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A REPORT ON

Rediscovering Earth's Circumference:

Recreating Eratosthenes' Method with Stellarium

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Abstract

This report investigates the versatile application of Stellarium, a popular free and open-source planetarium software, in the fields of geodesy and astronomical observation. Stellarium, known for its user-friendly interface and accurate celestial simulations that allows people to use their home computer as a virtual planetarium.

Stellarium proves to be an invaluable tool for enhancing the understanding of Earth's position in space and its relation to celestial objects. By utilizing its precise sky modeling capabilities, Stellarium aids in geodetic measurements, satellite tracking, and the analysis of Earth's rotation and orientation parameters.

This project revisits the landmark experiment by Eratosthenes, conducted over 2,200 years ago, aimed at estimating the Earth's circumference. Eratosthenes ingeniously measured the Sun's angle relative to the vertical at two locations during the summer solstice, Alexandria and Syene (modern-day Aswan), and used his observations to approximate the Earth's size. Using Stellarium, a modern planetarium software, this project replicates Eratosthenes' method virtually.

Ultimately, this project aims to determine the Earth's circumference, both in stadia and kilometers, using Stellarium's simulated observations and Eratosthenes' method. By comparing these estimations with the widely accepted modern value, this experiment sheds light on the accuracy and significance of Eratosthenes' groundbreaking technique in measuring our planet's size, showcasing the enduring impact of ancient scientific inquiry.

✓ Table of Contents

KEYWORDS: Earth's Circumference, Stellarium, Azimuthal coordinate system, Equatorial coordinate system, Summer solstice, Sun Altitude.

Introduction

Astronomical geodesy is a branch of geodesy that employs astronomical methods and observations to precisely determine the size, shape, and orientation of the Earth, as well as to establish reference frames for positioning on the planet's surface and in space. Astronomical geodesy combines astronomical observations with geodetic techniques to achieve high-precision measurements and models of Earth's properties. Its applications extend across various fields, including cartography, surveying, satellite navigation, and understanding Earth's dynamic processes.

Stellarium is an open-source free-software planetarium, having GNU General Public License. It is available for Linux, Windows, and macOS. Stellarium Mobile is also available for Android, iOS, and Symbian. In all the versions, Stellarium uses OpenGL to render a realistic projection of the night sky in real time, according to the system requirements given at the web site stellarium.org.

Its ability to simulate the night sky with remarkable precision has propelled its popularity beyond the realm of amateur astronomy, finding practical applications in geodesy and professional astronomical observation.

We can find Stellarium proposed and used for the education of young people in astronomy. Stellarium is clearly appreciated for the ease of use. Stellarium, besides its scientific and educational utility, can serve as an artistic tool to convey mood and emotion. Its ability to simulate the night sky in such a detailed and visually stunning manner can evoke feelings of wonder, awe, and inspiration.

Eratosthenes, a brilliant Greek scholar born in Cyrene (now Libya), was known for his diverse expertise across multiple fields. He became the librarian at Alexandria's renowned library in Egypt. While his exact methods remain unclear, Eratosthenes is believed to have made significant astronomical calculations, including estimations of the distances to the Sun and Moon. His most famous accomplishment was estimating the Earth's size, earning him the title of the "Father of Geography." As a geographer, he detailed the known inhabited world, laying the groundwork for early geography. Eratosthenes' remarkable contributions across astronomy and geography continue to influence our understanding of the ancient world.

Source: Star-Watcher Photography

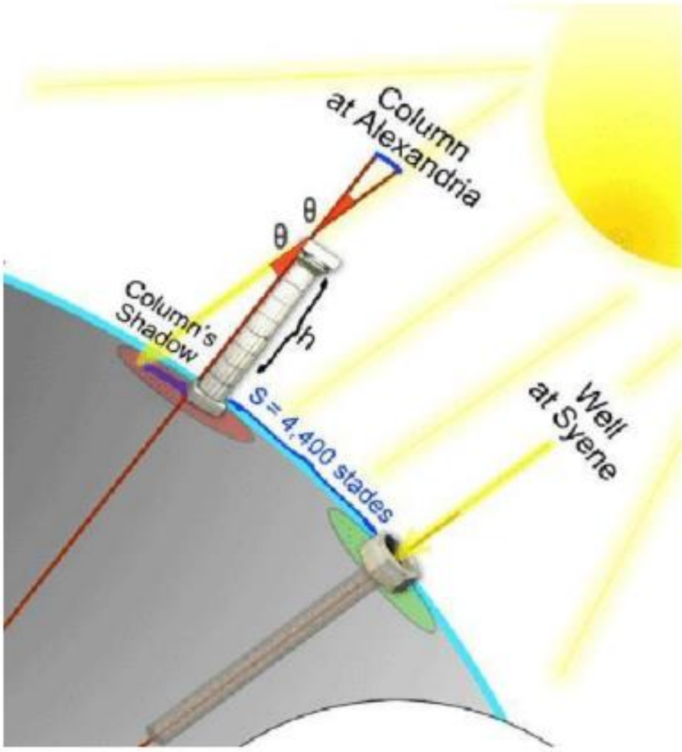
Eratosthenes

Source: Wikipedia

Objective

The goal is to use Stellarium to copy an ancient experiment by Father of Geography named as Eratosthenes. The objective of this report is to utilize the Stellarium software to replicate the ancient experiment conducted by Eratosthenes, the Father of Geography. Through this emulation, the aim is to comprehend the interface of Stellarium while gaining a comprehensive understanding of the azimuthal coordinate system and equatorial coordinate system utilized to track and locate celestial bodies. By observing the Sun's position during the summer solstice from both Alexandria and Syene (Aswan), the report aims to determine the angle of elevation of the Sun at these two locations. This data will be used to perform mathematical calculations, similar to Eratosthenes' methodology, to estimate the Earth's circumference. The objective further includes a comparative analysis between the calculated Earth's size from the Stellarium observations and Eratosthenes' historical calculation. The overall goal is to highlight the enduring relevance of ancient scientific methodologies in contributing to our contemporary understanding of the world.

Eratosthenes and his Calculation:



Eratosthenes made a remarkable observation by noting that on a specific day of the year, during the summer solstice, the Sun cast no shadows down a deep well in Syene, which suggested that the Sun was directly overhead at noon in that location. However, in Alexandria, located about 500 miles north of Syene, Eratosthenes noticed that at the same time, the Sun didn't shine directly down a well; it cast a shadow. This indicated to him that the direction of sunlight at noon in Alexandria was different from that in Syene.

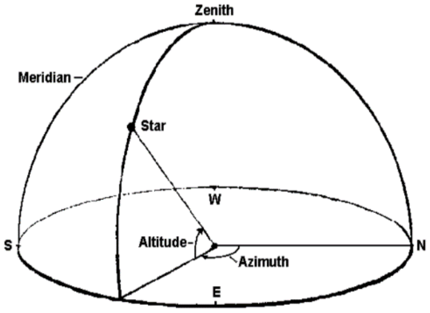
Eratosthenes assumed that the Sun was so distant from the Earth that its rays arrived nearly parallel. This assumption was crucial for his calculations. By measuring the angle of the shadow cast in Alexandria and knowing the distance between Syene and Alexandria, he inferred that the difference in the angles of the sunlight in the two cities corresponded to a fraction of the Earth's circumference. With this information, he estimated the Earth's size by extrapolating the known distance between the two cities to the entire circumference of the Earth.

Circumference of Earth= (360°÷ 7.12°) x 4,400 = 220,000 stades= 40700 Km.

Coordinate System

Azimuthal Coordinate System:

The Altitude/Azimuth coordinate system is a method used in astronomy to describe the apparent positions of celestial objects in the sky as observed from a specific location on Earth. It consists of two angular measurements:



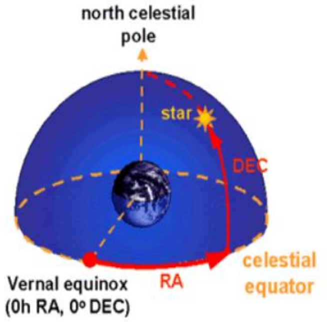
Source: http://homework.uoregon.edu/

1. Azimuth: This angle measures the horizontal direction of a celestial object from an observer, starting from due north and measured clockwise along the observer's horizon. It provides the bearing or compass direction to the object.
2. Altitude: This angle represents the object's apparent height above the observer's horizon. It measures the angular distance of the object above the horizon, indicating how high it appears in the sky.

The Altitude/Azimuth system provides an intuitive way for observers to locate and describe the positions of celestial objects relative to their horizon and cardinal directions.

Equatorial Coordinate System:

The Right Ascension/Declination (RA/Dec) Coordinate System, also known as the Equatorial Coordinate System in astronomy, is a method used to specify positions of celestial objects in the sky. This system, similar to longitude and latitude on Earth, uses two angles to locate objects on the celestial sphere.



Source: COSMOS - The SAO

1. Right Ascension (RA): RA is like longitude on Earth. It measures the angle eastward along the celestial equator from a standard reference point called the vernal equinox, often referred to as the First Point of Aries. RA is typically measured in hours, minutes, and seconds, with 15 degrees of celestial longitude equaling one hour of right ascension.
2. Declination (Dec): Dec is like to latitude on Earth. It measures the angle north or south from the celestial equator to a celestial object. Declination is expressed in degrees, with positive values for objects above the celestial equator and negative values for those below it.

In contrast to Altitude/Azimuth coordinates, RA/Dec coordinates remain fixed for celestial objects and don't significantly change with the observer's location on Earth or throughout the day due to the Earth's rotation. They provide a stable, universal way to pinpoint the positions of stars and celestial bodies in star.

Astronomical Observation

This report delves into the fascinating intersection of historical astronomical methodologies and modern technology. By employing Stellarium, a contemporary planetarium software, I engaged in an interesting journey of astronomical observation. This involved replicating Eratosthenes' ancient experiment to estimate Earth's circumference using the Sun's altitudes observed at Alexandria and Syene during the summer solstice of 240 BC. Through this experiential, I not only experienced my understanding of celestial observations but also unearthed the practical application of historical methods in contemporary astronomical exploration. This report strongly illustrates the interaction between past and present techniques, showcasing the significance of ancient astronomical inquiry in enhancing our understanding of the universe.

Similarly, I employed Stellarium to examine the positions of celestial objects using both the azimuthal and equatorial coordinate systems from two distinct locations: Kathmandu and Pokhara, Nepal simultaneously. Despite observing the same section of the sky, I noticed variations in Alt-Az coordinates between the two locations. This Altitude-Azimuth system, once useful for early astronomers in tracking objects like Mars across successive nights from a single location, demonstrates differences depending on an observer's position on Earth.

However, considering the advancements in modern astronomy, I conducted further observations using Stellarium to obtain the equatorial coordinate system of the same celestial body from both Kathmandu and Pokhara at the exact moment. Surprisingly, the Right Ascension and Declination (RA-Dec) coordinates were identical. This reveals the advantage of the equatorial system, which remains constant regardless of the observer's location on Earth. The consistency of RA-Dec coordinates emphasizes the convenience of a coordinate system that is independent of an observer's specific location, providing a more reliable and universally applicable framework for contemporary astronomical observations.

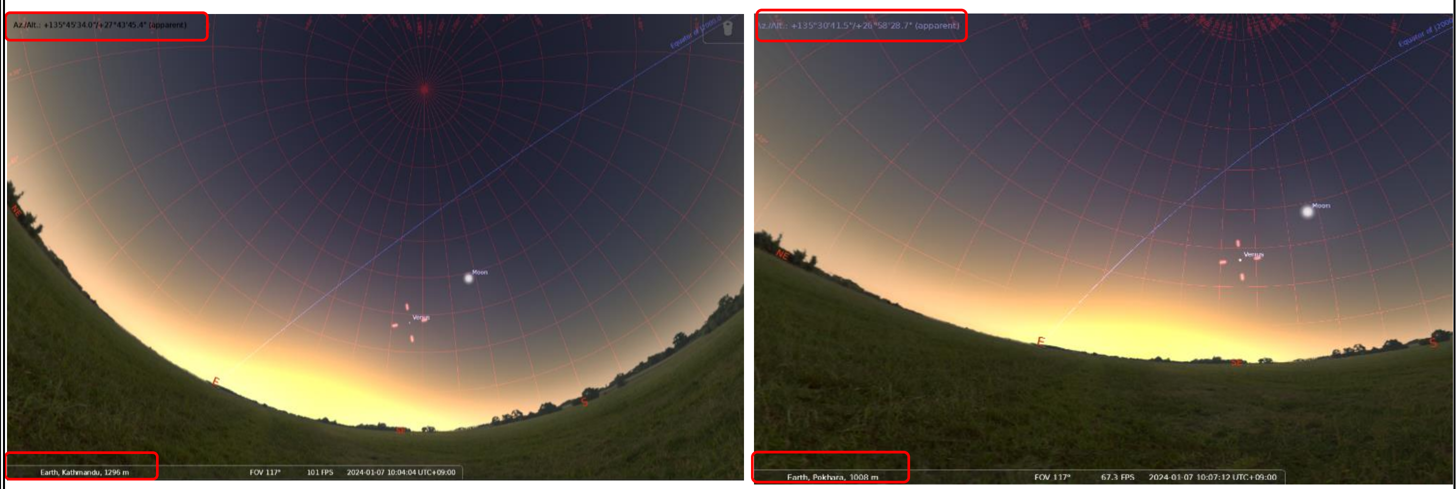


Fig: Screenshot of Stellarium software showing Azimuthal Coordinate system (Az/Alt) of Kathmandu and Pokhara, Nepal.

Fig: Screenshot of Stellarium software showing Equatorial Coordinate system (RA/Dec) of Kathmandu and Pokhara, Nepal.

Methodology

This methodology outlines the steps followed in replicating Eratosthenes' experiment using Stellarium, aiming to estimate Earth's circumference and explore its historical and scientific significance.

1. Set-up and Preparation:

a. Software Configuration: Utilizing Stellarium, a planetarium software, and ensuring accurate installation and settings.

2. Selection of Observational Locations:

a. Identify Locations: Choosing two locations—Alexandria and Syene (modern-day Aswan)—which Eratosthenes used for his experiment.

b. Time Differences Calculation: Determining the time differences between Alexandria/Syene and Nepal for local mean time at noon to reflect the conditions of 240 BC, specifically the summer solstice to ensure observations align accurately.

3. Observation Procedure:

a. Sun Altitude Measurement: Setting Stellarium to Alexandria and Syene at the designated date and time. Observing and recording the altitude at Local Noon by targeting Sun in Stellarium.

4. Calculation and Data Analysis:

a. Angle Computation: Calculating the difference in the Sun's altitudes between Alexandria and Syene to determine Eratosthenes' angle (θ).

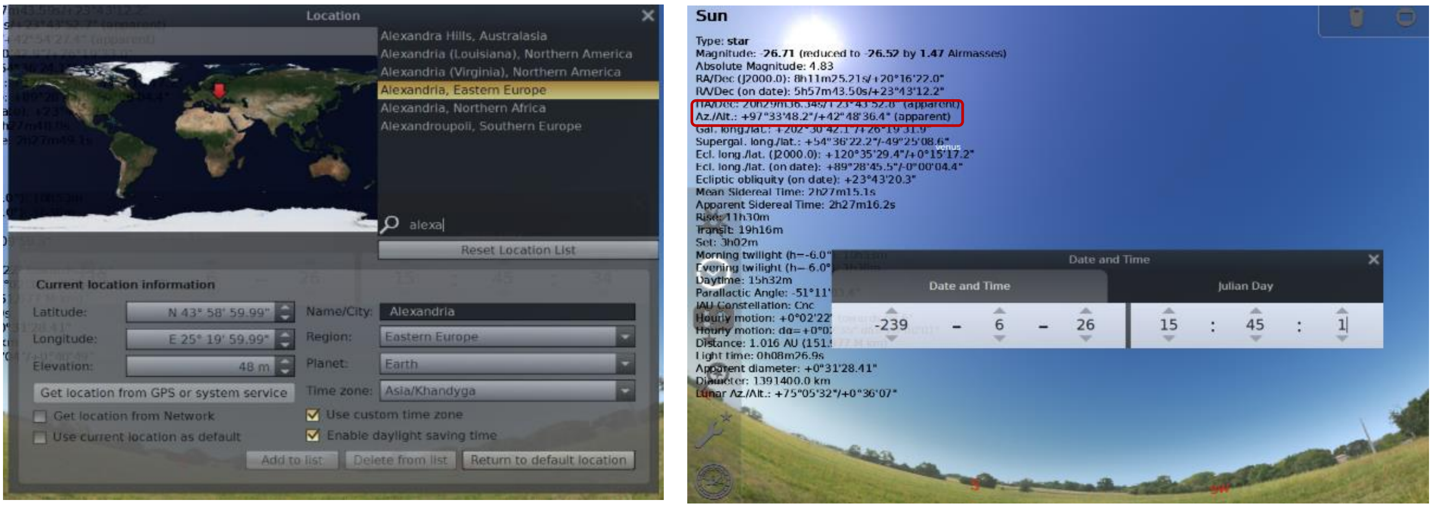


Fig: Setting Location, Date and Time of Syene (Aswan) according to Eratosthenes and Recording Sun Altitude at the moment

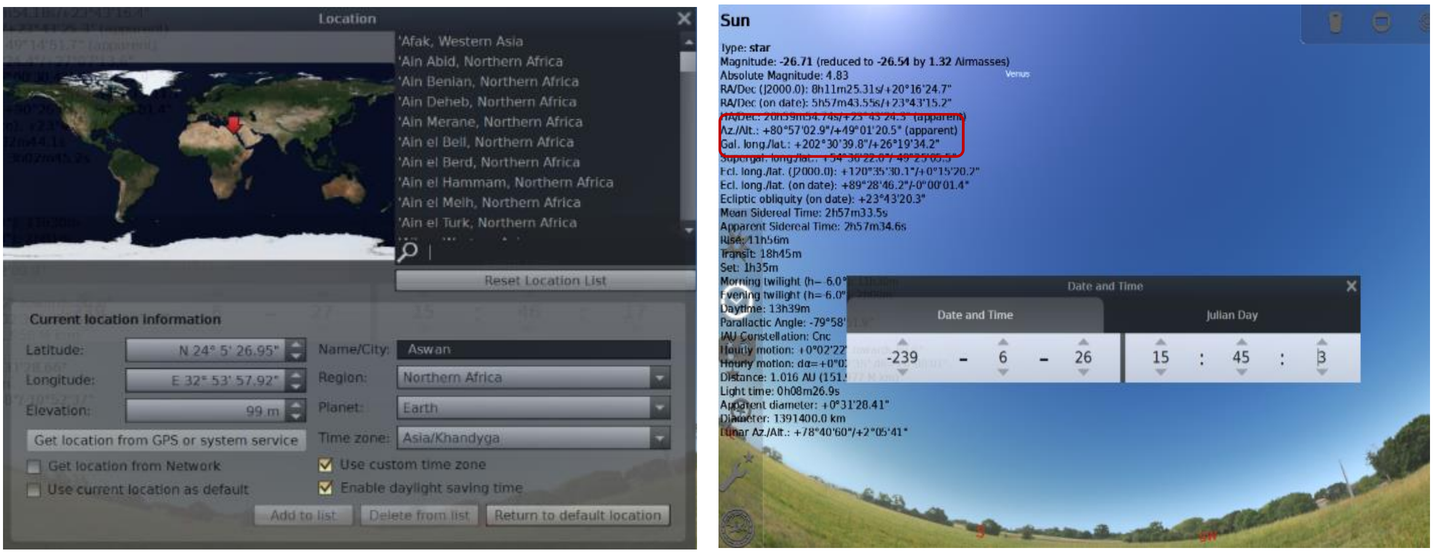


Fig: Setting Location, Date and Time of Alexandria according to Eratosthenes and Recording Sun Altitude at the moment

Calculation

Altitude of Sun at Alexandria: 42°48’36.4”

Altitude of Sun at Syene: 49°01’20.5”

Differences between Altitudes (θ): 49°01’20.5”- 42°48’36.4” =06°12’44.1”

Distance between Syene and Alexandria= 800 km (about)

Calculated Earth's Circumference= (360°÷ 06°12’44.1”) x 800= 46360 km.

Eratosthenes Earth's Circumference = 40700 km

Today’s Earth's Circumference = 40075 km

For the Calculated Circumference: Percentage Error= |(46360−40075)/40075|×100≈ 15.69%

For Eratosthenes' Estimation: Percentage Error=|(40700−40075)/40075|×100%≈1.56%

Sources of Error

Accuracy of Stellarium Data: Stellarium's precision, though advanced, may have limitations or inaccuracies in simulating historical astronomical conditions.

Conversion Errors: Accuracy in converting stades to kilometers or potential errors in applying the conversion factor might contribute to the variation.

Time Variation: The Local Noon time is not exactly at midday as you may have expected.

Conclusion

In summary, using Stellarium allowed me to explore how ancient and modern methods overlap in studying the stars. I recreated Eratosthenes' experiment, estimating Earth's size, which showed how old ideas are still relevant today.

Observing the sky from Kathmandu and Pokhara using different coordinate systems revealed how the old way of tracking stars changes depending on where you are on Earth. But with modern techniques, I discovered that a newer coordinate system, like the Equatorial one, stays the same regardless of where you're observing from. It's like having a universal address for stars, making it easier for everyone to agree on where things are in the sky. This experience taught me that while ancient methods are fascinating, new technology helps us create more reliable ways to understand the universe. It's like connecting the past with the present to keep learning more about the cosmos.

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