likely candidate for Mira. However, serendipitously after this analysis, John Lee found a relatively obscure reference not cited in the *Astronomy and Astrophysics Abstracts*, namely Huang (1988), which cites Korean records of the 1592 event in greater detail than Ho Peng Yoke's compilation, giving observations spanning November 23, 1592, through February 23, 1594 (Table 3). Phases based on the period of Mira indicate that the 1593–4 observations at maximum of the 1592 guest star span 208 days uninterrupted by the daylight proximity of the sun. This amounts to 63% of Mira's period, whereas most Mira cycles are within two magnitudes of maximum only about 20% of the time. Moreover, according to Huang, the position

Table 3. The 1592 Korean guest star (not Mira).

Date		*JD*	*Mira Phase* (331.691^d)	*Comment*
1592	Nov. 2	2302853	67	First record.
	Dec. 4	2864	78	In Tien-tsung.
1593	Feb. 4	2925	135	East star in Tien-tsung.
	Mar. 4	2954	178	No record; **too close to Sun**.
	July 30	3102	- 17	Reappears in record.
	Aug. 13	3116	- 2	0.3° SW of, and as bright as 3rd star in Tien-tsung = ζ Ceti. 12 more observations.
	Sept. 20	3154	+ 36	9 statements but no record of brightness.
	Oct. 2	3166	48	As bright as ζ Ceti. 6 statements.
	Nov. 19	3214	96	Brightness slightly reduced. 32 more statements.
	Dec. 15	3240	122	Brightness reduced a little more. 6 more statements.
1594	Feb. 23	3309	191	Last record of seeing the guest star.
	Mar. 5	3320	202	**Too close to Sun** (7°).

also is more specifically defined as being only 0.3° from the third star from the east in the constellation Tsien-Tshang, which corresponds to ζ Ceti. This means that the "guest star" is approximately half-way between ζ and λ Ceti. Professor Huang states that the star could not be Mira nor a supernova (a conclusion supported by the fact that no supernova remnant has been found). Rather, it is really a nova, but with a duration at naked eye brightness of some 458 days, resembling Nova HR Del, discovered in 1967, duration about 328 days. This type of nova is rare. Payne-Gaposchkin (1957), in her treatise on novae, noted only two with durations over 300 and under 1000 days, namely X Ser 1903, 370 days, and RR Tel 1946, 525 days.

Thus this has been an example of how a logical deduction from available facts can sometimes lead to erroneous conclusions. Hipparchus' in 134 BC, and/or Aratus' over a century earlier, and the Chinese in AD 1070 are as yet the only known instances of possible pre-Fabricius discoverers of Mira.

2. The first two centennials after Fabricius' discovery of Mira

Mira has been the prototype of a vast number of long period variables now called Mira-type. The first discovered after Mira itself was χ Cygni (3.3–14.2v), by Gottfried Kirch (1639–1710) of Berlin in 1686 (Zinner 1931). By the time of the first centenary of the discovery of Mira, only three variables, other than novae, had been discovered, Mira, the eclipsing variable Algol, and χ Cygni. In the actual years of the first (1696) and second (1796) centennials of Fabricius' discovery, no new variables were discovered. By the time of the second centennial, 1796, eleven variables had been discovered, four of them Mira type (Table 4, compiled from Müller and Hartwig 1922, **2**, p. 362). All four have been searched in early catalogues to ascertain if by any chance they may have been previously observed, even if not yet suspected of variability, or had been observed unexpectedly and assumed to be novae, as was originally the case with Mira itself.

From Ho Peng Yoke, χ Cyg (3.3–14.2v) appears to have been reported as a nova 14 November 1404, and it was recorded in Hevelius' catalogue as 5th magnitude in 1639. Strangely, Ho Peng Yoke's map of the region (Figure 4) fails to show the third magnitude star β Cygni, which does appear as a third magnitude star in all the old western catalogues (Ptolemy, Al Sufi, Ulugh Beigh, Tycho, and Hevelius).

R Hydrae (3.5–10.9v) has an interesting history as to who is to be credited with its first discovery. Argelander (1869, pp. 341–2) notes that although Montanari was credited with the first discovery of R Hya in 1670, it had already been discovered by Hevelius as a 6th-magnitude star some eight years earlier, on April 18 and 19, 1662.

Table 4. Variables discovered by 1796.

Name	*Year*	*Type*	*Period*	*Spectrum*	*Discoverer*
o Ceti	1596	Mira	372	M5e-M9e	Fabricius
β Persei	1667	EA	2.87	B8V	Montanari
χ Cygni	1686	M	408	S6.2e-S10.4e	Kirch
R Hydrae	1704	M	384	M6e-M9e	Maraldi
R Leonis	1782	M	310	M6e-M9.5IIIe	Koch
β Lyrae	1784	EB	12.9	B8II-IIIep	Goodricke
η Aquilae	1784	δ Cep	7.18	F6Ib	Pigott
δ Cephei	1784	δ Cep	5.37	F5-G1Ib	Goodricke
R CrB	1795	RCB	—	G0Iep	Pigott
α Herculis	1795	SRc	—	M5Ib-II	W. Herschel
R Scuti	1795	RVa	147	G0Iae-K2pIbe	Pigott

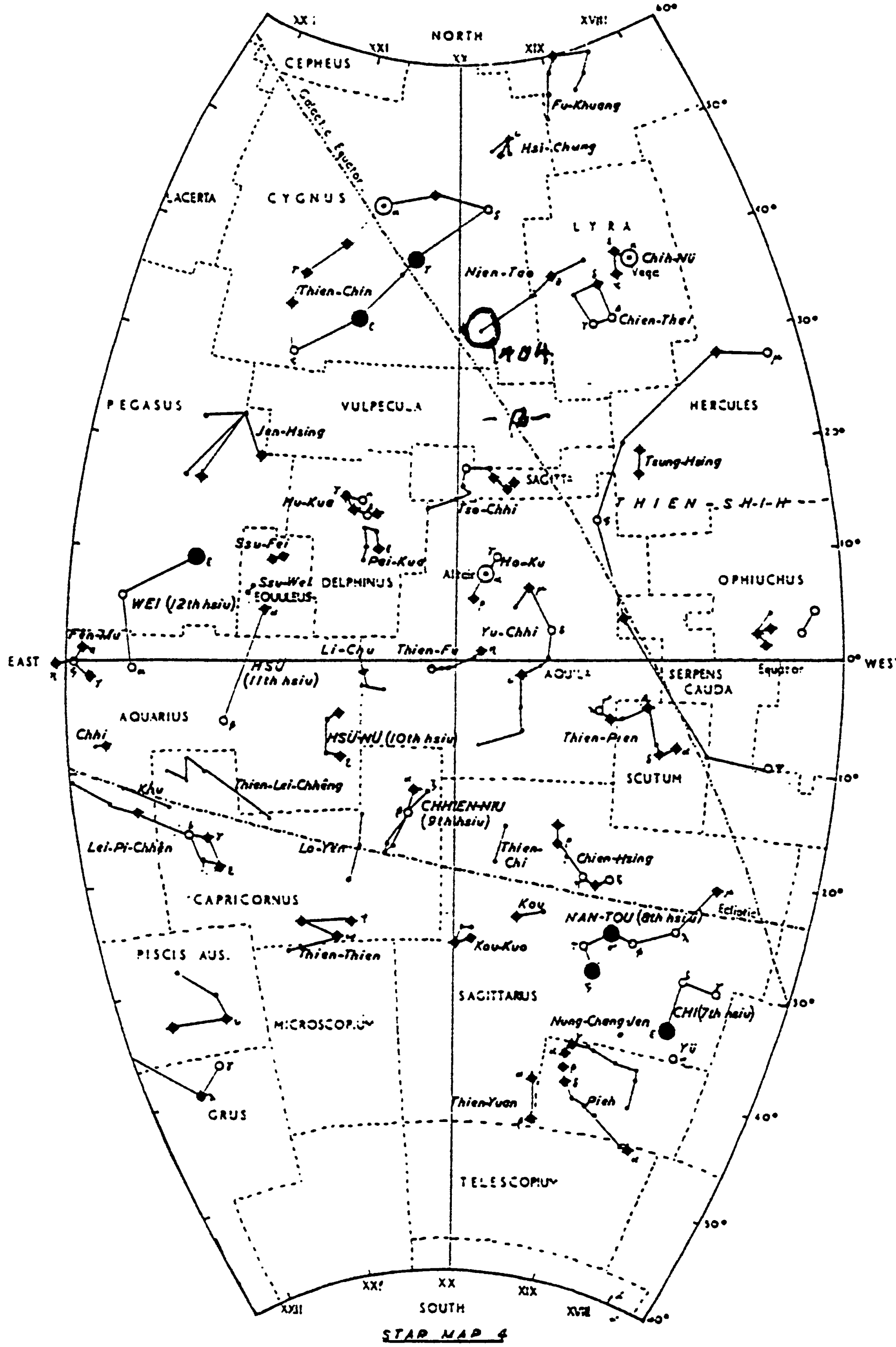

Figure 4. Ho Peng Yoke's map showing by open circle the position of χ Cygni. Note that β Cygni is missing on the map.

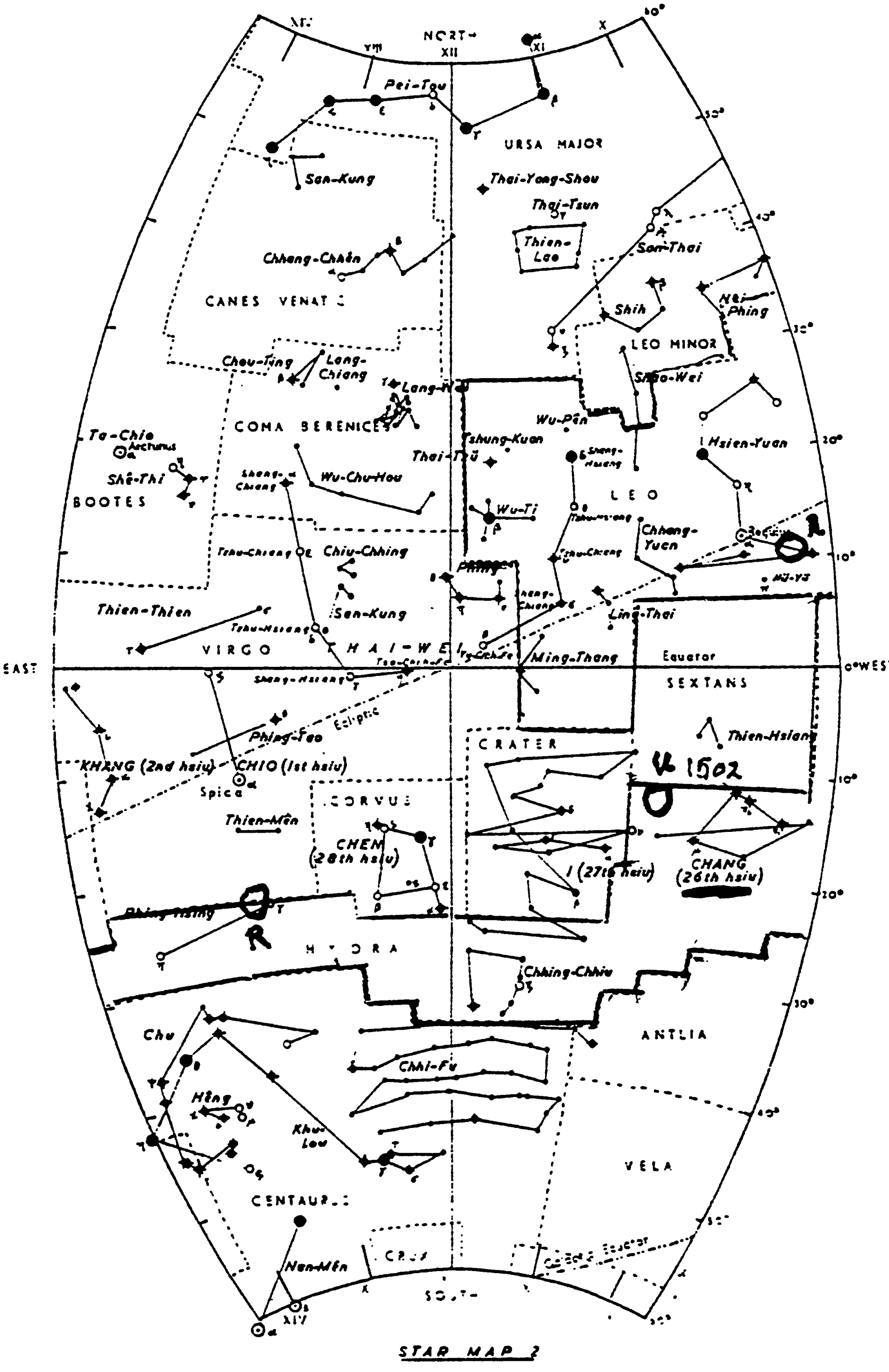

Figure 5. Ho PengYoke's Star Map 2, on which the locations of R Hya, R Leo, and U Hya (the possible nova or "guest star" of 1065 and 1502) are indicated by open circles.

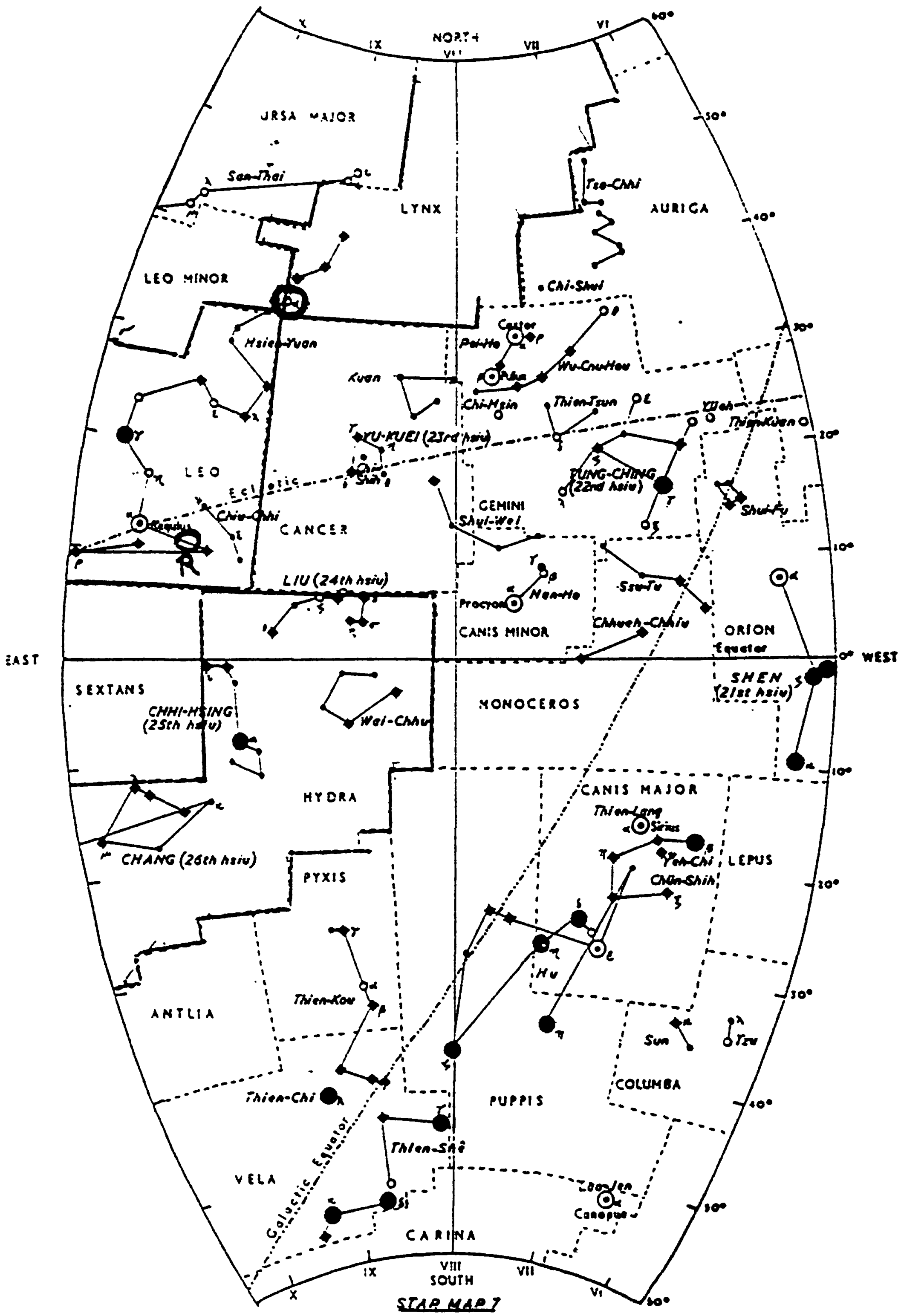

Figure 6. Ho PengYoke's Star Map 7, on which the positions of R Leo and the "guest star" of AD 101 (at the boundary between Lynx and Leo Minor) are marked by open circles.

However, Hevelius' discovery had not yet been published at the time of Montanari's discovery. Müller and Hartwig (1922, **1**), on the other hand, attribute the discovery of variability to Maraldi in 1704. Montanari had entered in pencil on a Bayer chart the position of a star he had observed but that was lacking on the chart. Maraldi discovered the chart and began in 1702 to search for the missing star, at first unsuccessfully; then in 1704, it did appear and he followed it through 1712. Clearly Maraldi clinched the fact of variability. For R Hya there seems to be no clear counterpart in Ho Peng Yoke's Chinese compilation. Although it notes two guest stars in Hydra, one in 1065 and the other in 1502, they seem to correspond to the same star, some 40° from R Hya (Figures 5, 6). The two guest stars evidently both correspond to the Mira type star U Hya, discovered by Gould in 1871 (Gould 1879; Müller and Hartwig, **3**, 24).

R Leo (4.4–11.3v) also presented difficulties of identification. In or near the constellation Leo, Ho Peng Yoke (p. 151, items 79 and 88) describes two guest stars in the Chinese configuration Hsein-Yuan. The first was found bright 22 December AD 70 to 19 January AD 71 and was followed for 48 days. The position assigned by Stephenson is 09^h40^m +25°, whereas Hsi Tsê-tsung called it 10^h +20°. These positions are 10° and 15° north of R Leo's position, but all are within the boundaries of the Chinese constellation. Hsein-Yuan is a narrow configuration extending some 30° in declination and 1.5^h in right ascension. So, specifying the constellation alone, which contains many bright stars, does not permit specific identification.

The second object, observed in AD 101, Ho Peng Yoke describes as "bluish-yellow in colour" (meaning pale green?), at the fourth star of Hsein-Yuan. Hsi Tsê-tsung says it is near 40 Lyn. The Chinese constellation embraces both Leo and Lynx (Figure 6). Counting from the northernmost star in Hsein-Yuan, some 25° north of R Leo, the fourth star is identified as α Lyn (40 Lyn). This is NSV 4456, 3.12–3.17v, K7IIIab with UV FeII emission, hardly compatible with either an ex-nova or a Mira type star, although the "guest star" might not be α Lyn but a nearby object. As the positions of both α Lyn and R Leo are well defined, a nova near α Lyn cannot be R Leo.

Argelander (1869, p. 361–5) confirmed the discovery of R Leo by Koch in 1782, but found that James Bradley had observed the star in 1753 but assumed it was 19 Leo, 6.45V only 8′ removed from R Leo, whence the two were frequently confused when only a single star could be recognized. T. Mayers, acccording to Argelander, also observed R Leo, on March 30, 1757, when the star was a third of a magnitude brighter than 19 Leo. (See also Auwers 1894, Star No. 433.) Thus the recognized discoverer of R Leo was preceded by two others, one British and the other German, about a quarter of a century earlier than Koch.

In conclusion, of the first four Mira-type variables discovered, all four—Mira, χ Cyg, R Hya, and R Leo—seem to have been observed and found to be variable before the astronomers who are generally credited with having made the initial discoveries. However, but for their independent discoveries, the earlier might still be forgotten.

3. Miras and the advent of photography

The year of the third centennial of Fabricius' discovery came after the advent of celestial photography, when new discoveries of all sorts proliferated. Through 1896, about 430 variable stars had been discovered. In 1896 alone, 45 were discovered, 23 of them Miras, 11 semiregular, and 11 assorted types. Of the 45, Williamina P. Fleming (1857–1911), Harvard's first famous woman astronomer who in 1881 had originally been appointed as a "computer," discovered 19 (11 Mira, 6 SR, 1 RV, and 1 RCB).

Between 1796 and 1896, 251 Mira type variables had been discovered, 49 of them by photography. Most visually-discovered variables had been found by pure chance, not by concerted effort for the purpose of discovery. Some were found when discordances were detected between modern observations and older catalogues or star charts, as in the case of R Hya, a previously observed star missing in the Bayer Atlas.

The first daguerreotype of a star was one of Vega in 1850 by W. C. Bond and J. A.Whipple at Harvard (Bailey 1931). But early daguerreotypes were not suitable for the purpose of discovery and there seems to be no indication that the subject was given any thought. It was only after the development of dry plate photography in the 1870s (Hoffleit 1950) that photography became feasible for the purpose of the discovery of variables. Several techniques were developed. The ones suitable for finding the relatively large amplitude stars, the Miras, included the use of stereocomparators and blink microscopes.

An early model of a stereocomparator (Figure 7) mounted two plates in parallel, with one microscope focused on the right hand plate and another microscope on the left hand (Pulfrich 1902). The plates were carefully aligned so that what the right eye of the observer saw through the right-hand microscope was exactly matched with the same field as viewed with the left eye through the left-hand microscope. Then the observer could tell which stars in the field were of differing magnitude on the two plates. With the blink microscope, only one microscope was used. A small rotating reflecting prism in the light path enabled the observer to view in rapid succession the alternate plates. Non-variable stars appeared constant in brightness whereas a variable in the field appeared to blink. This machine was also useful in detecting high proper motion stars in the field. Such a star appeared to wiggle back and forth in the period of the rotation of the prism. Luyten (1938) used such an instrument for his discovery of proper motion stars, and in the course of that work discovered or rediscovered 2350 variable stars. This procedure proved quite time-consuming. At Harvard a quicker scheme was devised, the positive-negative method. Here a negative was superimposed over a positive (very slightly enlarged) of a negative taken at a different time. As Figure 8 indicates, variables could rapidly be spotted where the upper image showed too large or too small a halo created by the slightly enlarged images on the positive. The vast majority of the approximately 12,500 new variables discovered at Harvard through 1956 were found by the positive-negative superimposition method.

The most significant epoch in the advent of photography for the discovery of variables came in 1889 when three astronomers, I. Roberts in England, J. Kapteyn in Groningen, Holland, and especially Mrs. Fleming at Harvard, each discovered one or more. Roberts made two exposures on the same plate, separated by five days, January 29 and February 3, 1889, with exposures of two and two and a half hours, respectively. The comparison of the images suggested that ten stars varied (Roberts 1889), of which six have been confirmed and are of the Orionid type, typically irregular erupting variables now classified In. Kapteyn in 1889 discovered the eclipsing binary U Col, and the Cepheid X Pup. Fleming at Harvard discovered her first variable, SR type S Cen, in 1889. But from then on she surpassed them all! In 1890 she discovered her first three Mira stars, R Cae, RS Sco, and RT Sgr. From 1890 through 1896, she discovered 62 variables, of which 49 are Mira type.

The major work for which Fleming was being employed at Harvard was helping Director E. C. Pickering develop a system of stellar spectral classification and then applying that system to the classification of multitudes of stars. In 1886, she was put in charge of classifying stars for the recently established Henry Draper Memorial. That year Pickering noted that the spectrum of o Ceti showed hydrogen lines in emission, in addition to the absorption features of M-type spectra. Pickering seems to have overlooked the fact that Secchi already made the same discovery almost two decades earlier, without, however, identifying the lines with hydrogen. Secchi's is the earliest description of a spectrum of Mira, which he observed on November 27–29, 1867, with a direct vision spectroscope in his program for setting up his system of spectral classification. He

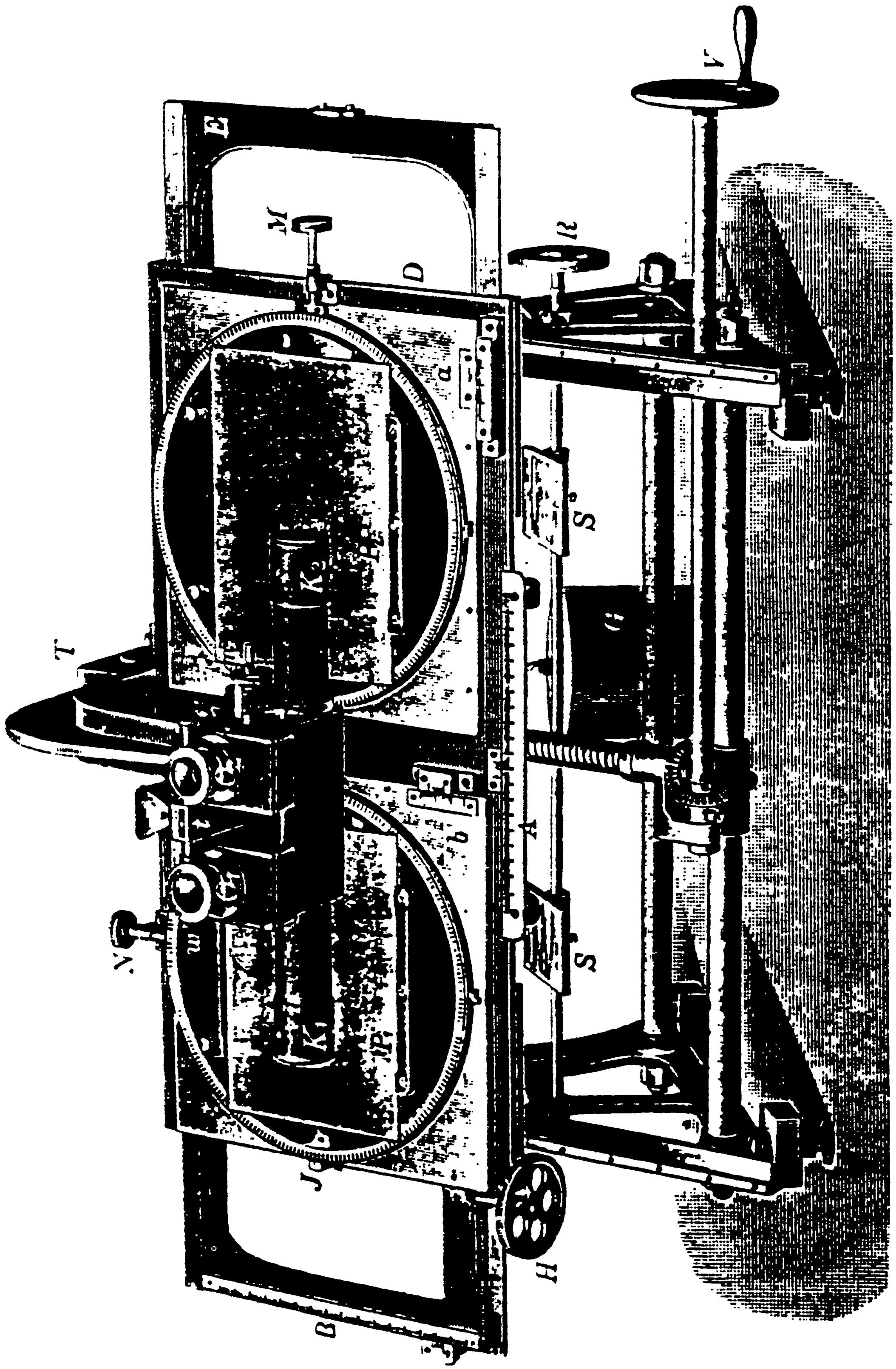

Figure 7. An early model stereocomparator, showing one microscope for viewing with the left eye the left of the two plates to be intercompared, and another microscope for viewing the right plate with the right eye. (From C. Pulfrich, 1902.)

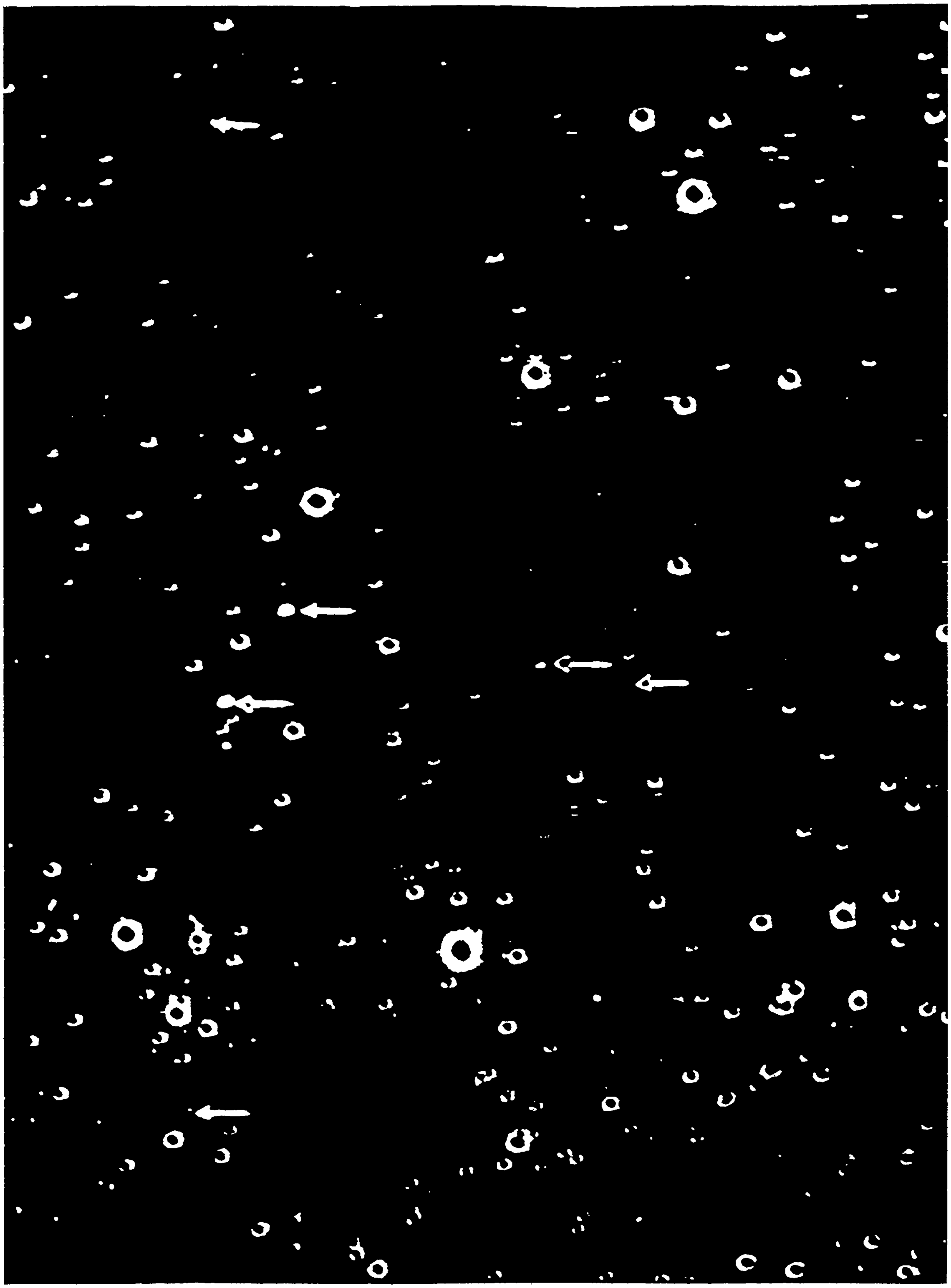

Figure 8. The positive-negative method for searching for variable stars. The positive is slightly enlarged so that all non-variable stars will show a white halo when a negative exposed at a different time is superimposed over the positive.

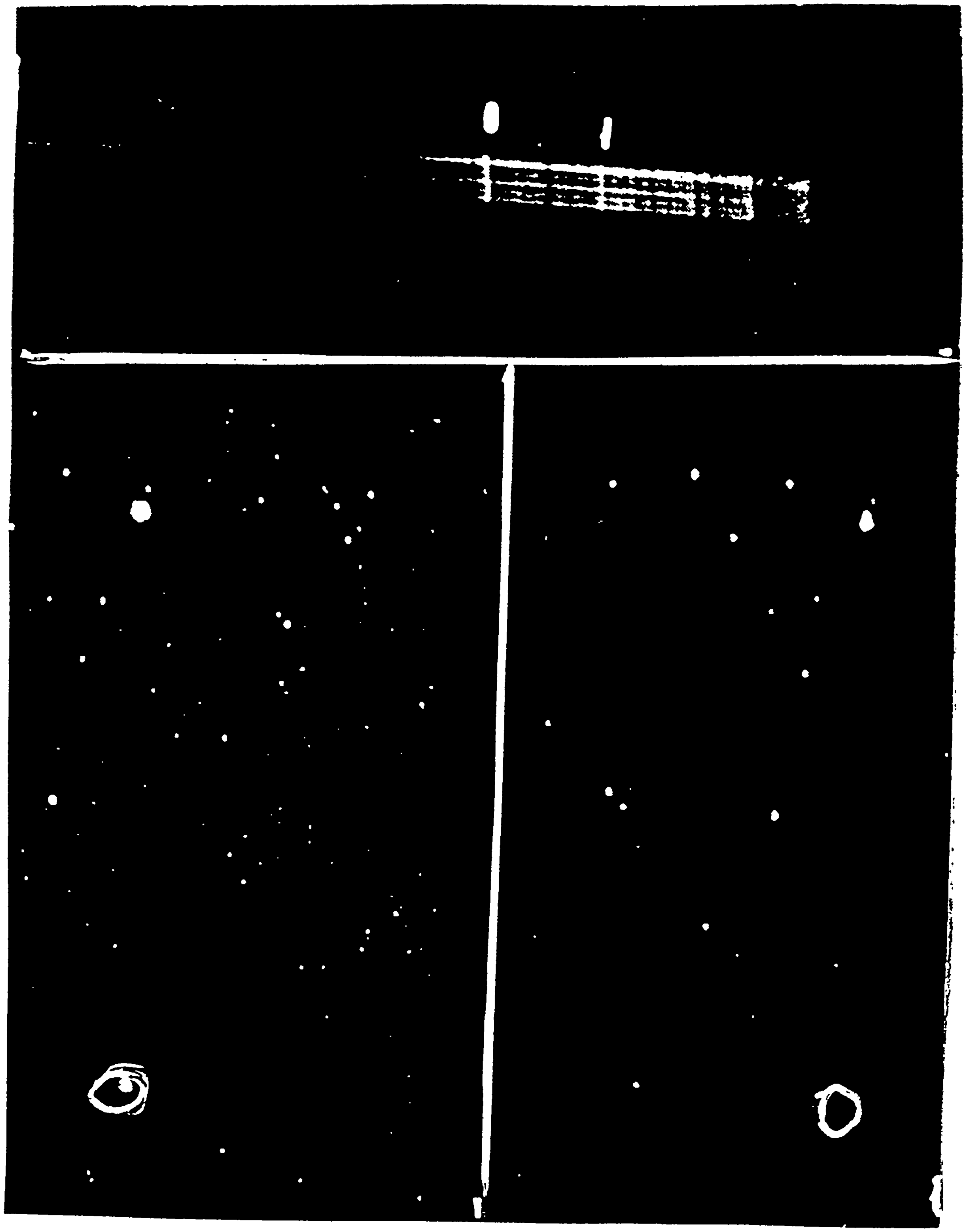

Figure 9. The spectrum of R Caelum that proved Mrs. Fleming's contention that a single spectrum would be sufficient to recognize a star as a Mira-type variable. It clearly shows the characteristic Hydrogen lines Hγ and Hδ in emission. The two lower diagrams are copies of chart plates used to confirm the variability. The left hand picture shows the variable at about maximum brightness, the right at minimum.

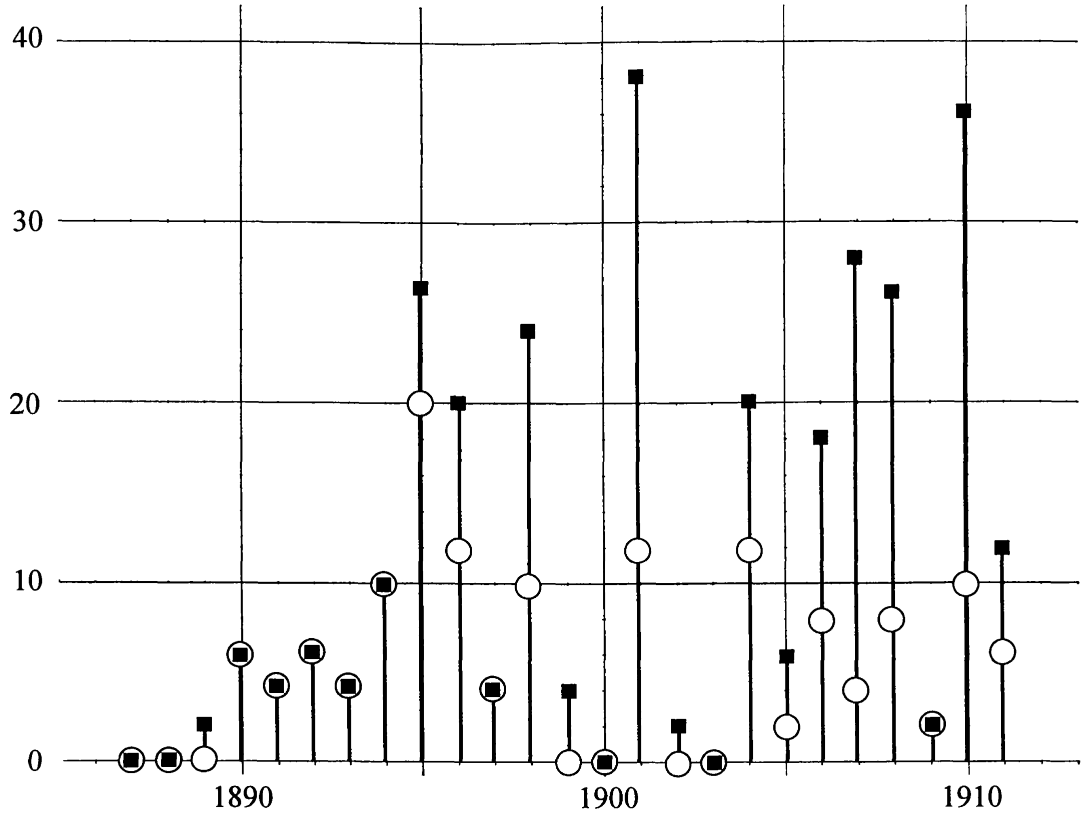

Figure 10. Annual discoveries of all types of variables by W. Fleming, 1887 through 1911 (black squares), and the corresponding numbers of Mira type stars (open circles).

described Mira as then of 3rd magnitude, ruby red in color, with a Secchi Type III spectrum (Secchi 1869; Merrill 1940). He stated, "Les lignes sont plus lumineuses et tranchées qu'en β Pégase" [the lines in the spectrum are brighter and more sharply defined than in β Peg]. β Peg is now classified M2.5II-III, as contrasted with Mira, M5.5-9IIIe.

Fleming, also in 1886, found that the spectrum of U Orionis was similar to that of Mira and confirmed its variability. When the star was first discovered by Gore in 1885, it was assumed to be "either a new star or a remarkable variable" (Gore 1886). In 1890, Mrs. Fleming found a similar spectrum for the star now known as R Caelum, ascertaining that it, too, showed the hydrogen lines in emission (Fleming 1890; Figure 9). Professor Solon I. Bailey at Harvard's southern station in Arequipa, Peru, took plates to help verify that the star was indeed a variable. With further such discoveries, Fleming surmised that all stars with such spectra were also variable. Hence she

Table 5. Numbers of Mira variables and percentages of all variables.

Year	*Total Number Mira*		*Total All Types Except Novae*	*% Mira*
Through 1596	1		1	(100)
1696	2		3	(67)
1796	4		11	(36)
1896	251	75 by photography	430	58
1996	6160±	Most by photography	31187	20

concluded that a Mira-type variable could be discovered from the observation of a single spectrum plate—a quick discovery in comparison with painstaking intercomparisons of many chart plates. Of course, her discoveries by means of the spectra did have to be verified by at least a sampling of chart plates, but that was quicker than blinking plates for original discoveries.

At Harvard's southern station in Peru, Professor Bailey had assistants taking the objective prism plates for the Henry Draper Memorial. After Mrs. Fleming's announcement that red stars with the peculiar hydrogen emission lines were probably all variable, Bailey's assistants, who were supposed to examine the plates they had taken for adequate quality, found a number of such new variable stars. Fleming protested that the discovery of such objects was her prerogative, and that the Arequipa assistants should desist. Bailey replied that taking the photographs required far more work than the easy detection of the bright lines in the spectra; that she was not the only one to have reason for complaints; the assistants should have the satisfaction of some small rewards for their work (Jones and Boyd 1971).

All told, between 1889 and 1911 Fleming discovered some 280 variables, of which 125 are Mira type (Figure 10).

4. The proliferation of discovery of Mira-type stars

Table 5 shows by century the proliferation of discovery of Mira-type variables from 1596 through 1996, and adds the total numbers of all types of variables (excluding novae), and the percentage of all variables that are Mira type. The first three centuries are represented by too small numbers to have much significance, except for the self-evident fact that stars of high amplitude are more easily discovered than small amplitude stars. The pronounced decline, percentage-wise, in the last century can be attributed to the advent of photoelectric photometry. Now the majority of newly-discovered variables have amplitudes far too small to have been detected earlier by either visual or photographic techniques. For stars brighter than, say, 15th photographic magnitude, vast numbers of Mira type were discovered, especially in the pre-1960 era when systematic surveys were being carried out at Harvard and at numerous European observatories. Among the naked eye stars in the *Bright Star Catalogue*, all five of the editions since 1930 have indicated the same 28 Mira-type stars (Schlesinger 1930; Schlesinger and Jenkins 1940; Hoffleit 1964; Hoffleit and Jaschek 1982; Warren and Hoffleit 1996). The 1922 edition of the *Geschichte und Literatur des Lichtwechsels* also already contains all 28, all but one having been discovered by 1896 (the last, W And, found by Anderson in 1899). Like the first four Mira stars discovered by western astronomers, at least a third of the 28 seem also to have been discovered earlier and designated as guest stars or novae in ancient and medieval records (Ho Peng Yoke 1962), but my search has not been exhaustive.

The most recent edition of *Name Lists of Variable Stars* (Kazarovets and Samus

Table 6. The decline of Mira discoveries, and the preponderance of low amplitude discoveries in the age of photoelectric photometry.

Source	*Year*	*All Var.*	*Mira*	*Amp. <0.5*	*Mira/Low*
GuL	1896		27	3	9.0
"	1922	2007	28	14	2.0
BS3	1964	1961	28	100	0.28
BS4	1982	2001	28	790	0.035
BS5	1996	2335	28	>1310	0.021

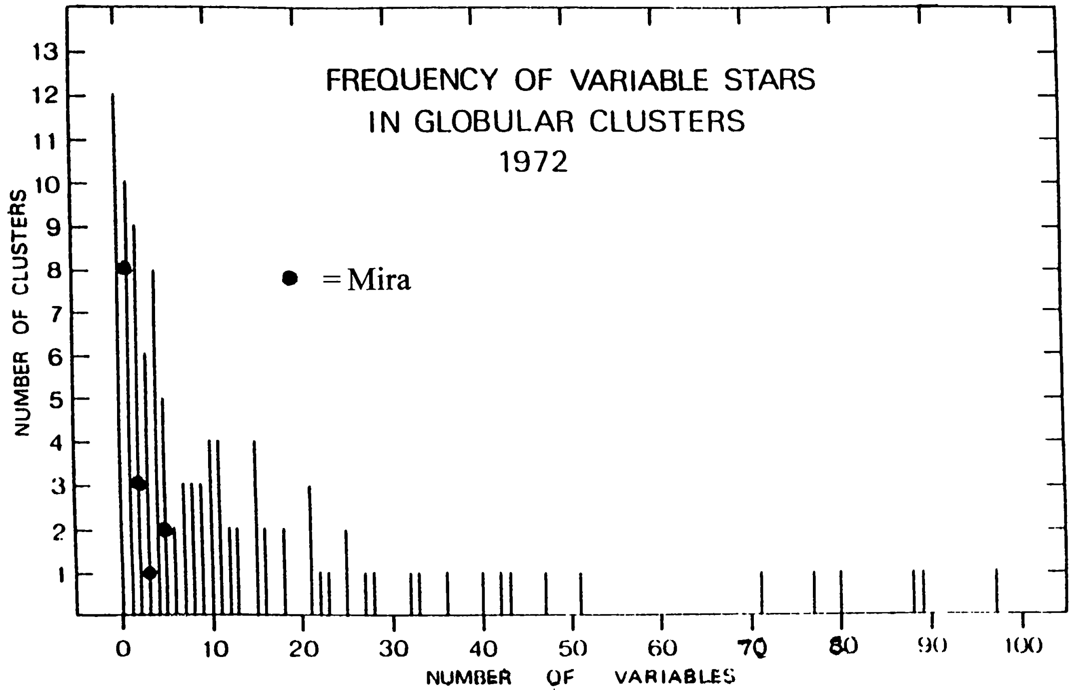

Figure 11. Frequencies of all variables and of Miras (large dots) in globular clusters. (From H. Sawyer-Hogg 1973.)

1995) includes 44 new Mira-type stars with V magnitudes, the brightest 10.0 at maximum, the others ranging to 14.2V at maximum. By contrast, Table 6 indicates the rapid proliferation of discoveries of bright stars with amplitudes less than half a magnitude in whatever color photometry was used. The numbers increased from three in 1896 to 100 in 1964, to over 1310 in 1996. As higher-precision techniques become progressively available, eventually all stars will presumably be found to be at least slightly variable.

5. In the direction of globular clusters

M. W. Feast (1973) presents results on Mira stars in the directions of 14 globular clusters. Included among them are 8 foreground Mira-type field stars, 5 Mira-type members with determined periods, and 9 stars with Me spectra—probable Miras, but whose types of light variation had not yet been determined.

In her final catalogue of variable stars in globular clusters, H. Sawyer-Hogg (1973) listed 2119 variables found in a search of 108 clusters. The numbers of discoveries ranged from none in 12 clusters to 212 in NGC 5272. Their distributions are shown in Figure 11, where the numbers of stars with periods over 150 days are indicated by large dots. Most of these have not been specifically designated as to variable type, but many are presumably Miras. As foreground stars are not always identified as such, even those that are so identified have been included. In the line of sight of fourteen of the clusters, a total of 27 variables with periods over 150 days have been discovered, or 1.3% of all the variables discovered in the fields of globular clusters. Obviously, globular clusters are not the happiest of hunting grounds for this type of variable. Table 7 summarizes the percentages of Miras among the variables in globular clusters, the GCVS (Kholopov *et al.* 1985), and in the current *Bright Star Catalogue* (Warren and Hoffleit 1996).

Table 7. Numbers of variables and percentages of Miras.

Source	*Total Var.*	*Mira*	*% Mira*
Clusters	2119	27	1.3
GCVS	31187	6160	19.8
BS5	2335	28	1.2

6. Summary

The first four Mira-type variables discovered by Europeans (Mira, χ Cyg, R Hya, and R Leo) had all been seen earlier, mainly by the Chinese or Koreans, who called them guest stars. After the advent of the application of photography for the systematic searches for variable stars, the numbers of discoveries rapidly proliferated. Then the introduction of wholesale classification of spectra on objective prism plates and the consequent discovery of the uniqueness of spectral characteristics of both novae and Mira-type long period variables expedited the discovery of these types of variables. Thus by the first, second, third, and fourth centennials of Fabricius' discovery, the numbers of recognized Mira-type stars increased respectively to 2, 4, 251, and 6160. Among the naked-eye stars the search for Miras appears to be complete, no new ones having been discovered since 1899. Still the most numerous of all the different types of known variables, their rate of discovery is declining, whereas the advent of photoelectric photometry has produced much higher rates of discovery of stars of such small amplitude that they could not have been discovered by the older visual and photographic techniques. The rare discoveries of the past have now become commonplace objects, yielding place to newer types of discoveries.

The history of the discovery of Mira itself represents a lesson in caution. "New" discoveries have frequently been found to be rediscoveries of forgotten past discoveries. On the other hand, sparse old observations may mistakenly, though logically, be misidentified as pre-discovery observations of now well-known variables, as in the case of the mistaken identification of the nova of 1592 as Mira.

7. Acknowledgements

I should like to thank Janet Mattei for inviting me to give this after-banquet talk at the AAVSO meeting celebrating the 400th anniversary of Fabricius' discovery of Mira. The fascinating search of the literature on the discovery of this wonderful star and other Mira-type variables I would otherwise not have undertaken.

To Professor Horace Smith of Michigan State University I am grateful for his calling to my attention Clark and Stephenson's *The Historical Supernovae*, which served as a check on some of my own tentative conclusions on early "guest stars," their crude inferred positions notwithstanding.

John Lee at Yale kindly supplied me with copies of original Chinese constellation maps and interpreted their symbolism for comparison with the maps included in the important paper by Ho Peng Yoke, and explained the conversion from the Chinese calendars to Gregorian. Most importantly, he found and abstracted for me a little-known Chinese publication revealing more detailed observations of the guest star of 1592 than were known from Ho Peng Yoke's compilation. Thanks to John Lee, I have been able to establish that the nova of 1592 cannot be Mira, as has on numerous occasions been rather logically inferred on the basis of the more sparse earlier published data.

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