# Contemporary *Haqiqī* Calculation: Analysis of Rinto Anugraha's Lunar Eclipse Calculation Methods

# Hisab *Haqiqī* Kontemporer: Analisis Metode Perhitungan Gerhana Bulan Rinto Anugraha

**'Alamul Yaqin***
Institut Agama Islam Negeri Pekalongan, Indonesia
*alamul.yaqin@iainpekalongan.ac.id*

| DOI: 10.24260/jil.v3i1.531 | | |
|---|---|---|
| *Received: December 29, 2021* | *Revised: January 19, 2022* | *Approved: January 24, 2022* |

* *Corresponding Author*

**Abstract:** Classical Islamic astronomy literature that discusses eclipse calculations still uses the *ḥaqiqī bi al-taqrīb* method with low accuracy. In its development, Islamic astronomical literature studies the calculation of lunar eclipses with high accuracy, including *Mekanika Benda Langit* work by Rinto Anugraha. This article aims to analyze the calculation method and accuracy of the Rinto Anugraha lunar eclipse and compare it with Jean Meeus, Bao Lin Liu, and Alan D. Fiala's calculations NASA (National Aeronautics and Space Administration). Using bibliographic research and descriptive-comparative methods, the author finds that the method of calculating the lunar eclipse of Rinto Anugraha is contemporary *haqiqī*. The calculation of the lunar eclipse proposed by Rinto Anugraha is based on Jean Meeus' lunar eclipse calculation, and slight modifications are using NASA data. Rinto Anugraha's lunar eclipse calculation has a high level of accuracy because it has the most significant average difference of 3 minutes 36 seconds in the penumbral eclipse begins stage with the results of the lunar eclipse calculations from Jean Meeus, Bao Lin Liu and Alan D. Fiala, and NASA. Anugraha's contemporary calculation method has implications for simplifying the lunar eclipse calculation formula and the range of lunar eclipses that can be calculated further.

**Keywords**: Lunar Eclipse, *Mekanika Benda Langit,* Rinto Anugraha, Contemporary *Haqiqī* Calculation.

**Abstrak:** Literatur-literatur falak (astronomi Islam) klasik yang membahas tentang perhitungan (*hisāb*) gerhana masih menggunakan metode *ḥaqiqī bi al-taqrīb* dengan akurasi rendah. Pada perkembangannya, terdapat literatur-literatur astronomi Islam yang mengkaji perhitungan Gerhana Bulan dengan akurasi tinggi, termasuk *Mekanika Benda Langit* karya Rinto Anugraha. Artikel ini bertujuan menganalisis metode perhitungan dan tingkat akurasi Gerhana Bulan Rinto Anugraha serta membandingkannya dengan hasil perhitungan Jean Meeus, Bao Lin Liu dan Alan D. Fiala serta NASA (*National Aeronautics and Space Administration*). Dengan menggunakan penelitian bibliografi dan metode deskriptif-komparatif, penulis menemukan bahwa perhitungan Gerhana Bulan Rinto Anugraha termasuk dalam hisab *ḥaqiqī* kontemporer. Perhitungan Gerhana Bulan yang dikemukakan oleh Rinto Anugraha ini bersumber dari hisab Gerhana Bulan Jean Meeus dan terdapat sedikit modifikasi dengan menggunakan data NASA. Hisab Gerhana Bulan Rinto Anugraha memiliki tingkat akurasi yang tinggi, karena memiliki selisih rata-rata terbesar 3 menit 36 detik pada fase penumbra dengan hasil perhitungan Gerhana Bulan dari Jean Meeus, Bao Lin Liu dan Alan D. Fiala serta NASA. Metode perhitungan kontemporer Anugraha berimplikasi pada penyederhanaan rumus perhitungan Gerhana Bulan dan rentang Gerhana Bulan yang dapat dihitung lebih jauh.

**Kata Kunci**: Gerhana Bulan, *Mekanika Benda Langit,* Rinto Anugraha, Hisab *Haqiqī* Kontemporer.

## A. Introduction

Solar and lunar eclipses are celestial events[1] included in one of the astronomy studies (Islamic Astronomy)[2] and have been studied by scholars since ancient times. This matter is evidenced by books from astronomers that discuss the calculation of lunar and solar eclipses. Among them are *Sullam al-Nayyirain* by Muhammad Mansur al-Battawi[3] and *Fath al-Rā'uf al-Mannān*[4] by Abu Hamdan Abdul Jalil. The two astronomy books are classic books that still use the *ḥaqiqī bi al-taqrīb* calculation method that does not have a high level of accuracy.[5] In the contemporary era, astronomy works have emerged that discuss the calculation of lunar eclipses with high accuracy. *Mekanika Benda Langit,* the primary data in this paper, is Rinto Anugraha (in the future referred to as Anugraha), a physicist who is an alumnus of Kyushu University, whose lunar eclipse calculations have a high level of accuracy.[6]

---

[1] Junhyeok Jeon and Seulki Kim, "A Study on the Accuracy of Predicted Solar and Lunar Eclipses for Seoul and Beijing by Qing China Astronomers between 1721 and 1881", *Advances in Space Research* 66, (2020): 1.

[2] Ahmad Izzuddin, *Metode Hisab-Rukyat Praktis dan Solusi Permasalahannya* (Semarang: Pustaka Rizki Putra, 2012), 3.

[3] Muhyiddin Khazin, *Ilmu Falak dalam Teori dan Praktik* (Yogyakarta: Buana Pustaka, 2004), 30.

[4] Ahmad Izzuddin, *Pemikiran Hisab Rukyah Abdul Jalil* (Semarang: Penelitian Individual IAIN Walisongo Semarang, 2005), 30-39.

[5] Rahma Amir, "Metodologi Perumusan Awal Bulan Kamariyah di Indonesia," *EL-FALAKY* 1, no.1 (2017): 100

[6] Rinto Anugraha, *Mekanika Benda Langit* (Yogyakarta: Jurusan Fisika FMIPA UGM, 2012), iv-vi.

Several previous studies discuss the calculation of eclipses. The first is the works of scholars who study lunar eclipses with sufficient accuracy. Muhajir focused on discussing the calculation of the lunar eclipse contained in *Nūr al-Anwār,* including in *ḥaqiqī bi al-taḥqīq* calculation, which has a pretty accurate accuracy, and the astronomical data comes from *al-Maṭla 'al-Sā'id* using the Jepara Markaz.[7] Putri pointed out that the calculation of the lunar eclipse in *Ittifāq āt al-Bain* combines classical and modern books. *Fath al-Ra'uf al-Mannān* is included in the *ḥaqiqī bi al-taqrīb* calculation. In contrast, *Badi'ah al-Miṣāl* is included in *ḥaqiqī bi al-tahqīq,* and some of them have followed Jean Meeus' lunar eclipse calculation theory which is included in contemporary *haqiqī* calculation. The accuracy of *Ittifāq āt al-Bain* in the early, middle, and final stages of the Lunar Eclipse has varying accuracy, which sometimes has a significant difference, and some are accurate.[8]

The second is the works of scholars who discuss the accuracy of the lunar eclipse records in ancient times. Ki-Won Lee et al. examine lunar eclipse records in the History of the Goryeosa Dynasty (918-1392 AD). Lee et al. found 222 valid lunar eclipses of the 228 lunar eclipses, two recorded total lunar eclipses, which should have been partial types and two lunar eclipses recorded two days after prediction.[9] Stephenson, Morrison and Hohenkerk analyzed the accuracy of seven solar and lunar eclipses in *Bede's Ecclesiastical History,* which were tested with modern calculations. They found out of the seven eclipses, four eclipses according to modern eclipse calculations and three eclipses 1 to 2 days apart from predictions.[10] Using Antikythera (an eclipse prediction tool from Ancient Greece), Tony Freeth argues that this tool functions to predict eclipse characteristics such as direction, magnitude, colour, Moon angle diameter, the relationship between the Moon's vertices and the eclipse time. Although the tool results are not entirely

---

[7] Muhajir, "Hisab Gerhana Bulan dalam Kitab *Nūr al-anwar* (Analisis Pemikiran KH. Noor Ahmad SS )," *Islam Nusantara* 3, no. 02 (2019): 457.

[8] Hasna Tudar Putri, "Tinjauan Astronomi Terhadap Hisab Gerhana Bulan dalam Kitab Ittifāq Żāt al-Bain Karya Moh. Zubair Abdul Karim," *Al-Marshad* 6, no. 2 (2020): 178.

[9] Ki-won Lee et.al., "Analysis of the Lunar Eclipse Records from the Goryeosa," *The Korean Astromical Society* 49, no. 4 (2016): 163.

[10] F Richard Stephenson, Leslie V Morrison, and Catherine Y Hohenkerk, "Astronomical Assessment of the Solar and Lunar Eclipse Records in Bede's Ecclesiastical History and Its Continuation," *Journal for the History of Astronomy* 51, no. 1 (2020): 75.

accurate, the result is a remarkable achievement for its time.[11] Azmi, Rofiuddin and Ainul Yaqin focus on visualizing the movement of the lunar eclipse in each stage of the lunar eclipse, which can be obtained from the Sun's position. On the other hand, the altitude and azimuth calculation data of the Sun and Moon can be seen from each stage of the Lunar Eclipse.[12]

This article discusses the method and accuracy of lunar eclipse calculations in Anugraha's *Mekanika Benda Langit,* which is included in the contemporary *haqiqī* calculation method different from previous studies. This article is included in bibliographic research using the descriptive-comparative analysis method. The primary data in this study is *Mekanika Benda Langit* by Anugraha. The secondary data are *Astronomical Algorithms* by Jean Meeus, *Canon of Lunar Eclipse 1500 BC-AD3000* by Bao-Lin Liu and Alan D. Fiala, Lunar Eclipse data from NASA (National Aeronautics and Space Administration), and articles, results from research and other works related to the focus of this paper. The purpose of this study was to determine the calculation method and the level of accuracy of the calculation of the Anugraha Lunar Eclipse in *Mekanika Benda Langit* and to compare it with the calculations of Meeus, Liu and Fiala, as well as lunar eclipse data from NASA.

## B. Rinto Angraha and *Mekanika Benda Langit*

Rinto Anugraha Nur Qomaruz Zaman is a physics lecturer who also serves as Head of the Material and Instrumentation Physics Laboratory at the Faculty of Mathematics and Natural Sciences (FMIPA), Gadjah Mada University (UGM) Yogyakarta, Indonesia. Anugraha is an alumnus of UGM from Bachelor to Master. Anugraha took his bachelor's degree in 1992-1997 AD. From 1997 to 2001, Anugraha studied master's degree at the Physics Department, FMIPA, UGM Yogyakarta. Anugraha continued his doctoral studies in Nonlinear Physics at the Applied Physic Laboratory, Kyushu University, from 2005 to 2008. Monbukagakusho sponsored his doctoral studies. In addition, he conducted post-

[11] Tony Freeth, "Eclipse Prediction on the Ancient Greek Astronomical Calculating Machine Known as the Antikythera Mechanism", *Plos One* 9. no. 7 (2014): 1.

[12] Muhammad Farid Azmi, Ahmad Adib Rofiuddin, and Ahmad Ainul Yaqin, "Prediksi Pergerakan Bayangan Bumi Saat Terjadi Gerhana Bulan Menggunakan Ephemeris Hisab Rukyat," *Al-Marshad* 4, no.2 (2018): 202.

doctoral research with sponsors from the Japan Society for the Promotion of Science (JSPS) from 2008 to 2010.[13]

Anugraha studied *Falak* (Islamic Astronomy) self-taught while studying for a doctoral degree in Japan. Anugraha's competence areas are physics (general relativity and cosmology, mathematical physics, electromagnetics, arithmetic (theory and computation), liquid crystal, magnetic spin simulation, chaos). In addition, Anugraha is proficient in image software (for image processing), primary languages, HTML, and Java programming. Regarding his competence in arithmetic, Anugraha was influenced by Jean Meeus and made the work of Astronomical Algorithms the primary reference.[14]

*Mekanika Benda Langit is* Anugraha's first work in the field of Islamic astronomy. He also wrote several articles related to astronomy on his website, *How to Calculate Prayer Times, Triangle Ball and Qibla Direction, Fundamentals of Astronomy, and Reflection on Astrology as One Evidence of the Integration of Islam and Science.* In addition to Mekanika Benda Langit, which is the focus of this article, Anugraha has several other scientific works, such as a book entitled*, The Theory of Relativity and Its Applications to Electrodynamics, Black Holes and the Universe,* which was published in 2018. In addition, Anugraha wrote ten journals as the first author and several other journals as the second or third author.

*Mekanika Benda Langit* consists of articles on astronomy written by Anugraha on the web and several additions. In Bachelor and Master Degree lectures, he used this book as a lecture module in the Mekanika Benda Langit subject.[15] This book has seven discussion chapters, namely time and calendar, Earth and spherical coordinates, the position of the Sun, the position of the Moon from the Brown and Meeus algorithm, the phases of the Moon, lunar and solar eclipses as well as facts related to eclipse phenomena, and *capita selecta*.[16] Methods for calculating lunar eclipses are listed in chapter six, and methods for calculating solar eclipses. The calculation of solar and lunar eclipses in celestial mechanics is based on Jean Meeus' calculation method. In addition to calculating

[13] Anugraha, 200.
[14] *Ibid*.
[15] Rinto Anugraha, “Saya,” n.d., https://rintoanugraha.staff.ugm.ac.id/saya/.
[16] Anugraha, iii.

the time of the eclipse for each stage, the calculation of the solar eclipse in this book also calculates the latitude and longitude of the occurrence of a solar eclipse.[17] At the same time, the calculation of lunar eclipses in this book calculates the time of the occurrence of a lunar eclipse for each stage. Anugraha also compared the results of the lunar eclipse calculations with the Bao Lin Liu and Alan D. Fiala and NASA lunar eclipses.[18]

## C. Lunar Eclipse dan Its Classification

Etymologically, the eclipse is called *khusūf* in Arabic. The word "*khusūf*" means 'to penetrate', 'to perforate' and 'reduce'[19], 'which shows natural events in the form of the Moon entering the Earth's shadow' and 'which results in a lunar eclipse'.[20] Some scholars argue that the lunar and solar eclipses are expressed in two words, namely "*khusūf*" and "*kusūf*" (meaning to cover).[21] These two words describe the two eclipses because there is a change. The use of the term makes sense, but the two words are not synonyms.[22] Another opinion says that *kusūf* occurs during a total eclipse because the light is completely lost, while *khusūf* is used to refer to the part of the light. According to another opinion, the word "*khusūf*" is used when the colour is not visible, while "*kusūf*" is used when a change is seen.[23] In terminology, a lunar eclipse is defined as a phenomenon when the Moon enters the Earth's shadow, when the Moon's position is in the middle of the Earth's shadow, resulting in the Sun's light not reaching the Moon.[24]

Lunar eclipses occur when the Sun, Earth and Moon are aligned to form a line called opposition or complete phase, in contrast to a solar eclipse that occurs

[17] Anugraha, 163.

[18] Anugraha, 136.

[19] A.W. Munawwir, *Kamus al-Munawwir Arab-Indonesia Lengkap* (Surabaya: Pustaka Progresif, 1984), 1209.

[20] Khazin, 187.

[21] Munawwir, 339.

[22] Al-Imām al-Ḥāfiẓ ibnu Hajar al-Aṡqalani, *Fatḥ al-Bāri*, vol. VI (Jakarta : Pustaka Azzam, 2011), 32.

[23] Al-Aṡqalani, VI: 33.

[24] Nihayatur Rohmah, "Fenomena Gerhana Matahari Cincin dan Konjungsi (Uji Akurasi Awal Bulan Syawal & Dzulqa'dah 1442 H dalam Perspektif Kriteria 29," *Al-Mabsut* 9, no. 2 (2015): 213.

during a new moon phase[25]. Earth has two parts of the shadow formed: the umbra (inside) or core shadow and the penumbral shadow (the outermost part). The Sun's shadow is smaller than the Sun's circular shape, so the shape of the Earth's umbral shadow becomes a cone, while the penumbral shadow forms a truncated cone with its centre on Earth. This shadow is getting farther and bigger until it disappears into space.[26] Jean Meeus, a Belgian astronomer, divided eclipses into three. First, a total lunar eclipse is when the Moon passes Earth's umbral cone. Second, a partial lunar eclipse is a moment when the Moon passes a portion of the Earth's umbra cone. Third, a penumbral lunar eclipse is a moment when the penumbral cone is passed by the Moon only until it passes through the umbral cone.[27]

There are several classifications of eclipse calculation. First, *hisāb ḥaqiq bi al-taqrīb*. It is a simple calculation system that uses only addition and subtraction using tables to solve it without a calculator or computer. Books that use this calculation system are found in *Sullam al-Nayyirain*, *Fath al-Ra'uf al-Mannān*, *Syamsul Hilāl*, and so on. Second, *hisāb ḥaqiq bi al-taḥqīq*, which is a spherical triangle-based calculation system with astronomical data using corrections to the movements of the Sun and Moon. Computer calculation systems or calculations such as in *Khulaṣah al-Wafiyah*, *Modified Ittifāq āt al-Bain*, *Nūr al-Anwār*, and so on. Third, contemporary *haqiqī* calculation is a development reckoning system from *hisāb ḥaqiqī bi al-taḥqīq* based on spherical trigonometry with very accurate correction data for the movements of the Sun and Moon. This calculation system is programmed and adjusts to the latest data. The works included in the third classification are *al-Dūr al-'Aniq*, *Astronomical Algorithms*, *Canon of Lunar Eclipses 1500 BC-AD 3000*, and *Mekanika Benda Langit*.[28]

[25] Ehsan Hidayat, "Penentuan Jumlah Gerhana Matahari dengan Argumen Lintang Bulan dan Teori Aritmetika," *Miyah* 15, no. 1 (2020): 63.

[26] Rizka Amalia and Titin Suprihatin, "Tinjauan Ilmu Falak terkait Fenomena Gerhana Bulan Penumbara terhadap Kebijakan Salat Gerhana pada Ormas Islam," *Jurnal Riset Hukum Keluarga Islam* 1, no. 2 (2021): 60.

[27] Muhyiddin Khazin, Kamus Ilmu Falak (Yogyakarta: Buana Pustaka, 2005), 115.

[28] Amir, 101.

## D. Rinto Anugraha Lunar Eclipse Calculation Method

The method for calculating lunar eclipses in *Mekanika Benda Langit* is based on the *Astronomical Algorithms* by Jean Meeus. The steps for calculating a lunar eclipse in the *Mekanika Benda Langit* are follows. First, calculate the approximate year formula by determining the approximate year in which the formula's eclipse is likely to occur. Second, calculate the formula for predicting the value and value of k (the constant of the phases of the Moon). Third, calculate the value of T (Julian century time since period (epoch) 2000). Fourth, calculate the value of F (Latitude of the Moon argument). Fifth, determine the occurrence of a lunar eclipse based on the F value in the previous calculation results. The F value in multiples of 180 degrees (0/360 degrees) must be less than 13.9 degrees. Sixth, calculate the value of E (Earth orbital eccentricity). Seventh, calculating M (the average anomaly of the Sun), M' (the formula for the average Moon), (the formula for the longitude of the rising point of the Moon omega), F1 (constant) and A1 (constant). Eighth, calculate the JDE (Julian Day Ephemeris) value of the month that has not been corrected. Ninth, calculate the JDE correction and the JDE values for a maximum eclipse. Tenth, calculate the P (constant), Q value (constant), W value (constant), value (closest distance from the centre of the Moon to the Earth's Shadow axis in units of Earth's Equatorial distance) and u value (distance of the Earth's Umbra cone in the base plane) and the unit of the Earth's Equatorial distance). Eleventh, calculate the value of the radius of the penumbra and the radius of the umbra. Twelfth, calculate the magnitude of the penumbral eclipse and the magnitude of the umbral eclipse. Thirteenth, calculate the formula for the value of Pu, T1, H and n (constant). Fourteenth, calculating the semi-duration formula for the penumbra stage, the semi-duration formula for the partial umbra stage and the semi-duration formula for the total umbra stage. Fifteenth, calculate the formula for each stage, beginning of the penumbral eclipse (P1), the beginning of the partial eclipse (U1), the beginning of the total eclipse (U2), the maximum eclipse = the greatest eclipse, the end of the total eclipse (U3), the end of the partial eclipse (U4), and the end of the penumbral eclipse (P2).[29]

[29] Anugraha, 136-139.

The heliocentric theory (the Sun being the centre of the solar system) is the basic theory used in *Mekanika Benda Langit*. Nicolas Copernicus coined the theory, who came from Poland and was born in Torun (formerly known as Thorn) in 1473 AD[30]. The lunar eclipse calculation method in this book is included in the *ḥaqiqī* current calculation system, which is a development of the *ḥaqiqī bi al-taḥqīq* calculation system and is input into computers based on the latest discoveries. The method of calculating lunar eclipses in the mechanics of celestial bodies is inputted into the Microsoft excel program and is entitled *lunar-solar eclipse 1900-2200 v1*. The excel program contains the calculation of solar and lunar eclipses between 1900-2200 AD. The calculation method for lunar eclipses in celestial mechanics is based on calculating lunar eclipses by Jean Meeus' *Astronomical Algorithms*. Jean Meeus' lunar data was taken from the Chapront ELP-2000/82 reduction and solar data using reduced and high-accuracy Bretagon-Francous VSOP87 data. Jean Meeus uses Julian Day as counting days. Julian Day is the number of days calculated from Monday, January 1, 4713 BC (BC) or -4712 at 12:00:00 GMT[31] and using the most recent epoch of 2000.[32]

Jean Meeus used Danjon's rule[33] with the Earth's image magnification of 1/85. The French almanac *Connaissance des Temps* uses this method. Meanwhile, Chauvenet, in determining the influence of the Earth's atmosphere on the Earth's shadow, the diameter of the umbral shadow was extended by 1/50. Many State agencies use the Chauvenet Rules.[34] The rules of Chauvenet are commonly referred to as traditional rules (traditional rules). Meanwhile, in 2007, NASA used the Danjon rule instead of the traditional rule in Eclipses. Eclipses During 2007 is a data collection of solar and lunar eclipses throughout 2007.[35] The difference between the Danjon rule and the traditional rule lies in calculating the magnitude of the lunar eclipse. Calculating the magnitude for the umbral eclipse with the traditional rule is 0.0005. The difference in the penumbral eclipse is 0.026

---

[30] Anton Pannekoek, *A History of Astronomy* (New York: Dover Publications, 1961), 188.

[31] Anugraha, 8.

[32] Jean Meeus, *Astronomical Algorithms* (Virginia: Willman Bell. Inc., 1991), 1.

[33] Meeus, 383.

[34] Russell Bagdoo, "Lunar Eclipses and Allais Effect", *Journal of Modern Physic* 12. (2021): 1784-1785, https://doi.org/10.4236/jmp.2021.1213104.

[35] Fred Espenak, "Diameters and Lunar Eclipses", n.d., https://eclipse.gsfc.nasa.gov/OH/OH2007.html#Shadow.

compared to the magnitude calculation using the Danjon rule.[36] Therefore, in several eclipses that are close to the criteria limit between types of penumbral eclipses, partial eclipses and total eclipses, as well as eclipses occur or not, the results will differ between the calculation method with the Danjon rule and the traditional rules. This matter is due to determining the type of eclipse using the umbra and penumbra magnitude values.

The author finds two different formulas for calculating the lunar eclipse of Rinto Anugraha with the calculation of the lunar eclipse of Jean Meeus in *Astronomical Algorithms*. First, there is a simplification of the formula in calculating JDE (*Julian Day Ephemeris*), the average anomaly of the Sun (M), the average anomaly of the Moon (M'), the argument for the latitude of the Moon (F), the longitude of the Moon's rising point omega (Ω). Table 1 below compares the calculation formulas that show the difference between Jean Meeus' lunar eclipse formula in *Astronomical Algorithms* and Rinto Anugraha in *Mekanika Benda Langit*.

**Table 1**

**Comparison of Correction Formulas between Jean Meeus and Rinto Anugraha**

| No. | Jean Meeus | Rinto Anugraha |
|---|---|---|
| 1. | $JDE = 2541\ 550{,}09765 + 29{,}580\ 588\ 853 + 0{,}0001337 \times T^2 - 0.000\ 000\ 150 \times T^3 + 0{,}000\ 000\ 000\ 73 \times T^4$ | $JDE = 2541\ 550{,}09765 + 29{,}580\ 588\ 853 + 0{,}0001337 \times T^2$ |
| 2. | $M = 2{,}5534 + 29{,}1053569 \times k - 0{,}0000218 \times T^2 - 0{,}00000011 \times T^3$ | $M = 2{,}5534 + 29{,}1053569 \times k - 0{,}0000218 \times T^2$ |
| 3. | $M' = 201{,}5643 + 385{,}81693528 \times k + 0{,}0107438 \times T^2 + 0{,}00001239 \times T^3 - 0{,}000000058 \times T^4$ | $M' = 201{,}5643 + 385{,}81693528 \times k + 0{,}0107438 \times T^2$ |
| 4. | $F = 160{,}7108 + 390{,}67050274 \times k - 0{,}0016341 \times T^2 - 0{,}00000227 \times T^3 + 0{,}000000011 \times T^4$ | $F = 160{,}7108 + 390{,}67050274 \times k - 0{,}0016341 \times T^2$ |
| 5. | $\Omega = 124{,}7746 - 1{,}56375580 \times k + 0{,}0020691 \times T^2 + 0{,}00000215 \times T^3$ | $\Omega = 124{,}7746 - 1{,}56375580 \times k + 0{,}0020691 \times T2$ |

Source: (Jean Meeus, 1991)[37] and (Rinto Anugraha, 2012).[38]

[36] Meeus, 383.
[37] Meeus, 319-320.
[38] Anugraha, 137.

The comparison in table 1 above shows that Anugraha simplifies the correction of the formula only to the value of $T^2$, while formulas of $T^3$ and $T^4$ are not used. According to Anugraha, this does not significantly affect the calculations because the T value per 100 years starts from the 2000 epoch, so it is still included in the range in Rinto Anuraha's excel program between 1900 to 2200 AD.[39]

Second, the Anugraha Lunar Eclipse calculation uses NASA's Delta T (ΔT).[40] Delta T is subtracting time from TD (Dynamical Time) and UT (Universal Time), with the following formula: T = TD – UT. Universal Time (UT), commonly called Greenwich Mean Time (GMT), is time-based on the Earth's rotational motion. Over time, the Earth's rotation experiences an erratic slowdown, thus making the UT time unstable. To get accurate calculation results, the calculation requires a fixed time scale. Therefore, the Dynamical Time (TD) system appears, considered uniform. The NASA polynomial formula in determining the value of delta T is divided into several years, namely the Delta T formula (1900-1920), the Delta T formula (1920-1941), the Delta T formula (1941-1961), the Delta T formula (1961-1986), the Delta T (1986-2005), Delta T Formula (2005-2050), Delta T Formula (2050-2150), and Delta T Formula for years 2150 and above. This data shows that the value of Delta T each year and the grouping formula for the range of years are also inconsistent. The data results from several years were then formulated for the following years. The formula approximates the value of Delta T.

Meanwhile, Jean Meeus uses Delta T data from 1620-1992 AD observations. The table below is the value for Delta T from observation data obtained by Meeus in 1620-1992 AD. This data is different from NASA, which formulates the Delta T value approach, and Meeus only shows the value of Delta T from the observations. The data can be seen in Table 2 as follows.

[39] Interview report with Rinto Anugraha on August 1, 2016.
[40] Interview report with Rinto Anugraha on August 1, 2016.

**Table 2**

**Delta T (ΔT) Data 1620–1992 M Jean Meeus**

| Tahun | ΔT | Tahun | ΔT | Tahun | ΔT | Tahun | ΔT | Tahun | ΔT |
|---|---|---|---|---|---|---|---|---|---|
| 1620 | +124 | 1700 | +9 | 1780 | +17 | 1860 | +7.9 | 1940 | +24.3 |
| 1622 | +115 | 1702 | +9 | 1782 | +17 | 1862 | +7.5 | 1942 | +25.3 |
| 1624 | +106 | 1704 | +9 | 1784 | +17 | 1864 | +6.4 | 1944 | +26.2 |
| 1626 | +98 | 1706 | +9 | 1786 | +17 | 1866 | +5.4 | 1946 | +27.3 |
| 1628 | +91 | 1708 | +10 | 1788 | +17 | 1868 | +2.9 | 1948 | +28.2 |
| 1630 | +85 | 1710 | +10 | 1790 | +16 | 1870 | +1.6 | 1950 | +29.1 |
| 1632 | +79 | 1712 | +10 | 1792 | +16 | 1872 | -1 | 1952 | +30 |
| 1634 | +74 | 1714 | +10 | 1794 | +15 | 1874 | -2.7 | 1954 | +30.7 |
| 1636 | +70 | 1716 | +10 | 1796 | +14 | 1876 | -3.6 | 1956 | +31.4 |
| 1638 | +65 | 1718 | +11 | 1798 | +13.7 | 1878 | -4.7 | 1958 | +32.2 |
| 1640 | +62 | 1720 | +11 | 1800 | +13.1 | 1880 | -5.4 | 1960 | +33.1 |
| 1642 | +58 | 1722 | +11 | 1802 | +12.7 | 1882 | -5.2 | 1962 | +34 |
| 1644 | +55 | 1724 | +11 | 1804 | +12.5 | 1884 | -5.5 | 1964 | +35 |
| 1646 | +53 | 1726 | +11 | 1806 | +12.5 | 1886 | -5.6 | 1966 | +36.5 |
| 1648 | +50 | 1728 | +11 | 1808 | +12.5 | 1888 | -5.8 | 1968 | +38.3 |
| 1650 | +48 | 1730 | +11 | 1810 | +12.5 | 1890 | -5.9 | 1970 | +40.2 |
| 1652 | +46 | 1732 | +11 | 1812 | +12.5 | 1892 | -6.2 | 1972 | +42.2 |
| 1654 | +44 | 1734 | +12 | 1814 | +12.5 | 1894 | -6.4 | 1974 | +44.5 |
| 1656 | +42 | 1736 | +12 | 1816 | +12.5 | 1896 | -6.1 | 1976 | +46.5 |
| 1658 | +40 | 1738 | +12 | 1818 | +12.3 | 1898 | -4.7 | 1978 | +48.5 |
| 1660 | +37 | 1740 | +12 | 1820 | +12 | 1900 | -2.7 | 1980 | +50.5 |
| 1662 | +35 | 1742 | +12 | 1822 | +11.4 | 1902 | 0 | 1982 | +52.2 |
| 1664 | +33 | 1744 | +13 | 1824 | +10.6 | 1904 | +2.6 | 1984 | +53.8 |
| 1666 | +31 | 1746 | +13 | 1826 | +9.6 | 1906 | +5.4 | 1986 | +54.9 |
| 1668 | +28 | 1748 | +13 | 1828 | +8.6 | 1908 | +7 | 1988 | +55.8 |
| 1670 | +26 | 1750 | +13 | 1830 | +7.5 | 1910 | +10.5 | 1990 | +56.9 |
| 1672 | +24 | 1752 | +14 | 1832 | +6.6 | 1912 | +13.4 | 1992 | +58.3 |
| 1674 | +22 | 1754 | +14 | 1834 | +6.0 | 1914 | +16 | | |
| 1676 | +20 | 1756 | +14 | 1836 | +5.7 | 1916 | +18.2 | | |

Source: (Jean Meeus, 1991).[41]

Based on the explanation above, it can be concluded that calculating lunar eclipses in celestial mechanics uses recent astronomical data and belongs to the contemporary *haqiqī* calculation. The author finds differences in calculating lunar eclipses in *Mekanika Benda Langit* with the Jean Meeus lunar eclipse calculation method in Astronomical Algorithms. The difference lies in the simplification of the $T^3$ and $T^4$ formulas. *Mekanika Benda Langit* only uses formulas up to the $T^2$

[41] Meeus, 71.

formulas and the value of delta T uses the NASA polynomial formula. In contrast, Meeus uses the value of delta T from observations from 1620 to 1992.

## E. Rinto Anugraha's Lunar Eclipse Calculation Accuracy Rate: A Comparative Study

The author has compared the results of the Rinto Anugraha Lunar Eclipse with three other lunar eclipse data to check the accuracy of the calculation. The data calculated by Jean Meeus' lunar eclipse in Astronomical Algorithms and the calculated data of the lunar eclipse in the Canon of Lunar Eclipses 1500 BC-AD 3000 are included in the category of lunar eclipse calculations that use actual data and are included in the category of the contemporary *haqiqī* calculation.[42] At the same time, the data calculated by NASA is known as the most advanced astronomical institution in research related to astronomical studies, including eclipses. The author has compared the data calculated from the lunar eclipse from the three data above to test the accuracy of this calculation from 1900 to 1924 AD. In those 24 years, there were 30 lunar eclipses. The average value of the difference between the calculation results of the lunar eclipse of *Mekanika Benda Langit* with three other lunar eclipse reckoning data for each stage of the lunar eclipse can be seen in table 3.

**Table 3**

**The Average Value of the Comparative Results of the Lunar Eclipse Calculation Rinto Anugraha, Jean Meeus, Bao Lin Liu and Alan D. Fiala, and NASA**

| No. | Lunar Stages | Jean Meeus-Rinto Anugraha | Bao Lin Liu-Rinto Anugraha | NASA-Rinto Anugraha |
|---|---|---|---|---|
| 1. | Penumbral eclipse begins | 00:00:00.43 | 00:03:36 | 00:01:02.83 |
| 2. | Partial eclipse begins | 00:00:00.59 | 00:01:28.24 | 00:00:51.39 |
| 3. | Total eclipse begins | 00:00:00.2 | 00:01:12 | 00:00:22.5 |
| 4. | Greatest eclipse | 00:00:00.5 | 00:00:20 | 00:00:08.1 |
| 5. | Total eclipse ends | 00:00:00.4 | 00:00:30 | 00:00:15.9 |

[42] Interview report with Rinto Anugraha on August 1, 2016.

| | | | | |
|---|---|---|---|---|
| 6. | Partial eclipse ends | 00:00:00.47 | 00:01:03.53 | 00:00:41.39 |
| 7. | Penumbral eclipse ends | 00:00:00.6 | 00:02:48 | 00:00:49.47 |

Source: (Data from the author's creativity).

The data in Table 3 shows that at each stage of the eclipse, from the penumbra begins to the umbra begins, the total starts, the greatest eclipse, the total ends, the end of the umbra and the end of the penumbra, the results of the comparison of the calculation of the Anugraha Lunar Eclipse with Meeus in *Astronomical Algorithms* have the slightest difference in each stage. compared with the average value of the Rinto Anugraha Lunar Eclipse calculation with the other two calculations. Thus, the simplification of the $T^3$ and $T^4$ formulas in several calculation steps in *Astronomical Algorithms* and the use of different Delta T does not have a significant impact, not even reaching 1 second.

The comparison of the average value of the most significant lunar eclipse calculation compared to the comparison of the other two calculations is the difference in the calculation results of the Rinto Anugraha lunar eclipse with Bao Lin Liu & Alan D. Fiala, with the average difference in the penumbral eclipse begins a stage of 3 minutes 36 seconds. The difference is due to the diameter of the umbra and penumbral shadows. Meeus uses the Danjon rule with the value of the umbra and penumbra shadow diameters being 1/85. At the same time, Bao Lin Lui and Alan D. Fiala refer to the traditional law, which is 1/50. The difference in reference certainly affects the timing of the lunar eclipse for each stage and determines the type of eclipse. These differences affect several eclipses, especially in determining the type of eclipse but have no significant effect on each stage of the lunar eclipse. The difference in the average reckoning of the Anugraha Lunar Eclipse with NASA is the largest at the beginning of the penumbra, which is 1 minute 2.83 seconds. The difference is relatively small, primarily since it is known that the reckoning of the Anugraha Lunar Eclipse, which is sourced from Meeus' calculations, uses lunar data because of reduction from Chapront ELP-2000/82 and solar data from Bretagon-Francous VSOP87 reduction, which has high accuracy. Based on the results of the comparison of the three calculations above, the writer can conclude that the calculation of the Anugraha Lunar Eclipse in the *Mekanika Benda Langit* has a high level of accuracy.

## F. Conclusion

The Anugraha Lunar Eclipse calculation method in the *Mekanika Benda Langit* is included in the contemporary *haqiqī* calculation. The calculation of the Anugraha Lunar Eclipse comes from the calculation of the Meeus Lunar Eclipse by simplifying the formula and using the delta T value from NASA. The comparison of the Anugraha and Meeus lunar eclipse calculation methods has a minor average difference at each stage of the lunar eclipse, which is less than 1 second. The difference between Rinto Anugraha's lunar eclipse and Bao Lin Liu and Alan D. Fiala's calculations is the largest in the initial penumbra eclipse begins stages of 3 minutes 36 seconds. Thus, the author can conclude that the calculation of the Anugraha Lunar Eclipse in *Mekanika Benda Langit* is a calculation with a high level of accuracy. The Anugraha calculation method has implications for calculating lunar eclipses to be more straightforward. Although simple, the accuracy of this method is still accurate. In addition, the use of NASA's delta T data with an extended year span can be used in calculating lunar eclipses with an extended year span as well.

## BIBLIOGRAPHY

Al-Aṡqalani, Al-Imām al-Ḥāfiẓ ibnu Hajar. *Fatḥ al-Bāri*. Jakarta: Pustaka Azzam, 2011.

Amalia, Rizka, and Titin Suprihatin. "Tinjauan Ilmu Falak Terkait Fenomena Gerhana Bulan Penumbara terhadap Kebijakan Salat Gerhana pada Ormas Islam." *Jurnal Riset Hukum Keluarga Islam* 1, no. 2 (2021): 60. https://doi.org/10.29313/jrhki.v1i2.430.

Amir, Rahma. "Metodologi Perumusan Awal Bulan Kamariyah di Indonesia." *EL-FALAKY* 1, no. 1 (2017): 100. https://doi.org/10.24252/ifk.v1i1.6434.

Anugraha, Rinto. *Mekanika Benda Langit*. Yogyakarta: Jurusan Fisika FMIPA UGM, 2012.

__________. "Saya", n.d., https://rintoanugraha.staff.ugm.ac.id/saya/.

Azmi, Muhammad Farid, Ahmad Adib Rofiuddin, and Ahmad Ainul Yaqin. "Prediksi Pergerakan Bayangan Bumi Saat Terjadi Gerhana Bulan Menggunakan Ephemeris Hisab Rukyat." *Al-Marshad* 4, no.2 (2018): 202. http://dx.doi.org/10.30596%2Fjam.v4i2.21402.

Bagdoo, Russell. "Lunar Eclipses and Allais Effect." *Journal of Modern Physic* 12, (2021): 1784-1785. https://doi.org/10.4236/jmp.2021.1213104.

Espenak, Fred. "Diameters and Lunar Eclipses," n.d.. https://eclipse.gsfc.nasa.gov/OH/OH2007.html#Shadow.

Freeth, Tony. "Eclipse Prediction on the Ancient Greek Astronomical Calculating Machine Known as the Antikythera Mechanism." *Plos One* 9, no. 7 (2014): 1, https://doi.org/10.1371/journal.pone.0103275.

Interview report with Rinto Anugraha on August 1, 2016.

Hidayat, Ehsan. "Penentuan Jumlah Gerhana Matahari dengan Argumen Lintang Bulan dan Teori Aritmetika." 15, no. 1 (2020): 62–93. http://dx.doi.org/10.33754/miyah.v15i01.166.g135.

Izzuddin, Ahmad. *Metode Hisab-Rukyat Praktis dan Solusi Permasalahannya*. Semarang: Pustaka Rizki Putra, 2012.

__________. *Pemikiran Hisab Rukyah Abdul Jalil*. Penelitian Individual IAIN Walisongo Semarang, 2005.

Jeon, Junhyeok, and Seulki Kim. "A Study on the Accuracy of Predicted Solar and Lunar Eclipses for Seoul and Beijing by Qing China Astronomers between 1721 and 1881." *Advances in Space Research*, 66. (2020): 1. https://doi.org/10.1016/j.asr.2020.07.019.

Khazin, Muhyiddin. *Ilmu Falak dalam Teori dan Praktik*. Yogyakarta: Buana Pustaka, 2004.

_______. *Kamus Ilmu Falak*. Yogyakarta: Buana Pustaka, 2005.

Lee, Ki-won et al. "Analysis of the Lunar Eclipse Records from the Goryeosa." *The Korean Astronomical Society* 49, no. 4 (2016): 163. https://doi.org/10.5303/JKAS.2016.49.4.163.

Liu, Bao Lin and Alan D. Fiala. *Canon of Lunar Eclipses 1500 B.C-A.D 3000*. Virginia: Willman-Bell, Inc, 1983.

Meeus, Jean. *Astronomical Algorithms*. Virginia: Willman Bell. Inc., 1991.

Muhajir. "Hisab Gerhana Bulan dalam Kitab *Nūr al-anwar* ( Analisis Pemikiran KH. Noor Ahmad SS )." *Islam Nusantara* 3. no. 2 (2019): 457, https://doi.org/10.33852/jurnalin.v3i2.149.

Munawwir, A.W.. *Kamus Al-Munawwir Arab-Indonesia Lengkap*. Pustaka Progresif, 1984.

Pannekoek, Anton. *A History of Astronomy*. New York: Dover Publications, 1961.

Putri, Hasna Tudar. "Tinjauan Astronomi terhadap Hisab Gerhana Bulan dalam Kitab Ittifāq Żāt al-Bain Karya Moh. Zubair Abdul Karim." *Al-Marshad* 6, no. 2 (2020): 178. http://dx.doi.org/10.30596%2Fjam.v6i2.5186.

Rohmah, Nihayatur. "Fenomena Gerhana Matahari Cincin dan Konjungsi (Uji Akurasi Awal Bulan Syawal & Dzulqa'dah 1442 H dalam Perspektif Kriteria 29." *Al-Mabsut* 9, no. 2 (2015): 213.

Stephenson, F Richard, Leslie V Morrison, and Catherine Y Hohenkerk. "Astronomical Assessment of the Solar and Lunar Eclipse Records in Bede's Ecclesiastical History and Its Continuation." *Journal for the History of Astronomy* 51, No. 1 (2020): 75. https://doi.org/10.1177/0021828619899188.