LONG-TERM BEHAVIOR OF MIRA CETI MAXIMA

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Abstract

We gathered the maxima of Mira Ceti (1596–2000) in order to evaluate the frequency of two consecutive bright apparitions. We did an evaluation of the correlation between two following maxima in order to verify the probability of occurrence of two consecutive bright maxima.

Analyzing the maxima of Mira, we found a probability of seeing it brighter than α Ceti once every 21 years. In this case, as in February 1997, Mira can be detected at the first sight as a new component near the most significant asterism in its zone, composed of α, γ, and δ Ceti.

We found also a correlation between the magnitude of two consecutive maxima described by the linear fit:

$$M_{i+1} - M_i = -(1.10 \pm 0.08)\, M_i + (3.74 \pm 0.26), \text{ with } R = -0.74.$$

This study was done to test whether Mira could have been the Star of Bethlehem and fulfilled the hypothesis suggested by Kepler of a new star that appeared during the triple conjunction at 1° of Jupiter and Saturn that occurred in 7–6 B.C.E.

1. Introduction

Mira is a variable star, well visible to the naked eye at its maxima, officially discovered in 1596 by the Lutheran pastor and astronomer David Fabricius (1564–1617) in the little town of Osteel, East Frisia (northwest Germany). He was a correspondent of Johannes Kepler. We have considered the possibility that the Bible's Gospel of Matthew could report the earliest observation of Mira. In fact, Mira fulfills the basic requirements to be the Star of Bethlehem as described in the Gospel according to Matthew (Mt 2:1–12). Mira was visible at least two times with a time interval (not specified in Mt text) in which it disappeared. Moreover, Mira was close (15°) to the position were the triple conjunction of Jupiter and Saturn at 1° occurred in the years 7–6 B.C.E. and it could be the new object—*aliquid novi*—which Kepler considered a direct consequence of the conjunction (Kepler 1614). Mira could have been observed during that period by ancient astronomers, as probably the Magi were, who studied the same conjunction. The discovery of Mira in 1596 and its second observation 12.5 years later also occurred when Jupiter approached it at 20°.

We studied the maxima of Mira in order to evaluate both the frequency of one and of two consecutive bright apparitions. We did an evaluation of the correlation between two successive maxima in order to verify the probability of occurrence of two consecutive bright maxima, because that condition would have been indeed the most favorable for the candidature of Mira as the Bethlehem Star.

2. Mira maxima variability

We studied two aspects of its variability: its maxima and their time correlation, and the probability of seeing two consecutive bright maxima.

2.1. Databases

We did this study on the data gathered from the books of Paul Guthnick (1901) covering the period 1596–1899, E. W. Pickering (1900), Müller and Hartwig (1920), and in the works of Leon Campbell (1918, 1955) for covering the period at the turn of the nineteenth century, and the AAVSO International Database (Mattei *et al.* 1990; Mattei 2001) covering the period 1906–2000. We gathered the largest record of Mira maxima nowadays available: 212 values. Among those maxima 175 are consecutive.

2.2. The work of Paul Guthnick

Guthnick (1901) gathered several observations of Mira made before and after the introduction of the method of Argelander (1839) for determining the magnitude of a variable star. Different observers used different reference stars. Guthnick converted to Argelander's units all the determinations of Mira's magnitudes made by comparison with known stars by different observers; he used the least squares method for calculating the magnitudes of the reference stars observed by them. The whole dynamical range from maximum to minimum for Mira is 70 Argelander units. Guthnick gives a table of the observed maxima of Mira (1596–1899); a table of minima spans the years 1855–1900.

2.3. Calibration

The visual magnitudes of the reference stars used in Guthnick's sample and by the AAVSO (assumed homogeneous with Campbell's magnitudes) have been calibrated with the photometric Johnson V magnitudes presented in the *Bright Star Catalogue*, fifth edition (Hoffleit and Warren 1991). The magnitudes in Müller and Hartwig (1920) were obtained by several visual observers taking the average value for each maximum with its variance as intrinsic uncertainty. All the other uncertainties have been considered ±0.1 magnitude.

3. Results

3.1. The average of Mira's maxima

William Herschel observed the maximum brightness of Mira (1.3) on November 9, 1779 (Guthnick 1901). Friedrich W. A. Argelander (1869) observed the faintest, which occurred November 11, 1868 (5.1). The range of Mira maxima is 3.8 magnitudes. The average magnitude of maximum calculated for 212 values spanning 404 years is 3.40 with a standard deviation of 0.66.

We defined bright maximum when Mira is as bright as α Ceti, which is magnitude 2.5 and is the brightest neighboring star in a region fairly poor in bright stars. In those cases, in past ages Mira could have been easily spotted if one was looking in its direction. In fact, it appears at first sight as a new component near the most significant asterism, composed of α, γ, and δ Ceti.

The Gaussian fit (with reduced $\chi^2 = 0.89$) of the number of occurrences versus magnitude (Figure 1) yields a mean magnitude of the maxima of 3.46 with a standard error of 0.044, a standard deviation of 0.606, and a cumulative probability to have a bright maximum (brighter than magnitude 2.5) of 5.6%. Our sample of Mira maxima is not really complete, because Mira is not observable when in conjunction with the Sun (from April to June) for about 3 cycles out of 12. So the probability of seeing Mira in a given year shining as a bright star drops to 4.2%, namely to once every 24 cycles or 22 years.

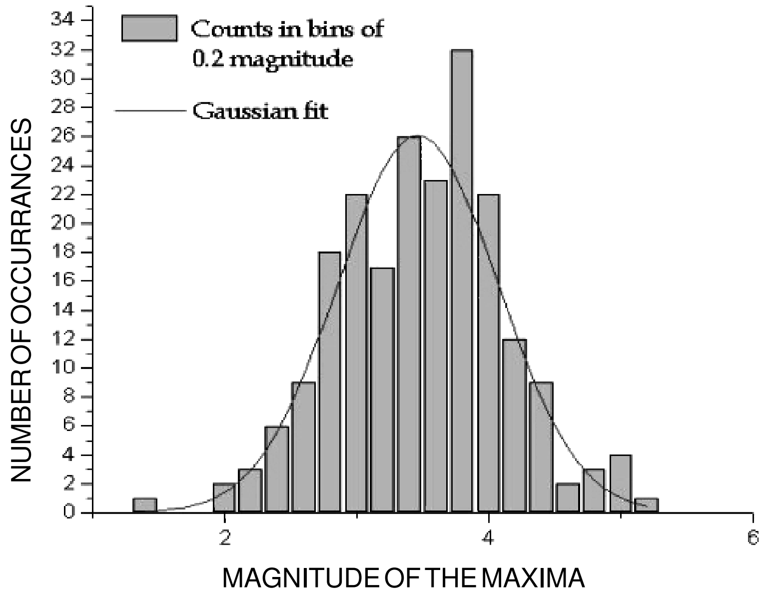

Figure 1. Frequency distribution of magnitudes at maximum of observed cycles for Mira Ceti 1596–2000.

3.2. The correlation between two consecutive maxima

In order to determine the probability of having two consecutive bright maxima we have to verify if the brightness of the maximum of Mira is a random function of time. In this case the probability would be the square of the probability of a single bright event. We plotted the brightness of the maxima M_i as abscissa and the difference $M_{i+1} - M_i$ as ordinate (Figure 2) and we found a linear dispersion of the data with correlation parameter R = -0.74. That yields an indication of time correlation between Mira maxima on a time scale of a single period. The best fit of the linear regression is the following equation:

$$M_{i+1} - M_i = -(1.10 \pm 0.08)\, M_i + (3.74 \pm 0.26), \text{ with } R = -0.74.$$

4. Discussion

4.1. Perception in ancient Astronomy: psychological implications

The problem of understanding why Mira was discovered so late remains open. Helen L. Thomas (1948) suggested that in ancient Astronomy a general lack of interest in magnitude determinations and the lack of good star charts made possible only the discovery of a few bright novae, leading to a late discovery of Mira. We examined statistically the brightness of Mira's maxima and its eventual time correlation: those parameters could have been crucial for allowing an earlier discovery of Mira.

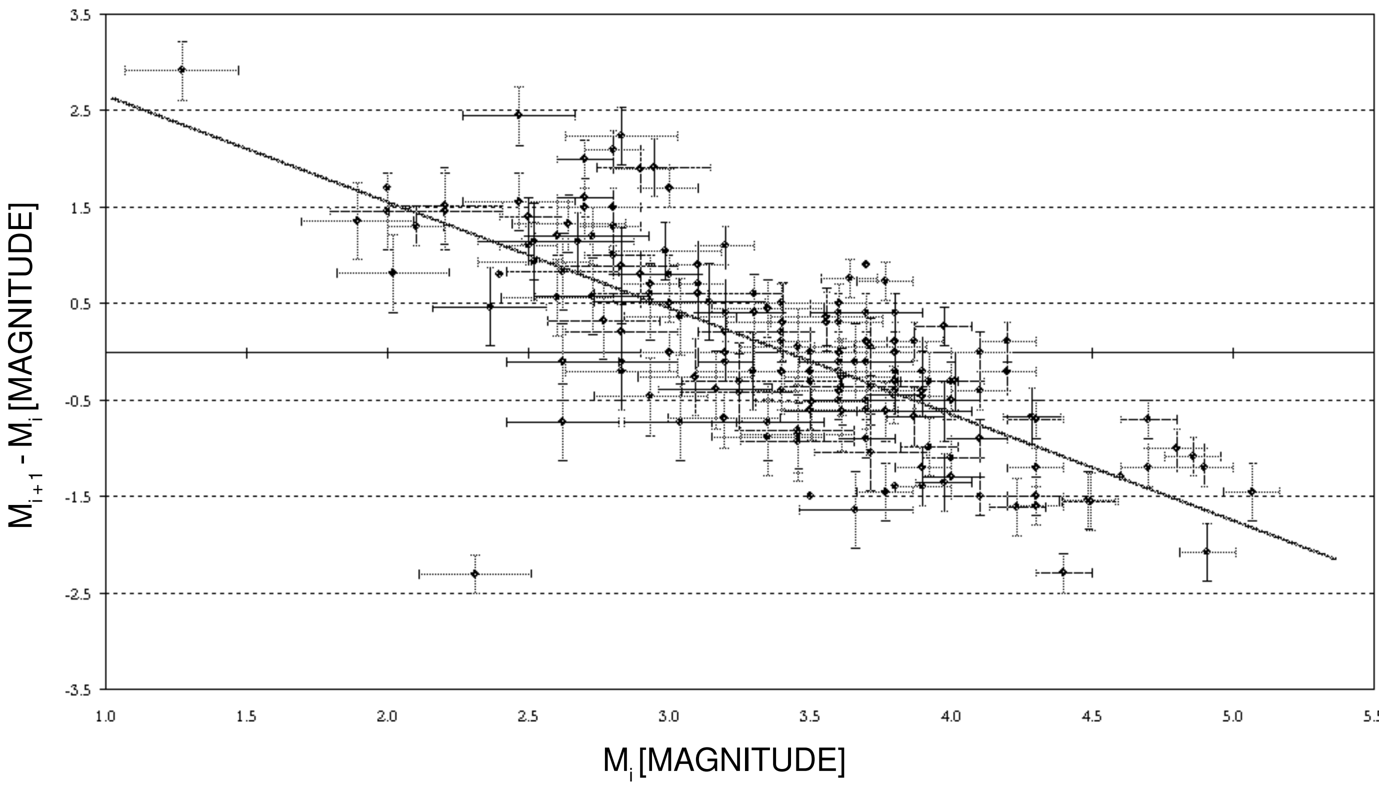

Figure 2. For Mira Ceti, correlation of magnitudes at maximum with difference in magnitude of successive cycles, according to $M_{i+1} - M_i = -(1.10 \pm 0.08)\, M_i + (3.74 \pm 0.26)$, with $R = -0.74$. The straight line is the linear regression fit to the data (diamonds).

4.2. Different kinds of attention in Psychology

The statistical results on Mira maxima leave an open question: why Mira was discovered as variable only in 1596. Its discovery should have been fairly probable at least once every 24 cycles, or 22 years, for ancient astronomers who observed during all the night, or every 44 years if we also want to consider occasional observations made before midnight. The question can be posed in other words: "If a new star of average magnitude (not too bright, not too faint) appears in the heavens, which condition is more probable for it to be discovered by naked-eye observers: to appear in a constellation made by bright stars—as in Orion, for example—with well known geometries, or to appear in a region fairly poor in bright stars—like Pisces?"

According to modern Psychology, in order for an item to be noticed in a field of other items, it must be attended (Mack and Rock 1998). In general, we tend not to see things that we do not expect. There are two ways for an item to be attended: either a person can voluntarily allocate attention to it: the endogenous attention, obtained typically via a search; or the item can automatically capture attention: the exogenous attention. An example of the former is searching around your desk for your lost keys. Examples of the latter include items which suddenly appear from nowhere, items which suddenly loom toward you, such as a single red item in a field of blue items (Egeth and Yantis 1997). If a new star (or supernova) were to appear suddenly in the sky precisely when somebody happened to be looking up, then it would be more likely to capture attention, and thus be noticed, in a relatively sparse region, because the sudden change in luminance would create a larger transient due to the greater contrast with the surrounding area (Scholl 2001).

Mira rises from sixth magnitude to maximum in about 100 days (Fischer 1969a), not quickly enough to be a sudden apparition and to justify a case of exogenous attention by observers, unless the maximum appears just after the period of the conjunction with the Sun. This happened to the discoverer, David Fabricius, on August 13, 1596 (Fabricius 1605; Kepler 1606). However, in the far more likely case in which somebody is only stargazing after the fact, the star would only be noticed via endogenous attention. It would have to appear in an area which somebody is likely to watch, and to be noticed as a "new" star; it would have to conflict with a stored representation of that area of the sky. It would be more likely to be noticed in Orion, since the representation of Orion is relatively robust and specific, in that each star plays a distinct role (these are the waist, these are the shoulders, etc.). In the case of Pisces, these roles are not so distinct, and so the observers' internal representations would be fuzzier, *i.e.*, the circlet in Pisces would be stored as "as circle," rather than as a specific arrangement of stars. A new star could thus just be added to the circle, without being noticed. A perception-memory experiment could be set up for evaluating those statements from a statistical point of view (Scholl 2001).

Psychology evidences how a discovery of a "new star" among a field of relatively faint stars would be possible if the attention of the observers is already oriented to look for small modifications of that field. Good star charts could have improved the endogenous attention of ancient astronomers, in agreement with the conclusions of the earlier study by H. L. Thomas.

4.3. The discovery of Mira by David Fabricius

The discussion on perception in Astronomy is confirmed by the circumstances reported by the discoverer himself (Fabricius 1605) in the correspondences with Tycho in 1596 and Kepler in 1609. Here we report the integral text of the letters of David Fabricius included in the volume De Stella Nova in Pede Serpentarii of Kepler, for describing the supernova of 1604 (Kepler 1606):

> Agnosco testimonium tuum in Opticis de novis stellis et item de illa stella anni 96. Ceti et adjungo observationes D. Tychoni aliquando communicates: Cum 3/13. Aug. a. 96. mane ♃ observarem, vidi claram stellam versus merid., paulo majorem stellis 3 in capite Arietis eratque rubri coloris. ♃ distabat ab ea 20°31'. ♃ tunc in alt. merid. in ortu ☉ erat 50°7'. 11/21. Aug. stellae hujus novae altitudinem merid. quadrante capiebam 31°30', ♃ tunc ab ea distabat 20°35', decl. mer. datur 4°51', locus in 25°47' ♈, lat. mer. 15°54 ½', asc. recta 29°39'. Oriebatur in elevatione nostra 53°38' cum 13°15' ♊, occidebat cum 14°45' ♈, culminabat cum 1°51' ♉, distabat a cauda Ceti 27°50', a mandib. Ceti 12°51', a tertia ♈ 26°36'. Erat secunda magnitudinis. Hae observationes sunt certae. Post Michaelis festum disparuit.

> **Ex literis diei 12.22 Mart. 1609.** Cum 5. Feb. ☌ ♃ et ♂ futuram observarem, animadverti in Cete stellam insolitam, quam statim observavi. Cum in globo quaererem distantias, vidi eas convenire ad locum stellae in globo annotatae, quam anno 96. in Aug. et Sept. observavi, quae ab eo tempore a me visa non erat. **Res mira**. Testor Deum me ita bis diversis temporibus vidisse et observasse, et quod notandum, Jupiter fere ad eundem locum pervenerat, in quo anno 96. erat. **Non possum satis mirari Dei Opera admiranda**, et vides hinc mi Keplere, meam de novis stellis et cometis esse veram, quod non de novo creentur, sed priventur saltem interdum lumine et sic cursus suos nihilominus perficiant. Quando vero Deo visum fuerit, nobis aliquid praeter ordinem significare, accendit illa corpora invisibilia, ut appareant et in publicum prodeant. Ego puto, me non falso conjectasse antea de istis corporibus aethereis. In fine Februarii adhuc vidi, nunc ob Lunae radios animadvertere non potui. Quaero an vos eam quoque videritis aut quemquam observasse audiveritis? Sententiam tuam de his scire aveo. **Res mira et vera**. Locus ejus, ut in tractatu Germanico de nova stella scripsi, in 25°47' ♈, lat. aust. 15°54'.

Translation:

> I know your report in Optics regarding the new star [of 1604] and also of that star of year [15]96 of Cetus and I add the observations sent sometime to Tycho: When in the morning of 3 [Julian calendar] / 13 [Gregorian Calendar] of August of 1596 I observed Jupiter, I have seen a bright star towards South, slightly brighter than the star 3 in the head of Aries and it was of red color. Jupiter was 20° 31' from it. At that time Jupiter was 50° 7' of altitude in the South meridian, when the Sun rose. On August 11/21 I have measured 31° 30' with the quadrant the meridian altitude of this new star. Then Jupiter was 20° 35' from it, being [this new star] at South declination of 4° 51' in the 25° 47' locus of Aries, South latitude 15° 54' 1/2 [with respect to the ecliptic], right ascension 29° 39' [all coordinates are consistent with the equinox epoch of 1600]. In our latitude of 53° 38' it rose with the 13° 15' [locus] of Gemini, it set with 14° 45' of Aries, the transit occurred with 1° 51'[locus] of Taurus, it was 27° 50' from the tail of the Cetus, 12° 51' from its mouth, 26° 36' from the third star of Aries. It was of second magnitude. Those observations are certain. After the feast of Michael [the Archangel, on September 29, reliably of Julian Calendar] it disappeared.
>
> From the letter of 12/22 of March 1609. On February 5 observing the incoming conjunction of Jupiter and Venus [occurred on March 26], I have seen an unusual star in Cetus. Measuring with the sphere (globe) the distances, I have seen that they were showing the place of the star I have noted on the sphere (globe), which I observed in August and September [15]96, and which I have not seen since that epoch. Wonderful thing! I witness to God to have seen and observed twice in so different times and, what is to be noticed, Jupiter was almost in the same place of that one of [15]96. I can't enough contemplate the admirable Work of God, and see here, my Kepler, that my [star] among new stars and comets is real, it is not created ex novo, but they are sometimes deprived of the light, and nevertheless they complete in this way their motions. When actually God wants to show to us something that is beyond the [normal] order mean, he enlightens these invisible bodies, letting them to appear and to move in public. I think that I have not wrongly argued regarding those bodies of ether. At the end of February up to now I have seen, now I could not observe because of the Moonlight. I ask: do you have observed it or you know someone who observed it? I desire to know your opinion on those facts. Admirable thing and true! Its position, as I wrote in the German treatise on the new star, is 25° 47' of Aries and 15° 54' of austral latitude [South from the ecliptic].

According to the text, the presence of Jupiter in the neighborhood of Mira was crucial for both those observations of Fabricius. His attention was captured by the new star only because he was studying Jupiter. And after 12 whole years he again saw Mira because Jupiter was again approaching that zone of sky.

Johannes Bayer in 1603 evaluated Mira at magnitude 5, assigning to it the fifteenth letter of the Greek alphabet— "ο"—so its magnitude was between that of one of the stars before "ο" and one after "ο": comparing with the modern values of the magnitudes of γ, μ, ν, π, σ, and τ Ceti (Hoffleit and Warren 1991), the magnitude of Mira was probably 4.6±0.5 when Bayer observed it during the compilation of his *Uranometria* (Bayer 1603).

The measurements of position of Jupiter prompted Fabricius to measure angular distances to nearby bright stars; among them there was one new at 20° (a case of exogenous attention). Johannes Bayer in 1603 recorded Mira in his charts, without recognizing that it was not present in the Ptolemy catalogue (Grasshoff 1990). This is a case of endogenous attention, not fully attentive.

4.4. Other studies on variable star maxima

Since the brightest maxima occurred in 1660, 1779, 1839, and 1898, Guthnick (1901), analyzing his time series with a polynomial of sinusoids, predicted a peculiar maximum in 1957–1958, but nothing peculiar happened.

The variability of the period of Mira has been studied statistically by Eddington and Plakidis (1929) for the period 1596–1928 (this is also not fully covered because sometimes Mira was not observed or its maximum occurred when in conjunction with the Sun), showing that the period is a constant value plus a random contribution that is not the intrinsic uncertainty of some days in the determination of the maximum's date because the maximum itself is not sharply defined. This study immediately suggests that a prediction of maximum dates two millennia before now is meaningless.

Koen and Lombard (1995) have reviewed the changes in the period and in the amplitudes of Mira-like variables, generalizing the approach of Eddington and Plakidis.

The pulsation of Mira has been fairly stable in the last four centuries, without any trend of diminution of the period (Percy and Colivas 1999; Percy and Au 1999; Percy and Bagby 1999), while this diminution occurs in other Mira-type variables (Hoffleit 1979) which probably undergo helium flashes (Koen and Lombard 1995; Mattei and Foster 1995; Whitelock 1999). Harrington (1965), studying 16 variable stars in AAVSO databases, found a correlation between M_{i+1} -M_i and t_{i+1} -t_i: fainter maxima occur later than normal; Wallerstein *et al.* (1985) found the same result studying AAVSO data on R Cyg. They suggest that the mass of the material falling back into the star from the previous cycle may have a significant effect on the new cycle.

4.5. Time intervals of maxima repetition and helium-shell flashes

Whitelock (1999) studied the evolution of Mira stars of one solar mass. The lifetimes are about 2×10^5 years for low mass and low metallicity stars. Only for 1/1000 of such time the star is expected to undergo helium-shell flashes. Changes larger than one magnitude occur in that very brief helium-shell flash phase. An indication of helium-shell flash occurrence is when the changes in the duration and the amplitude of the pulsation period are monotonic. During helium-shell flash phase, the period is expected to change most rapidly as the luminosity plummets. Mattei and Foster (1995) considered T UMi in this phase. The quest for fossil shells around Miras or semiregular variables has found few candidates: CV Leo, TT Cyg, and U Hya, which give a constraint on the evolutionary models. As the mass of the star increases, the interval between helium-shell flashes diminishes from 12000 to 3000 years, passing from 1 to 4–5 solar masses (Whitelock 1999). The evolution in a binary system, even if it is wide, owing to the large radii (~1 AU) (Whitelock and Feast 2000) of the Mira-like stars, can be significantly different. Mira has a mass about 0.7 to 1.8 solar masses (Fernie and Brooker 1961; de Jager 1980).

4.6. Studies of Mira and semiregular variables using visual databases

The wavelet analysis has been used (Bedding *et al.* 1999) to detect a small decrease in the amplitude previously unnoticed for R Aql of about half a magnitude in the last century. That approach has been exploited also in the study of multiperiodicity in semiregular variables (Kiss *et al.* 1999, 2000). Fischer (1969a, 1969b) studied correlations between different characteristics of the light curve of Mira, averaged over 23 cycles. He found well-defined features like the eruption point, useful for characterizing a cycle.

5. Further developments

A more general approach to time correlations should be the study of the autocorrelation function of the entire dataset. The problem of our sample is the non-completeness of the dataset due to maxima that were not observed because they fell in the period in which the star is too close to the Sun. So the present analysis is the more complete analysis on time series of Mira maxima available at the moment.

Another indication that ancient astronomers could have observed Mira is present in the only work of Hipparchus (II century B.C.E.) nowadays existing: the Commentary of the three books of Phenomena of Aratus (c. 315–c. 245 B.C.E.) and Eudoxus (c. 400–c. 347 B.C.E.) . In the astronomical appendix in the Greek-German edition of this book (1894) K. Manitius identifies the star Mira as being "over the finback" of the whale which is defined by the stars τ, ζ, λ, and α (Manitius 1894). Müller and Hartwig (1920) quoted Manitius' hypothesis and even identified Mira as the Nova Hipparchi in 134 B.C.E.. The hypotheses of Manitius (1894) and of Müller and Hartwig (1920) are in good agreement with our conclusions on the relatively high probability of seeing Mira at its maxima through the centuries.

6. Conclusions

This study on Mira, with the particular perspective of the fulfillment of Kepler's hypothesis on the Bethlehem Star (Kepler 1614) has enlightened three main aspects on Mira itself, adding new insights on its history (Hoffleit 1997):

1) The frequency of bright maxima of Mira is ~5.6% of the total; on average they are seen once every 22 years. Its discovery as a variable was surprisingly late.

2) The fact that the earliest observations of Mira made by David Fabricius (1596 and 1609) are connected with his observations in the neighborhood of Jupiter, and that Mira was the new component among known asterisms.

3) The brightness of the maxima of Mira is correlated with the brightness of the immediately-following or -preceding peak. The correlation between M_{i+1} -M_i and M_i in the variable star Mira is presented here for the first time; all previous statistical studies concentrated on the time variations of the pulsation period.

And, regarding the hypothesis that Mira could be the Bethlehem Star?

1) Jupiter and Saturn in conjunction in 7–6 B.C.E. could help the Magi to see Mira twice, with Mira 15° from the two planets. Moreover, the circumstances are fairly similar to the ones of the discovery made by David Fabricius with Jupiter at 20°.

2) This hypothesis is simple, parameters-free, and in agreement with what is reported in the Sacred Scriptures, once we consider all the motions of the Star simply as the reflection of the motion of the observers with respect to the objects in the foreground.

Kepler was thinking about a nova for fulfilling the requirement of the apparition of *aliquid novi*—"something new"—in his hypothesis, but nothing similar has been found in the ancient Korean (Cullen 1979) and Chinese records (Peng-Yoke 1962; Cullen 1979) in those years. The same thing applies to comets.

Being near the ecliptic, the favorable conditions for the discovery of Mira occurred several times; nevertheless we cannot have the certitude that Mira did not undergo pulsations systematically different from the ones observed in the last four centuries.

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