ZODIAC LIGHT DETECTION BASED ON SKY QUALITY METER (SQM) DATA: PRELIMINARY STUDY

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Abstract

Zodiacal light is a phenomenon that occurs in the sky just before sunrise. This phenomenon is known as the dawn of *kadhib* in astronomy, the false dawn that precedes the appearance of the dawn of *ṣadiq* as a signal of the beginning of the Fajr prayer time. The appearance of the zodiacal light on the eastern horizon can now be detected using various astronomical instruments, one of which is using the Sky Quality Meter (SQM) intensity meter. Observation of the light intensity of dawn at six locations using SQM resulted in a light curve that had similarity. Based on the plot of a number of dawn light curves which are approximated by a linear function in the data range with the Sun's elevation value less than -20°, it shows that there is a linear pattern that tends to decrease. The linear pattern obtained indicates that the zodiacal light in a light-polluted location can detect its occurrence.

Keywords: *fitting linear*; dawn light curve; *Sky Quality Meter* (SQM)

Abstrak

Zodiacal light merupakan salah satu fenomena yang terjadi di langit ketika menjelang Matahari terbit. Fenomena ini dikenal sebagai fajar kadzib dalam ilmu falak, fajar semu yang mendahului kemunculan fajar shodiq sebagai penanda awal waktu salat subuh. Kemunculan *zodiacal light* di horizon timur saat ini dapat diketahui dengan beragam instrumen astronomi, salah satunya dengan menggunakan alat tera intensitas *Sky Quality Meter* (SQM). Pengamatan intensitas cahaya fajar di enam lokasi dengan menggunakan SQM menghasilkan kurva cahaya yang memiliki keserupaan. Berdasarkan plot sejumlah kurva cahaya fajar yang didekati dengan fungsi linear pada rentang data dengan nilai elevasi Matahari lebih kecil daripada -20° menunjukkan adanya pola linear yang cenderung menurun. Pola linear yang diperoleh ini menunjukkan bahwa *zodiacal light* pada lokasi yang bebas polusi cahaya dapat mendeteksi kemunculannya.

Kata Kunci: *fitting linear*; kurva cahaya fajar; *Sky Quality Meter* (SQM)

A. Introduction

Dawn is one of the natural phenomena that has attracted the attention of mankind since ancient times. The brightness of dawn changes with the zenith distance of the Sun.[1] Astronomy divides dawn into three groups that are affected by the zenith distance of the Sun, namely: Astronomical Dawn (astronomical twilight, Z=108°), Nautical Twilight, Z=102°) and Civil Dawn (Civil Twilight, Z=96°). The division is based on the visual appearance of dawn that can be captured by the human eye. Dawn observations are part of astronomical observations. Currently, relatively many observations of dawn in Indonesia are carried out to analyze the problem of the early dawn prayer time. In general, observations are made with the principle of photometry using SQM (Sky Quality Meter) and a photographic camera.

Dawn observations with photometric principles produce light curves. The light curve which is an intensity-time plot becomes a simple analytical tool that is relatively good enough to describe and explain changes in intensity as a function of time. Based on the results of the light curve analysis, information on the light source, and the medium through which we pass, we tried to analyze the light curve obtained from the photometric observations.

The sky brightness light sources captured by the detector (SQM and Photography) can be grouped into: Zodiacal Light, Twilight, stars and light pollution. From the four light sources, the intensity of Zodiacal Light and Twilight changes with time (seems getting brighter). Therefore, by assuming that starlight and light pollution have a constant intensity, the light intensity of Zodiacal Light and Twilight can be known and separated, so that the initial appearance of Twilight can be known by using a linear function approach to observational data which is considered linear.

B. Method

Dawn observations were made at six different locations with different times. Observation data were obtained by using camera (photography) and SQM instruments. The following table shows the location of dawn observations used in this paper.

[1] Di-Fu Guo et al., "Sky Brightness at Weihai Observatory of Shandong University," *Publications of the Astronomical Society of the Pacific* 126, no. 939 (2014): 496–503, https://doi.org/10.1086/676819.

Table 1. Location

Location	Coordinate		Date	Source	
	Latitude (S)	Longitude (E)		Image	SQM
Mombhul Beach, Gresik	5° 47' 7.96"	112° 43' 33.28"	July 09, 2018	Yes	Yes
Labuan Bajo	8° 23' 9.28"	119° 40' 55.01"	April 24, 2018	Yes	Yes
Imahnoong	6° 50' 1.72"	107° 36' 59.59"	May 11, 2018	No	Yes
Bosscha Observatory	6° 49' 46.82"	107° 36' 51.14"	July 17, 2015	No	Yes
Amfoang	9° 35' 46.20"	123° 56' 47.64"	May 10,2013	No	Yes
Sedan, Rembang, Jawa Tengah	6° 45' 21.89"	111° 35' 14.19"	June 16 2018	No	Yes

The data used in the study is divided into two types according to the source of data acquisition, namely image data and SQM data. The following is a table of data acquisition information used in the study.

Table 2. Data Resources

Location	Resources		Time		Observer / Institution
	Citra	SQM	Citra	SQM	
Mombhul Beach, Gresik	Yes	Yes	03:37:00 - 04:49:00 LT (UT + 7)	03:33:53 – 05:39:23 LT (UT + 7)	Lajnah Falakiyah Nahdhatul Ulama (LFNU) Gresik
Labuan Bajo	Yes	Yes	04:32:58 - 05:04:01 LT (UT + 8)	04:16:43 – 05:07:49 LT (UT + 8)	Hendro Setyanto, M.Si., AR Sugeng Riyadi (CASA Assalaam)
Imahnoong	No	Yes	No Data	04:52:02 – 07:05:37 LT (UT + 7)	Hendro Setyanto, M.Si.
Bosscha Observatory	No	Yes	No Data	00:00:01 – 06:11:12 LT (UT + 7)	Dr. Dhani Herdiwijaya, M.Sc.
Amfoang	No	Yes	No Data	03:30:01 – 05:59:21 LT (UT + 8)	Dr. Dhani Herdiwijaya, M.Sc.
Sedan, Rembang, Jawa Tengah	No	Yes	No Data	03:42:09 – 05:39:58 LT (UT + 7)	Imam Qusthalaani

This paper uses a linear fitting method to the dawn light curve as a result of observations using a camera and SQM. Linear fitting is carried out on data on the intensity of the night sky brightness against the height of the Sun before the alleged appearance of dawn, which has been known so far (-20°). The following is a table of the range of values for h or the angle of elevation of the Sun (°) for linear fittings.

Table 3. Range of *h* or Sun Altitude (°) for Linear Fittings

Location	Range of Sun Altitude (°)	
	Data from Citra	Data from SQM
Mombhul Beach, Gresik	-28,76 – -20,69	-28,99 – -20,98
Labuan Bajo	-25,90 – -21,03	-22,87 – -20,98
Imahnoong	No Data	-25,60 – -22,95
Bosscha Observatory	No Data	-75,44 – -24,24
Amfoang	No Data	-32,98 – -22,99
Sedan, Rembang, Jawa Tengah	No Data	-27,40 – -20,97

The linear fitting method was also carried out by Guo in 2014 to measure the brightness of dawn at the Weihai Observatory of Shandong University, China, so that the distribution of night sky brightness data against the height of the Sun before dawn can be approximated by a linear function. The linear function that has been obtained is a function of the Zodiacal Light which physically increases its brightness linearly.[2]

B.1 Fitting Linear Process

The linear fitting process is conducted by taking a sample of the intensity of the night sky before dawn. The following is a linear fitting process for two image intensity data and six intensity data from SQM measurements.

a. Determine the range of *h* or sun altitude (°) for linear fittings. The range of h values is different for each observation data because each observation data has a different observation time span.

b. After determining the range of *h* for each observation data, then linear fitting is done with the basic equation f(x) = ax + b. The fitting process is carried out using GNUPLOT software version 5.2 patch level 8. Statistical information used is linear function, R2, average, and standard deviation. If the distribution of data has a tendency to decrease or increase, then

[2] Guo et al.

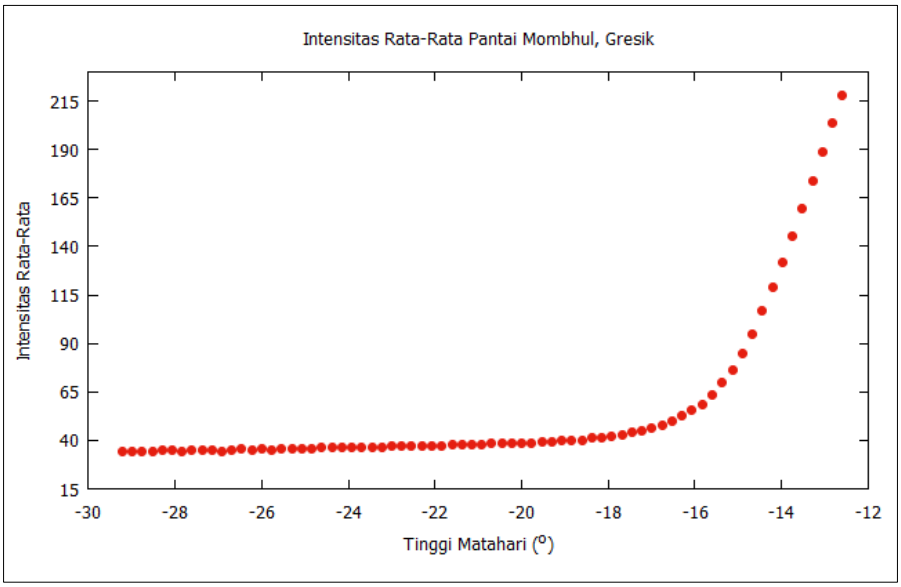
the linear equation from the fitting results is used. However, if the data distribution has a flat tendency, then the linear equation used is f(x) = average.

c. The linear equation along with the standard deviation that has been obtained is then plotted with the overall data. The analysis is done by looking at the distribution of the data around the linear function or the Zodiacal Light function along with the standard deviation f'(x) = ax + b±. If there is a datum that has an intensity value of *i* (standard deviation) for SQM observations or *i* (standard deviation) for image observations from the Zodiacal Light function, then the datum is confirmed to be a combination of Zodiacal Light brightness and dawn. Thus, the beginning of the appearance of dawn can be determined.

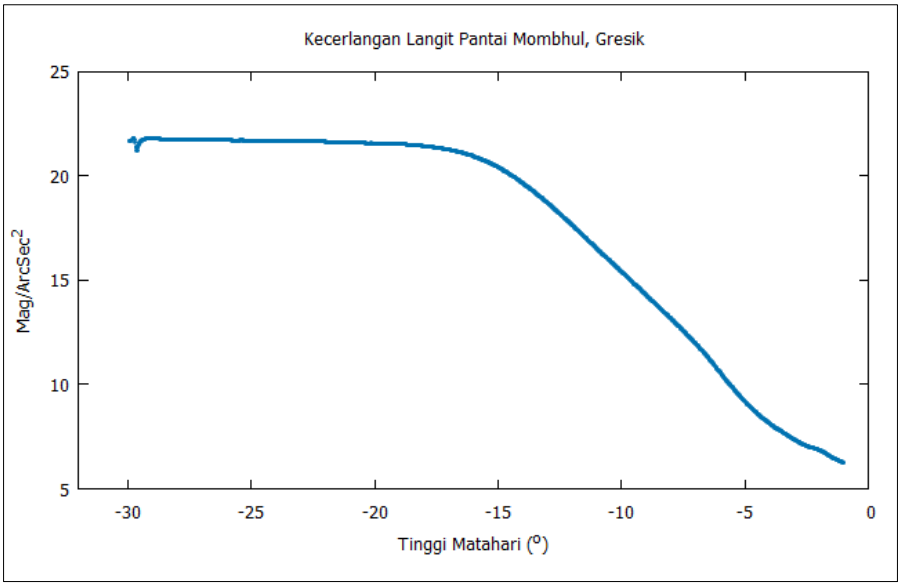
C. Results

C.1 Dawn Light Curve at Mombhul Beach, Gresik

Dawn light curve at Mombhul Beach, Gresik, consists of two kinds based on the data source. The first light curve is the average light intensity curve from the image data and the second light curve is the light curve from the SQM data. Here's the curve of the dawn light at Mombhul Beach.



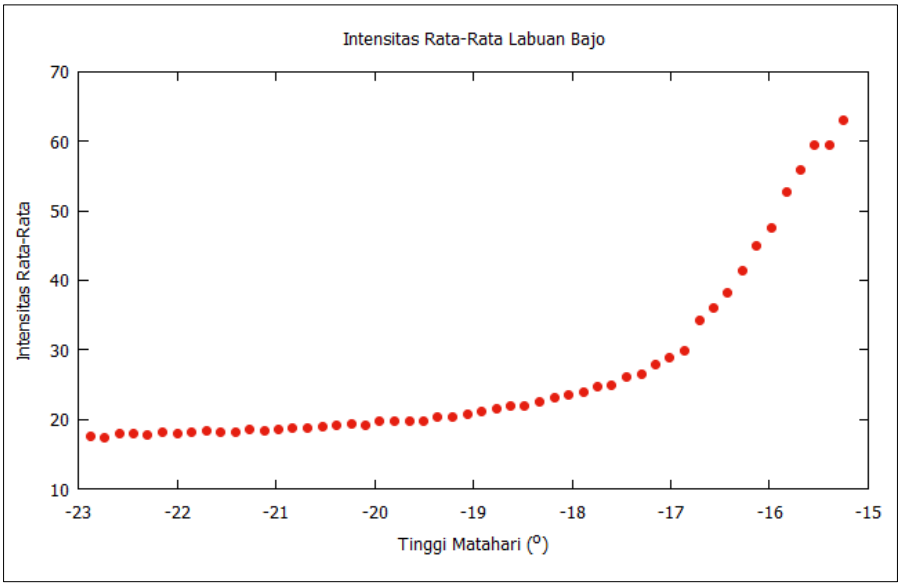
Figures 1. Average Intensity Light Curve (Citra)



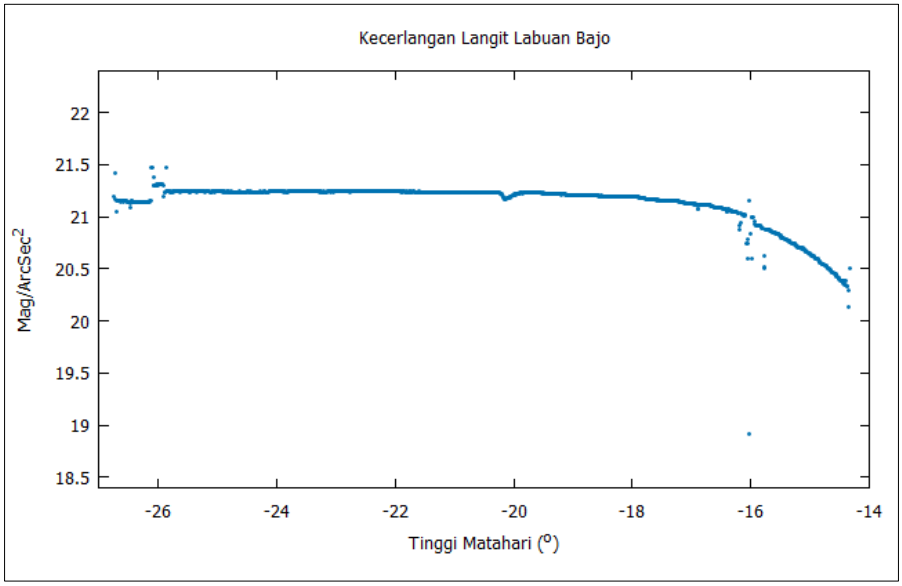
Figures 2. Sky Brightness Light Curve (SQM)

C.2 Dawn Light Curve at Labuan Bajo

The dawn light curve in Labuan Bajo consists of two categories based on the data source. The first light curve is the average light intensity curve from the image data and the second light curve is the light curve from the SQM data. The following is the curve of the dawn light in Labuan Bajo.



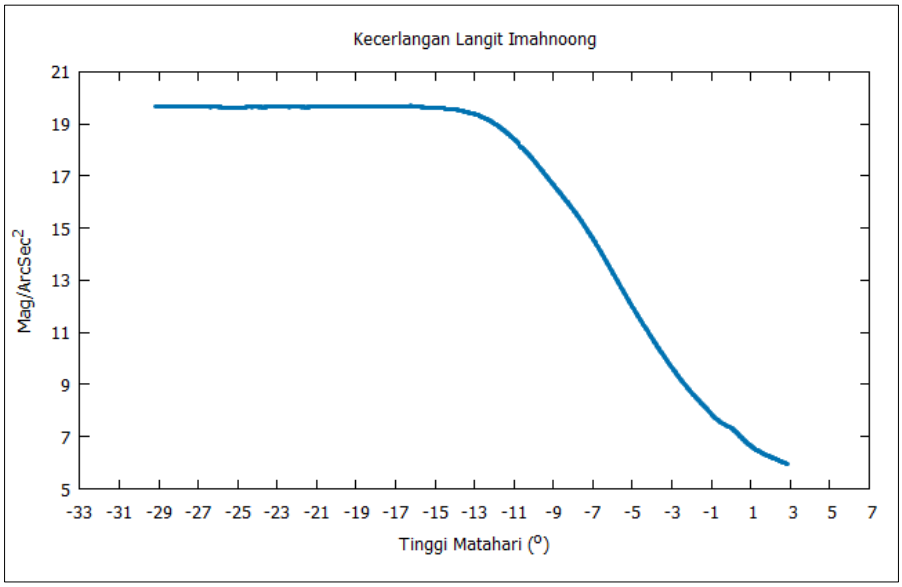
Figures 3. Average Intensity Light Curve (Citra)



Figures 4. Sky Brightness Light Curve (SQM)

C3 Dawn Light Curve at Imahnoong Observatory

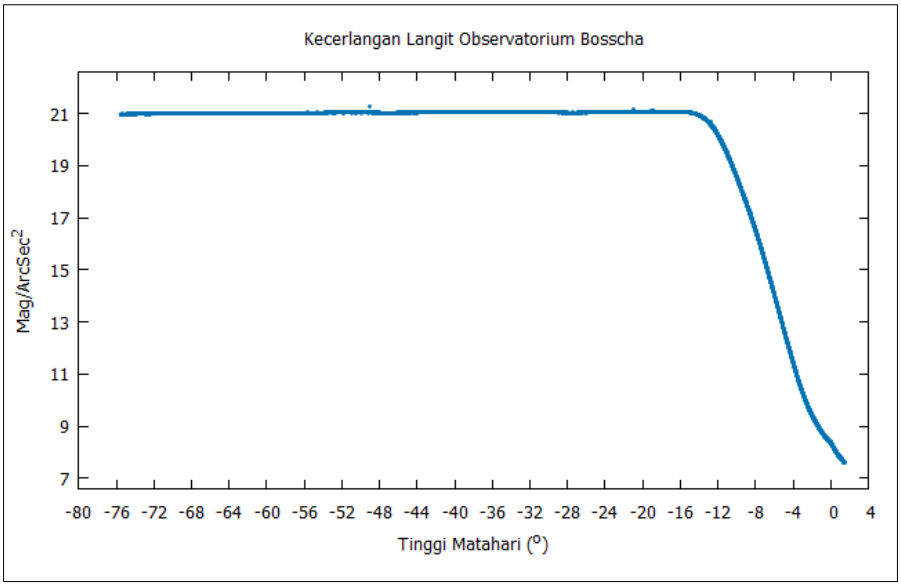
The dawn light curve at Imahnoong Observatory is the light curve from SQM data. Here's the curve of the dawn light at Imahnoong.



Figures 5. Sky Brightness Light Curve (SQM)

C4 Dawn Light Curve at Bosscha Observatory

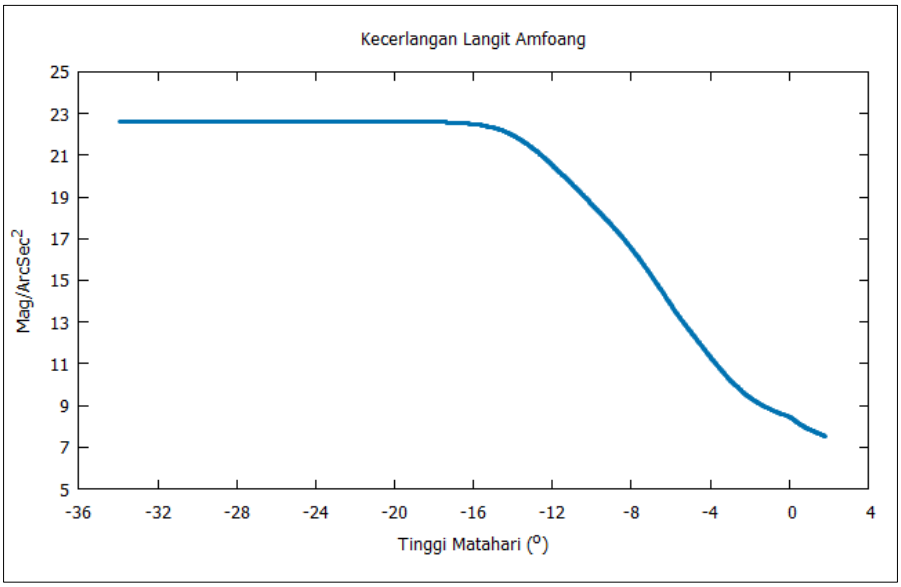
The dawn light curve at *Bosscha* Observatory is the light curve from SQM data. Here's the curve of the dawn light at *Bosscha* Observatory.



Figures 6. Sky Brightness Light Curve (SQM)

C5 Dawn Light Curve at Amfoang

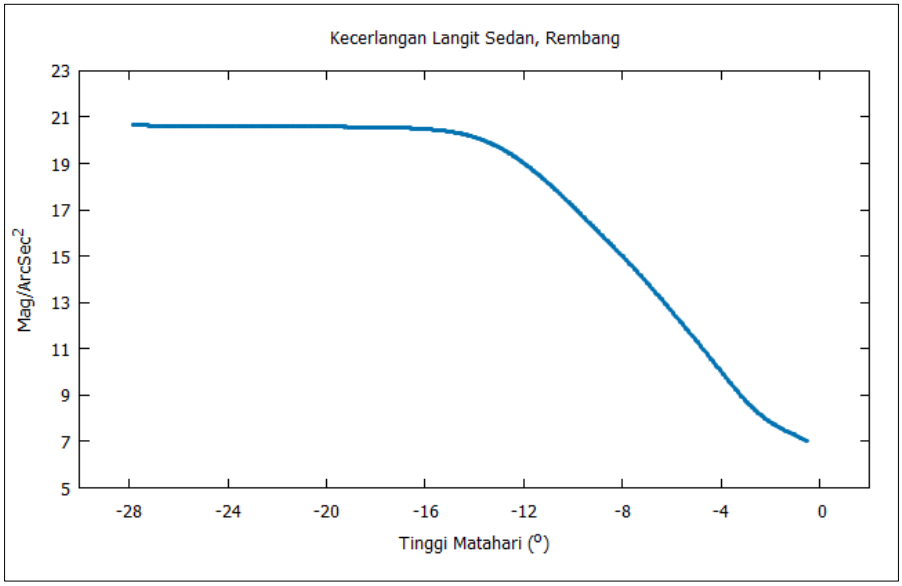
The dawn light curve at *Amfoang* is the light curve from SQM data. Here's the curve of the dawn light at *Amfoang*.



Figures 7. Sky Brightness Light Curve (SQM)

C6 Dawn Light Curve at Sedan, Rembang, Central Java

The dawn light curve at *Sedan, Rembang, Central Java* is the light curve from SQM data. Here's the curve of the dawn light at *Sedan, Rembang, Central Java*.



Figures 8. Sky Brightness Light Curve (SQM)

D. Discussion

D.1 Zodiacal Light Functions

Based on the results of the linear fitting analysis, the zodiacal light function is obtained from the image data and SQM. The zodiacal light function is a mathematical function of the dawn intensity data which can be fitted with a linear function. Fittings with linear functions are used if the data obtained has an intensity that tends to decrease or increase. If the data obtained shows that the intensity tends to be flat, then fitting is done with $i_{ZL}(h)$ = the average value of the linear function fitting sample. The following is a table of the zodiacal light functions as a result of fitting with a linear function.

Table 4. *Zodiacal Light Function*

Location	*Zodiacal Light Function*		Dawn Appearance (Sun Altitude)	
	Citra	SQM	Citra	SQM
Mombhul Beach, Gresik	$i_{ZL}(h) = 0{,}21h + 36{,}61$ $R^2 = 0{,}70$	$i_{ZL}(h) = -0{,}0194h + 21{,}22$ $R^2 = 0{,}84$	-19,30	-19,15
Labuan Bajo	$i_{ZL}(h) = 0{,}03h + 20{,}65$ $R^2 = 0{,}55$	$i_{ZL}(h) = -0.0074h + 21.08$ $R^2 = 0{,}67$	-19,93	-19,13
Sedan, Rembang, Central Java	-	$i_{ZL}(h) = -0{,}0079h + 20{,}43$ $R^2 = 0{,}93$	-	-17,64
Bosscha Observatory	-	$i_{ZL}(h) = 0{,}0018h + 21{,}12$ $R^2 = 0{,}80$	-	-16,07
Imahnoong	-	$i_{ZL}(h) = 19{,}6419$	-	-15,26
Amfoang	-	$i_{ZL}(h) = 22{,}5965$	-	-17,68

Based on Table 4, it is clear that the appearance of dawn is a marker of the combination of the intensity of the zodiacal light with the intensity of dawn. With a linear approach, it can be known when the dawn appears by comparing the intensity value with the standard deviation of the linear function or the zodiacal light function. Table 4 shows that from photographic observations (C*itra*), the initial appearance of dawn is on h on average -19.61°. In contrast to the results from SQM observations, the early appearance of dawn is on h on average -17.49°. The difference in the value of h is due to the unequal location of observations, where for photographic observations, it is carried out in locations that are not polluted by light, while SQM observations are also carried out in locations that are polluted by light. If the initial appearance of dawn in Labuan Bajo and Mombhul Beach with SQM observations is averaged, then the value of h is -19.14°. The results of our study differ from those of Semeida et al. (2018) which states that the appearance of the zodiacal light is when h = -19.71°, while the end of the zodiacal light is when h = -14.59°.[3] By looking at the results of the dawn twilight light curve pattern and the appearance of the zodiacal light, it shows that light pollution, weather, and the position of the tool in data collection greatly affect the early appearance of dawn.

E. Conclusion

Based on the results of the analysis using linear fittings, it is known that the appearance of dawn is a marker of the joining of the intensity of the zodiacal light with the intensity of dawn. By taking a linear approach to the observation data, it can be known when the dawn appears by comparing the intensity value with the standard deviation of the linear function or the zodiacal light function. If the initial appearance of dawn in Labuan Bajo and Mombhul Beach with SQM observations is averaged, then the h value is -19.14°. The results of our study differ from those of Semeida et al. (2018) which states that the appearance of the zodiacal light is when h = -19.71°, while the end of the zodiacal light is when h = -14.59°.

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