REPLICATING OBSERVATIONS OF THE SUN´S MOTION AS DESCRIBED IN ICELANDIC MANUSCRIPTS FROM THE 12TH CENTURY

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Documented observations
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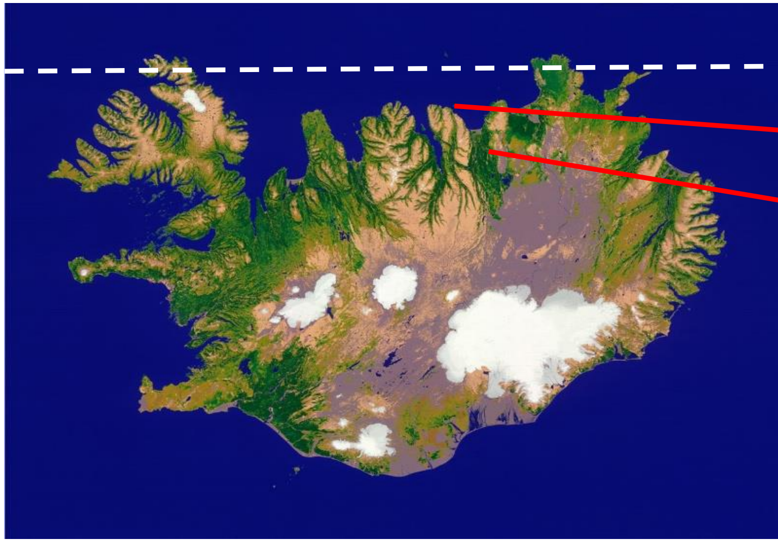
Abstract

Old Icelandic manuscripts contain some interesting astronomical material, for example calendar calculations and solar observations. We know the names of some of the original authors though their work was not written down during their lifetime, but preserved orally for decades or even centuries. The primitive Nordic almanac year of 2x26 weeks (364 days) caused problems in daily life and administration before Christianity was adopted and the Julian calendar introduced in 1000 AD. *Thorsteinn Hallsteinsson,* called *"the Black",* found an inventive solution in the middle of the 10th century, thoroughly studied by philologists and mathematicians. This presentation, however, concentrates on observations of the Sun made by *Oddi Helgason*, nicknamed "*Star-Oddi*", who lived in northern Iceland in late 11th and early 12th century. He is still remembered for his timing of solstices and measuring changes in the Sun´s declination between them. Oddi´s choice of the apparent diameter of the Sun as an angular unit is remarkable. His conclusion was that the total change over 26 weeks from winter minimum to summer maximum was 91 units. In modern terms it means that the diameter of the Sun is 47°/91=0.52° which is close to the actual mean value of 0.532°, contrary to the accepted value of 360°/216=1.67° in continental Europe at that time. Oddi´s mathematical model of the progression of increments in weekly observations approximates surprisingly well an accurate curve. The purpose of the poster is to describe and interpret Star-Oddi´s results and propose a plausible method, not documented in the manuscripts. Even if it is possible to track the Sun´s coordinates along the horizon at sunrise or sunset, the most obvious procedure is to measure the Sun´s altitude at culmination. In order to apply the Sun itself as a unit a hypothetical portable equipment could be a combination of pinhole camera and meridian circle. The image at the end of the camera tube is then used to calibrate a circular scale on the back side of the instrument. Hopefully a prototype will be tested this summer but comprehensive measurements on location may take a few years.

Star-Oddi´s Life



Arctic circle AD 1100

Flatey: 66°10´ N; 17°52´ W

Muli: 65°48´ N; 17°22´ W

A short story called *Star-Oddi´s dream* is the only source of him as a person. The dream takes place at a royal court in Sweden where Oddi changes identity with one of the king´s knights, recites long poems and the king´s sister becomes his bride as a reward before he wakes up to reality. The scenario in the dream is very absurd, including battles with berserks and amazons, but may have some prophetic meaning about Oddi´s nature.

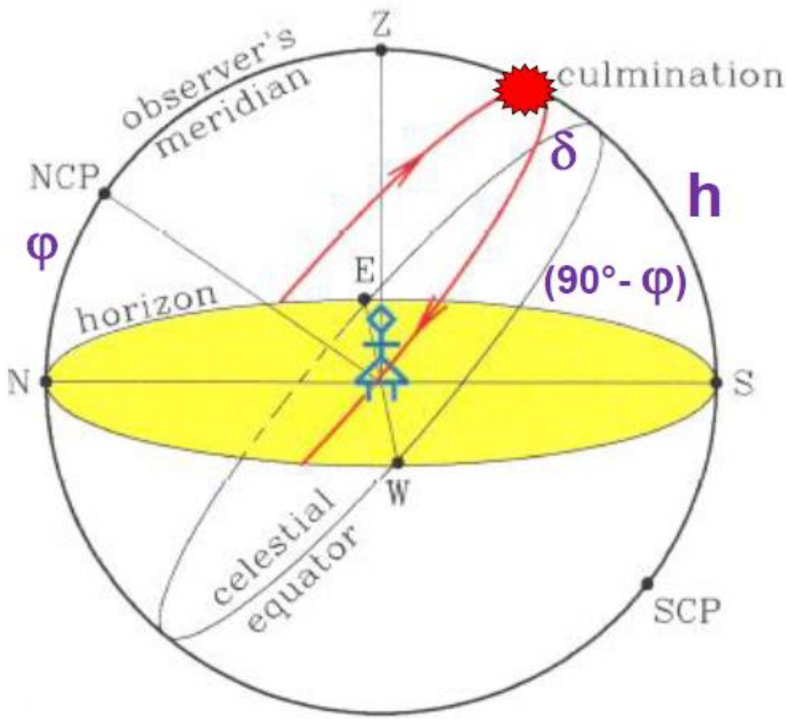
Labourer at the farm *Muli* in Adal-dale, fisherman on the island *Flatey* in Skjalfandi-bay.

„Had little money, not hard-working, honest and loyal, not a poet, never told a lie, keenest in the land on time-reckoning, wise in many respects, looked at stars by night“.

Probably the father of *Styrkar Oddason* who was a lawspeaker late in the 12^{th} century.

Composed *Oddi´s* tale with two pages of solar observations, part of the book *Rimbegla,* a collection of manuscripts containing calendar tables and calculations and diverse astronomical and mathematical material. Much of it is imported knowledge in translation but some solutions are original, for example leap weeks instead of leap days.

Celestial Explanations



Principle behind Oddi´s method to measure the altitude of the Sun above the horizon at culmination:

$$h = (90° - \varphi) + \delta$$

At that time the declination (δ) varied from – 23.55° at winter solstice to + 23.55° at summer solstice. The total change in altitude between the solstices was therefore 47,1° without correcting for athmospheric refraction at low altitudes.

He may not have known the Babylonian „degree“- unit but used the natural unit of „solar wheel“ which means the apparent diameter of the Sun. A very modern idea.

NCP: North celestial pole
SCP: South celestial pole
Z: Zenith
φ: Observer´s latitude
δ: Sun´s declination

http://astronomy.nmsu.edu/geas/labs/manual/chapter02.pdf

Star-Oddi´s Measurements

A	B	C	D	E	F
Week number counted from winter solstice	Increment of meridian altitude meausured in „solar wheels“	Accumulated increase in wheels	Calculated ° increase 1100 AD	Accumulated increase in degrees	Oddi´s error D-E
0	0	0	0	0	0
1	0.5	0.5	0.18	0.27	-0.1
2	1	1.5	0.77	0.81	0.0
3	1.5	3	1.72	1.63	0.1
4	2	5	3.02	2.71	0.3
5	2.5	7.5	4.62	4.06	0.6
6	3	10.5	6.50	5.68	0.8
7	3.5	14	8.63	7.56	1.1
8	4	18	11.0	9.72	1.2
9	4.5	22.5	13.5	12.1	1.3
10	5	27.5	16.1	14.8	1.3
11	5.5	33	18.8	17.7	1.1
12	6	39	21.6	20.9	0.6
13	6.5	45.5	24.3	24.3	0.0
14	6.5	52	27.1	27.8	-0.7
15	6	58	29.8	30.9	-1.2
16	5.5	63.5	32.4	33.8	-1.4
17	5	68.5	34.9	36.4	-1.5
18	4.5	73	37.2	38.7	-1.5
19	4	77	39.4	40.7	-1.4
20	3.5	80.5	41.3	42.5	-1.2
21	3	83.5	43.0	44.0	-1.0
22	2.5	86	44.5	45.3	-0.9
23	2	88	45.6	46.3	-0.7
24	1.5	89.5	46.4	47.0	-0.6
25	1	90.5	46.9	47.5	-0.6
26	0.5	91	47.1	47.8	-0.7

Translation from a manuscript:

„Solar motion in sight increases by a half „solar wheel“ (diameter of the sun) in the first week after winter solstice. The second week one whole wheel, third week half another wheel, the fourth two wheels, the fifth two and a half, the sixth three, …. , thirteenth six and a half, forteenh six and a half again. Those two weeks the increase is the most because that is the middle between solstices. The fifteenh week the solar motion increases six whole wheels, …. , twenty sixth half a wheel. Then summer solstice has arrived.“

Mathematical interpretation:

The text describes two arithmetic progressions, one from winter solstice to spring equinox, another from the equinox to summer solstice:

(1) $\Delta h = 0 + n\cdot 0.5$
for n=1, 2, 3, 4, ……. , 13

(2) $\Delta h = 6{,}5 - (n-14)\cdot 0.5$
for n=14,15,16, ……. , 26

Analytically this corresponds to a second degree polynomial approximation for the summation of increments.

Definition of columns: **A, B, C observations**
D Correct values calculated from the Sun´s declination by Roslund, C. (1984)
E Wheels multiplied by variable solar diameter (http://astropixels.com/ephemeris/sun/sun2017.html)
F Difference between calculations and observations

Discussion and Conclusion

Estimation of the the Sun´s apparent diameter:

Oddi measured the total „increase in sight“ from winter to summer solstice as 91 „wheels“, but modern astronomers can calculate that this change in the sun´s altitude was 47.1° at that time as column D in the table shows. Therefore:

d = 47.1°/91 = 0.517° Taking the latitude 66° N into account and correcting for refraction at the lowest altitude the final result becomes: **d = 0.51°** with two significant decimals.

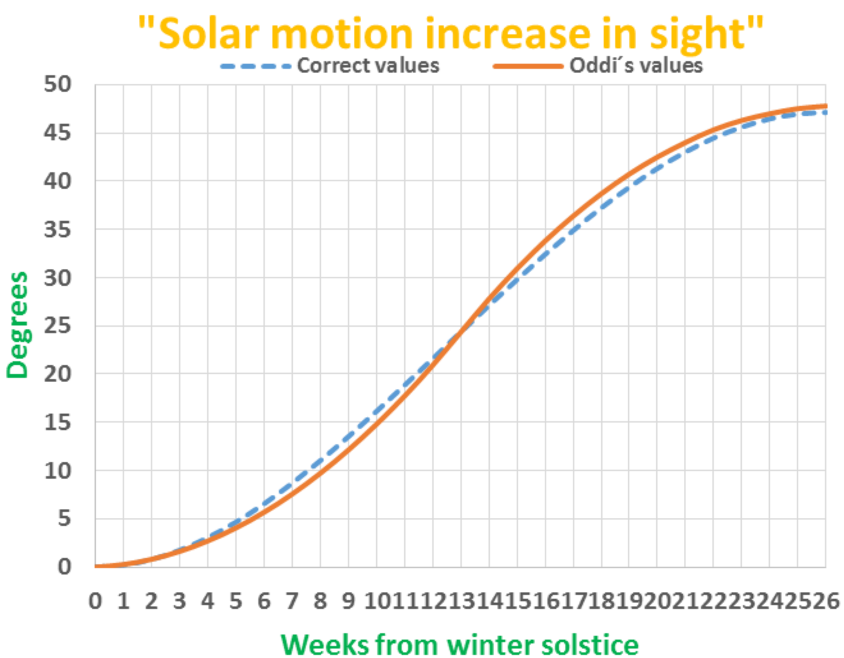
The actual mean value is 0.5325° but in the middles ages the value 360°/216=1.67°, according to the fifth century Roman scholar Macrobius Theodosius, was still accepted. In ancient Greece Archimedes wrote in the third century BC that Aristarchos of Samos was the first to determine that the Sun and Moon had an apparent diameter of half a degree. He described a clever experiment to measure d and improved the estimate by his usual method of inequalities: 90°/164 > d > 90°/200 ⇔ 0.55° > d > 0.45° (*Shapiro, A.E. (1975) Journal for the History of Astronomy; pp. 76-83*) but that knowledge faded away on the long journey of Greek culture through the dark ages to the Renaissance in Europe.

Thus, the Nordic Star-Oddi was closer to the Greek philosophers than his European contemporaries.

Errors and accuracy:

Today we can convert Oddi´s measurements in his wheel-units (Column C) to degree-units (Column E) by multiplying his values by the real solar diameter that varies between 0.542° and 0.525° during the half-year. Column F is the difference between this quantity and the theoretical value in Column D. In the majority of the cases this „error“ is less than 1.0° and never more than about 1.5°.

However, Oddi should have been able to measure the altitude (h) more accurately, as explained later in the presentation, but seems to have relied more on his mathematical intuition of the arithmetic regularity in the increments (Δh) than actual observations.



Camera Obscura

May have inspired palaeolithic cave paintings.

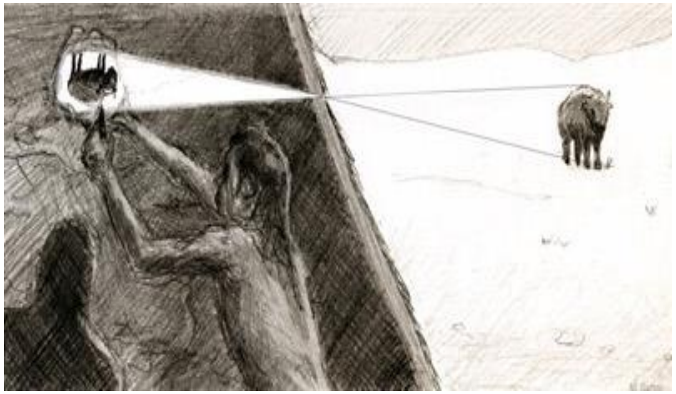
Chinese philosopher Mo Di (470-390 BC) describes
<u>inverted image</u> in a "collecting point".

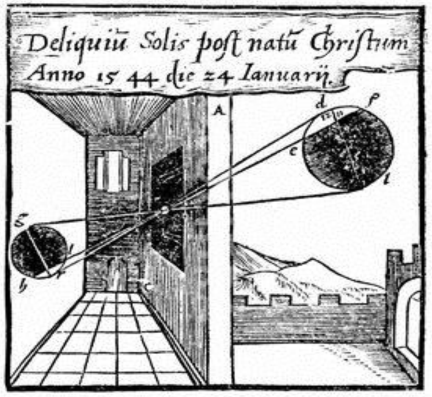
Aristotle (384-322 BC) asks in *Problems Book XV :*

"Why is it that when the sun passes through quadri-laterals, it does <u>not</u> produce a figure <u>rectangular</u> in shape but <u>circular</u>?"

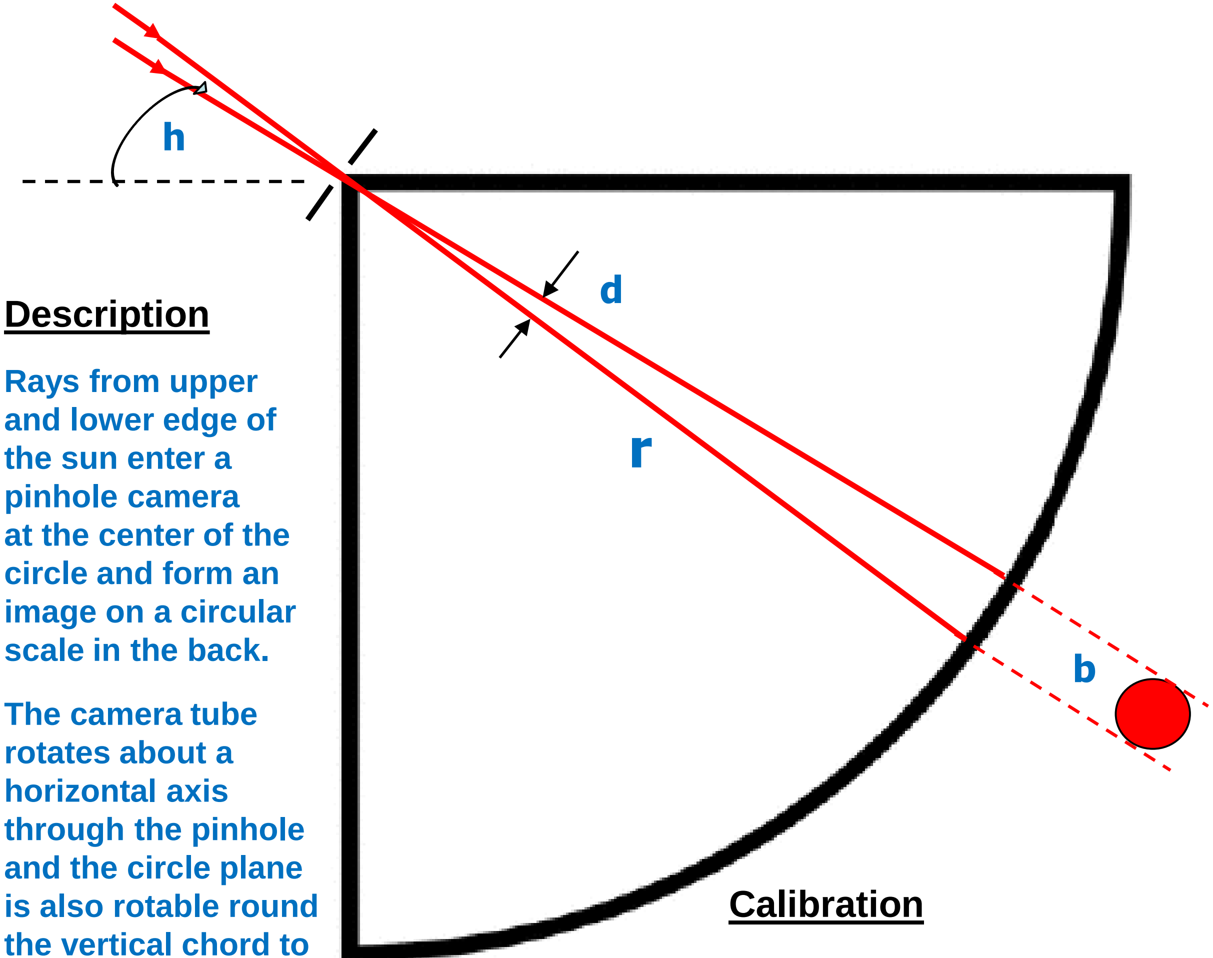
"Why is it that an <u>eclipse of the sun,</u> if one looks at it through a sieve or through leaves, the rays are <u>crescent</u>-shaped where they reach the earth?"

Used by Renaissance artists and scientists.





Hypothetical Instrument Design



Description

Rays from upper and lower edge of the sun enter a pinhole camera at the center of the circle and form an image on a circular scale in the back.

The camera tube rotates about a horizontal axis through the pinhole and the circle plane is also rotable round the vertical chord to detetermine culmination at high noon.

Symbols

d: Sun´s apparent angular diameter (exaggerated)
b: Linear diameter of Sun´s image (one „wheel“)
r: Radius of quarter-circle
h: Sun´s altitude

Relation

$$b = r \cdot d$$

Image

Calibration

If $r = 1140$ mm and $d = 0.5°$ then $b = 1140\text{mm} \cdot 0.5°/360° \cdot 2\pi \approx 10$ mm

With a stable alt-azimuth mount it should be possible to read the altitude with an accuracy of ±4 mm which means ± 0.2° in angular units. Systematic errors may increase the uncertainty of the resulting measurement.