Iraqi Journal of Science, 2023, Vol. 64, No. 5, pp: 2627-2634
DOI: 10.24996/ijs.2023.64.5.43

ISSN: 0067-2904

Determination of the Time and Coordinates Required for Measuring the Milky Way's Rotation Curve Using BURT in 2023

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Received: 1/8/2022 Accepted: 16/9/2022 Published: 30/5/2023

Abstract

Baghdad University Radio Telescope (BURT) is a 3 meter radio telescope that was installed in the main campus of the University of Baghdad in Jadiriyah. Radio telescopes, in general, offer a wide range of applications in radio astronomy, which are usually used to detect the neutral hydrogen emission line at a wavelength of 21 cm. One of the key applications of BURT is to observe the Milky Way galaxy and to determine its rotation curve. However, performing such observations requires accurate determination of the appropriate observing time as well as the coordinates. This paper focuses on how the observing time and coordinates are calculated correctly and accurately. The horizontal coordinate that corresponds to the galactic coordinates (b=0° and 0° ≤ l ≤ 90°) in every single day of 2023 at 10 am have been calculated using a c++ code that has been written for the purpose of this work. The results showed that the appropriate time for observing the Milky Way using BURT in 2023 is during January, February, March, November and December of 2023. The medians of altitude during those months are 50.9798°, 62.7919°, 50.6198°, 9.6562° and 30.5041°, respectively. During those months, the altitude is found, in general, larger than zero which means that the galactic position is above the horizon.

Keywords: Radio telescopes, Milky Way, Neutral hydrogen emission line, Rotation curves, Astronomical coordinate systems

حساب الوقت والاحداثيات المطلوبة لقياس منحني الدوران لمجرة درب التبانة باستخدام *BURT* لعام 2023

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الخلاصة

تلسكوب جامعة بغداد الراديوي هو تلسكوب راديوي ذو قطر 3 متر، تم انشاؤه في المجمع الرئيسي لجامعة بغداد في الجادرية. التلسكوبات الراديوية بصورة عامة توفر طيف واسع من التطبيقات في تخصص الفلك الراديوي وتستخدم عادةً في رصد خط انبعاث الهيدروجين المتعادل ذو الطول الموجي 21 سم. احد اهم التطبيقات التي يوفرها تلسكوب جامعة بغداد الراديوي هو رصد مجرة درب التبانة وحساب منحني الدوران الخاص بها. لكن اجراء مثل هذه الارصادات يتطلب حساب دقيق لوقت الرصد المناسب وكذلك الاحداثيات اللازمة لذلك.

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هذا البحث يركز على كيفية حساب وقت الرصد والاحداثيات بصورة دقيقة. حيث تم حساب الاحداثيات الافقية التي تتوافق مع الاحداثيات المجرية (b=0° and 0° ≤ l ≤ 90°) لكل يوم من عام 2023 عند الساعة 10 صباحاً باستخدام برنامج تم كتابته بلغة c++ لغرض تحقيق هدف هذا العمل. بينت النتائج ان اكثر وقت ملائمة لرصد مجرة درب التبانة باستخدام تلسكوب جامعة بغداد الراديوي لعام 2023 خلال الاشهر كانون الثاني، شباط، اذار، تشرين الثاني وكانون الاول من عام 2023. حيث وجد ان قيم المتوسط الحسابي للارتفاع خلال هذه الاشهر 50.9798°، 62.7919°، 50.6198°، 9.6562°، 30.5041° على التوالي. وان قيم الارتفاع خلال هذه الاشهر بصورة عامة اكبر من صفر مما يعني ان الموقع المجري المراد رصده فوق الافق.

1. Introduction

or absorbed by interstellar dust. One of the most important radio emissions is the emission line of neutral hydrogen at a wavelength of 21 cm which can be detected using radio telescopes. This emission line was first detected using radio telescopes in 1951 and it occurs due to the change in spin of the electron and proton in a hydrogen atom [1]. Such radio observations provide information about astronomical objects like galaxies, quasars, neutron stars as well as the Cosmic Microwave Background [2].

Radio astronomy becomes a very important branch of astronomy due to its significant contribution to improve our understanding about astronomical objects that emit radio waves. Such radio waves are detected using radio telescopes [3]. The world's largest single dish radio telescope is the Five-hundred-meter Aperture Spherical Telescope (FAST) that was built in China and was completed in 2016. The main goal of this telescope is to observe a large area of sky with high precision that leads to information on the Universe [4].

Small Radio Telescopes, on the other hand, can also provide information about astronomical objects. For instance, a small radio telescope of a diameter of 4.5m in Thailand was used to map the distribution of neutral hydrogen in our galaxy [5]. Another small radio telescope, whose diameter is 2.6 m, was built at the Hanoi astrophysics laboratory. This telescope is known as VATLY and was used to observe the Sun and the centre of the Milky Way [6]. In addition, the emission line at a frequency of 1.42 GHz from the Sun was detected using a small radio telescope at the Astronomical Observatory of the Department of Astronomy, University of Sofia [7].

BURT was installed on the roof of the Department of Astronomy and Space, College of Science, University of Baghdad. This telescope has a diameter of 3 meters, a focal length of 1.18 meters and f/D ratio of 0.39 [8 and 9]. BURT provides opportunities to astronomers in Iraq to achieve several scientific goals. For example, BURT was calibrated using the Sun as a reference source [10]. It was also used to investigate the background radio emissions at 1.42 GHz [11]. This research is part of a project that aims to use BURT to measure the rotation curve of the Milky Way. The results of this research are essential to achieve the goal of the proposed project because measuring emission line at 21 cm from the Milky Way requires accurate determination of the coordinates and time of observation.

2. Calculations and Results

The Milky Way's rotation curve can be determined using a method known as Tangent Point Method. In this method, the Doppler shift of HI emission line at a wavelength of 21 cm is used to measure the maximum radial velocity (V_{max}) in the HI profile. This maximum radial

velocity corresponds to an HI cloud that is located along the line of sight closest to the Galactic center. For more information on this method, the reader is referred to e.g. [12].
The distance to the Galactic center (R) and the rotational velocity (V_C) at a particular galactic position are measured from the following formulas [12]:

$$R = R_o \sin l \quad (1)$$

$$V_C = V_{\max} + V_o \sin l \quad (2)$$

where R_o and V_o are the distance of the sun from the galactic center and the circular velocity of the sun, respectively and l is the galactic longitude. This basically implies that measuring the maximum radial velocity at different galactic locations (at galactic latitude $b = 0°$ and $0° \leq l \leq 90°$) leads to determining the rotation curve of the Galaxy.
Therefore, observing the gas clouds at different galactic locations and measuring V_{max} using Baghdad University Radio Telescope (BURT) would require converting the galactic coordinates to the horizontal coordinates. However, this cannot be achieved directly instead one needs to convert the galactic coordinates to equatorial coordinates and those, in turn, are converted into the horizontal coordinates.

The goal in this paper is to measure the horizontal coordinates, which are coordinates used by BURT, at different galactic coordinates (at $b = 0°$ and $0° \leq l \leq 90°$).
To convert the galactic longitude and latitude (l and b) into right ascension and declination (α and δ) in degrees, the following formulas are used [13]:

$$\alpha = \tan^{-1}\left\{\frac{\cos b \cos(l-33^{\circ})}{\sin b \cos(27.4^{\circ}) - \cos b \sin(27.4^{\circ}) \sin(l-33^{\circ})}\right\} + 192.25^{\circ} \quad (3)$$

$$\delta = \sin^{-1}\{\cos b \cos(27.4^{\circ}) \sin(l-33^{\circ}) + \sin b \sin(27.4^{\circ})\} \quad (4)$$

To convert the Equatorial coordinates to horizontal coordinates, the following formulas are used [13]:

$$\sin a = \sin\delta \sin\phi + \cos\delta \cos\phi \cos H \quad (5)$$

$$\cos A = \frac{\sin\delta - \sin\phi \sin a}{\cos\phi \cos a} \quad (6)$$

Where a, A, H and ϕ are altitude, azimuth, hour angle and the observer's geographic latitude, respectively. The geographic latitude of BURT in Baghdad, Jadiriyah is 33.275°.
The hour angle is measured from the formula:

$$H = LST - \alpha \quad (7)$$

Where LST is the local sidereal time. Both H and α can be expressed in hours or degrees. To calculate LST, one should calculate the Greenwich Sidereal Time (GST). In order to do so, the Julian date should be calculated according to the steps shown in a flowchart; see Figure 1.
In this work, the abovementioned steps have been used to calculate the horizontal coordinates for every day in 2023 at 10 am that correspond to the galactic coordinates (b=0° and $0° \leq l \leq 90°$). The graphical representation of the horizontal coordinates is shown in Figure 2. The medians, along with the 16th and 84th percentiles of altitude and azimuth, are shown in Figures 3 and 4. It should be pointed out here that the 16th and 84th percentiles have been used to interpret the results of this research because they basically represent the 68% of the data points that lie between the 16th and 84th percentiles.

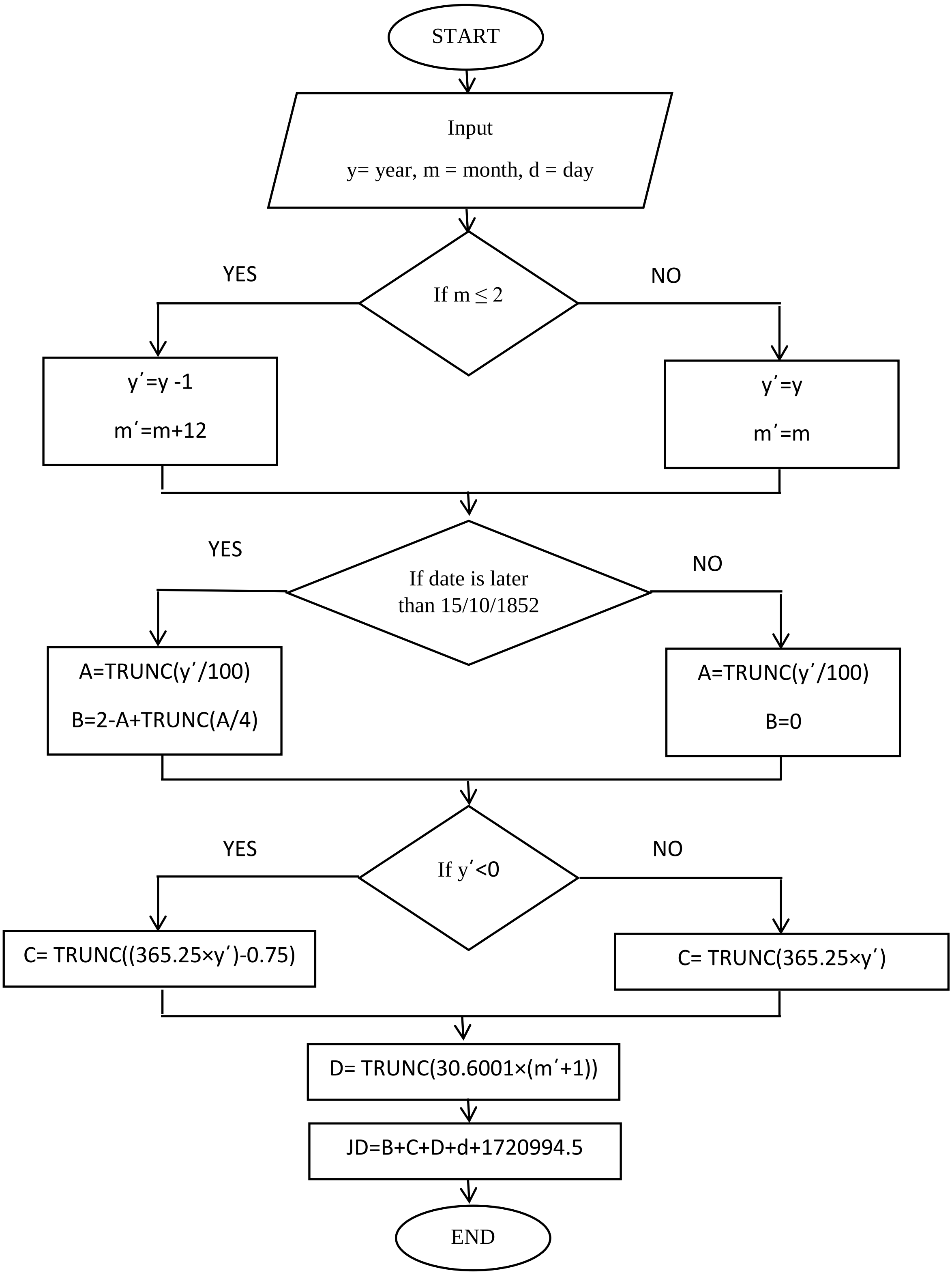

Figure 1: The calculation steps of Julian date.

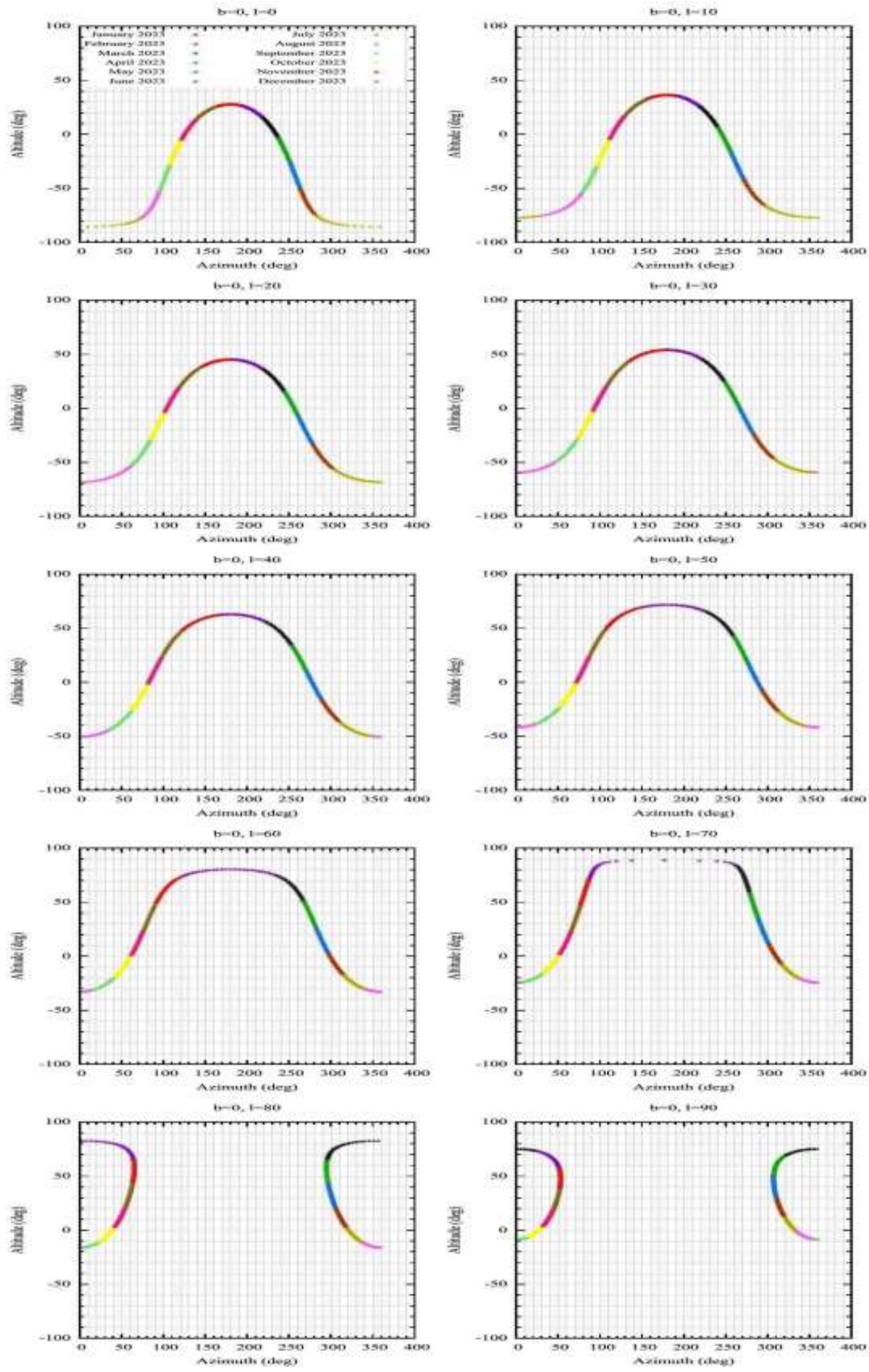

Figure 2: The altitude as a function of azimuth in 2023 from Baghdad.

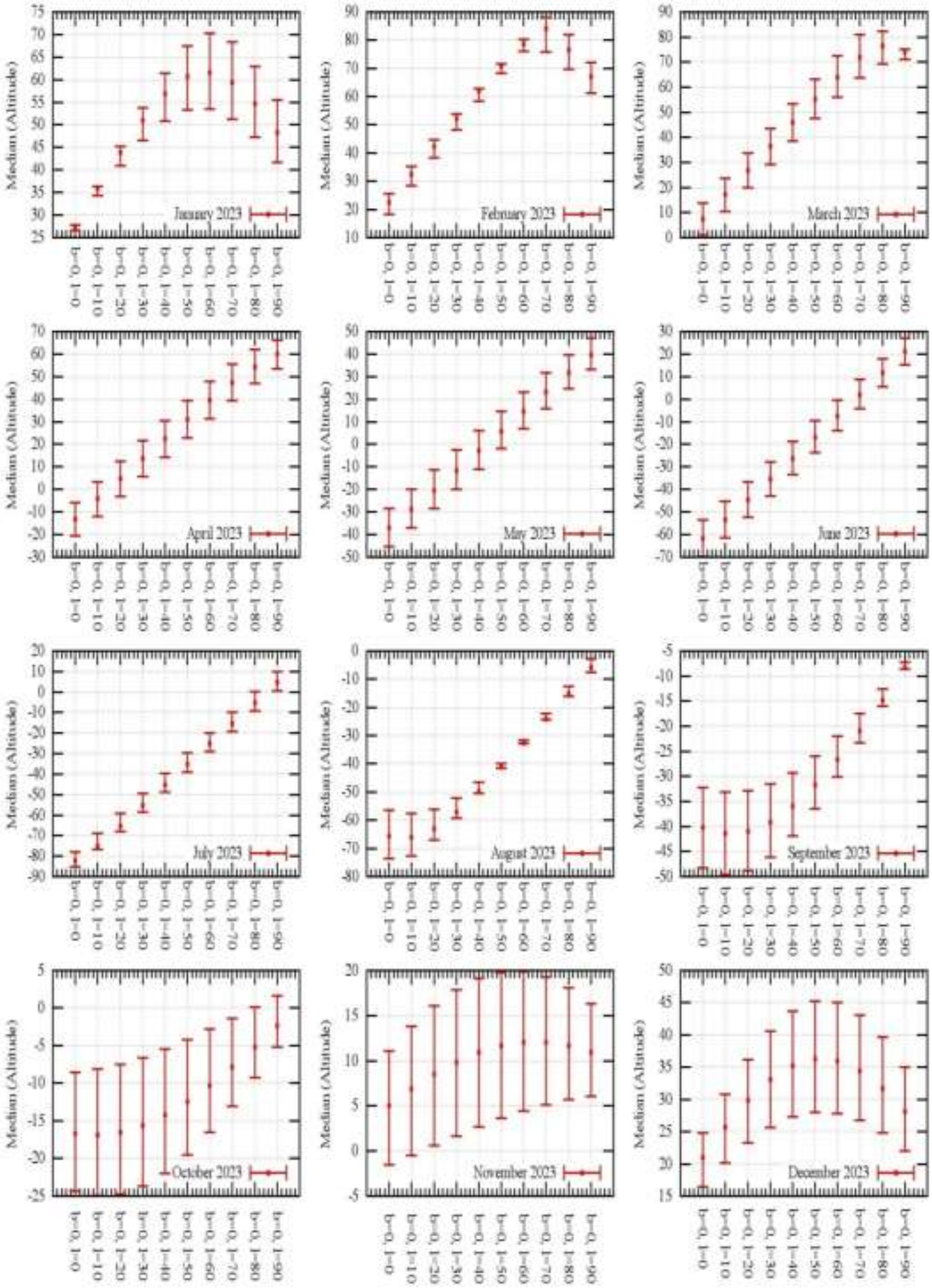

Figure 3: The median of altitude as a function of galactic coordinates for the 12 months of 2023. The error bars represent the 16th and 84th percentiles of altitude.

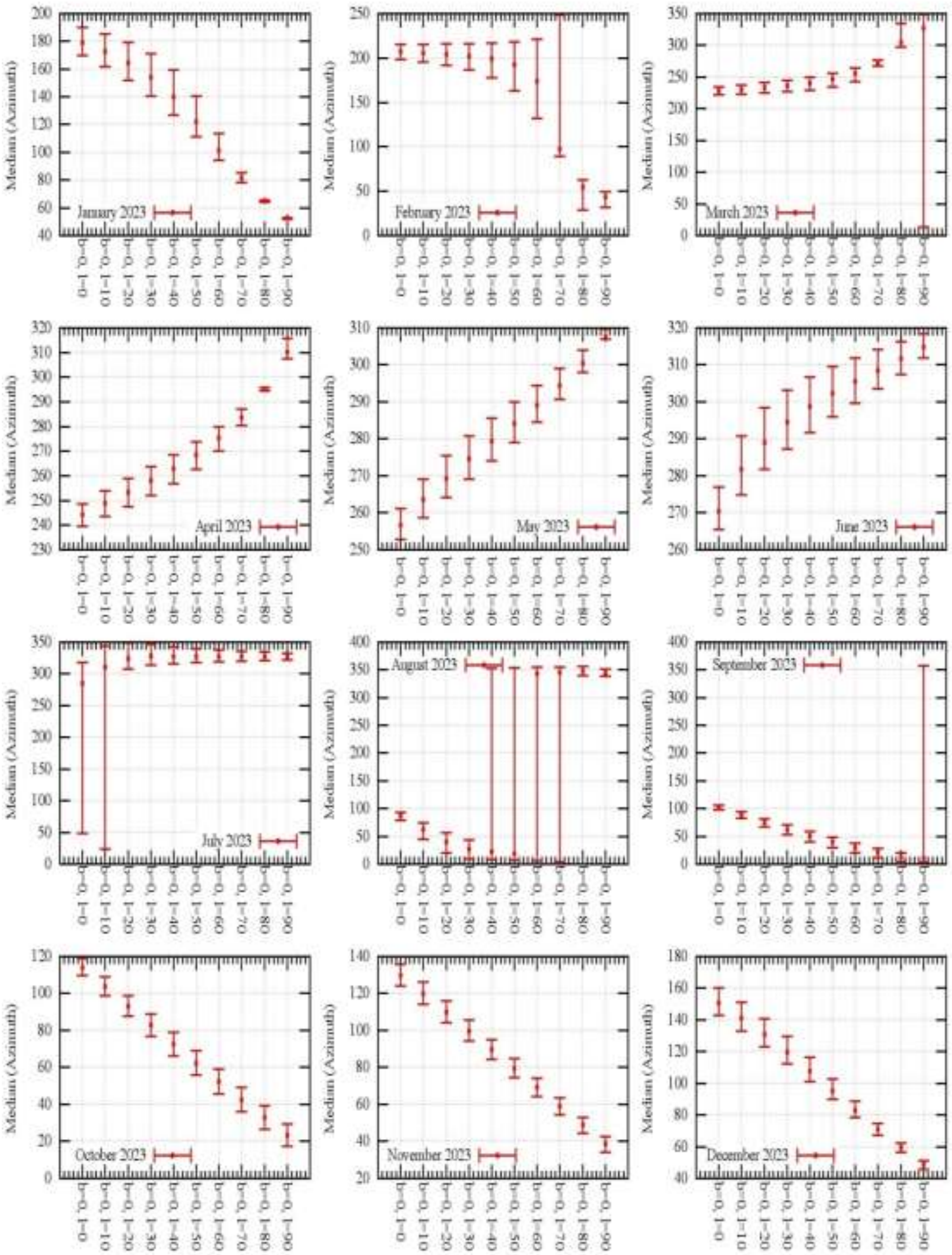

Figure 4: The median of azimuth as a function of galactic coordinates for the 12 months of 2023. The error bars represent the 16th and 84th percentiles of azimuth.

3. Discussion and Conclusions

The focus of this research was on the calculation of the appropriate times and coordinates for observing the Milky Way galaxy from Baghdad for every day in 2023 at 10 am. Particularly, the horizontal coordinates that correspond to the galactic coordinates (b=0° and $0° \leq l \leq 90°$) have been determined. The results showed that the best time for observing the inner Milky Way (0° ≤ *l* ≤ 90°), for the purpose of measuring the rotation curve of the Milky Way using BURT, is during the first three months (January, February and March) as well as the last two months (November and December) of 2023. This is because the altitude during those months of 2023 is larger than zero, which basically means that the clouds of neutral hydrogen in the Milky Way, which are located in the galactic coordinates (*b*=0° and 0° ≤ *l* ≤ 90°), are above the horizon. Other months of 2023 are, in general, inappropriate to observe the inner Milky Way. The results of this work also proved that calculating the appropriate time and coordinates is an essential step to observe the Milky Way and measure the rotation curve of the Galaxy using BURT, which would be the purpose of a further study.

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