Measuring the Sun's rotation

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An exercise you can do with your children or students using any telescope

It's vacation time! It's time to do things we don't normally have time for! So, I asked myself: "Can I roughly measure the sun's rotation speed with my Seestar S50?" Seestar S50 is an all-in-one smart telescope. It is highly automated and integrates a telescope, an electrical focuser, an astronomical camera, an ASIAIR, an altazimuth mount, a dew heater, and a filter wheel at a very low cost. It is the ideal tool for getting started in astrophotography. Measuring the Sun's rotation will help us better understand some fundamental principles of astronomical observation and unlock some of Seestar's capabilities.

Safety measures

Of course, this exercise can be done with any type of telescope, as long as you take the necessary safety measures for solar observations.

- ***Do not look directly at the sun***. The only safe way to do so is to use certified solar glasses or filters.
- ***Protect your camera and telescope.*** Never point your telescope or camera toward the sun without a solar filter covering the objective lens. Otherwise, the internal mirrors, lenses, and circuits can be seriously damaged. Since the Seestar S50 is a telescope that does not allow direct observation (only photography), I use an OD 3.8 solar filter. Specifically, I use a **Baader AstroSolar Photo Film filter**.

Since there aren't any major obstacles, let's go!

The first try

Imagine we have no idea how long the rotation takes (hours or days). The first thing we can try is to create a time-lapse video. We can make it span an hour. Then we can *"see what happens."* Using Seestar, it is an easy task, and we see some rotation, but things are at least *"strange"* (see Video 1)

Video 1. *1-hour time-lapse video of the Sun as seen from our location (click on the icon or here to see the video)*

This 1-hour video shows:

1. The Sun's axis of rotation is oriented toward us.
2. The rotated angle is 15°.

Since we are neither flat-earthers nor the center of

Figure 1: *Seestar S50 in alt-azimuthal mode.*

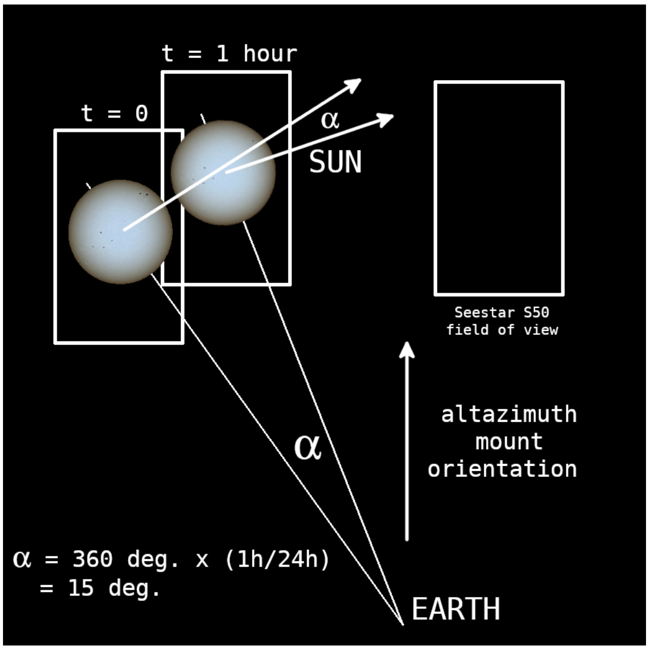

Figure 2: *Scheme of the observation of a star (in this case, the Sun) using an altazimuthal mount.*

the universe, this rotation must be apparent. The value of 15° is simply the angle by which the Earth rotates in one hour. Therefore, we are seeing the effect of the Earth's rotation, not the Sun's. **Why?**

The daily rotation of the Earth makes it appear as if the Sun moves from east to west across the sky, but this is not its actual movement. To explain this behavior, we need to understand what our telescope is capturing.

The Seestar S50 operates in alt-azimuthal mode by default. It tracks an object by rotating around two axes, thereby varying its altitude and azimuth (Figure 1).

This kind of mount is called the **altazimuth mount**, or alt-azimuth, or simply alt-az. In this case, the orientation of the field of view is always the same (for Seestar, a vertical rectangle). This is illustrated in Figure 2.

Note how the orientation of the Sun inside the telescope's field of view changes as it moves across the sky. When the Earth rotates an angle α, the image of the Sun rotates the same angle inside the field of view. Our video is one hour long and compressed into four seconds. Considering that the Earth makes a full rotation in 24 hours, the angle between the first and last frames of the video is 360°/24 = 15°. You can check this using the video and a capturing program.

Does this mean that it's impossible to measure the sun's rotation with an alt-az mount? No, but using an alt-az mount complicates the measurement process. The solution is to operate the telescope with a mount that mitigates the Earth's rotation effect.

The equatorial mount

The artifact that enables us to mitigate the Earth's rotation effect is the **equatorial mount**. This mount allows the telescope to be oriented toward celestial north (or south, if we are in the Southern Hemisphere). The axis pointing toward celestial north or south (the right ascension axis) remains parallel to the Earth's axis of rotation. The second axis, the declination axis, is perpendicular to the former.

Figures 3 and 4 show the Seestar adapted to the equatorial mount and the orientation of the Seestar in the Earth's reference system. Compensation for the Earth's rotation is obtained by rotating the right ascension axis with the same angular velocity ω but in the opposite direction. Maintaining a constant rotation requires an automatic system. Fortunately, Seestar is equipped with such a system. Then we only need to point the telescope to the celestial north by adjusting the elevation angle to be the same as our latitude λ) and balance the deviation. This is easy in the Northern Hemisphere because Polaris is close to the North Celestial Pole. When operating in azimuthal mode, Seestar automatically orients itself by finding this star. However, Polaris is not visible if we want to track the sun or if it is a cloudy night. How do we orient our equatorial mount in this case?

How do you orient an equatorial mount with daylight?

We need to align the telescope following the axes defined by two angles: the elevation (your latitude as seen in Figure 4) and the deviation (the deviation from true geographic north should be zero).

The elevation angle is not a problem because it must be the same as our latitude λ. In addition, Seestar's app helps us to do that (Figure **??**)

The deviation angle, or the west-east angle, can be obtained using different methods. *Do not use a compass* to measure the position of north (the deviation angle). We need geographical north, not magnetic

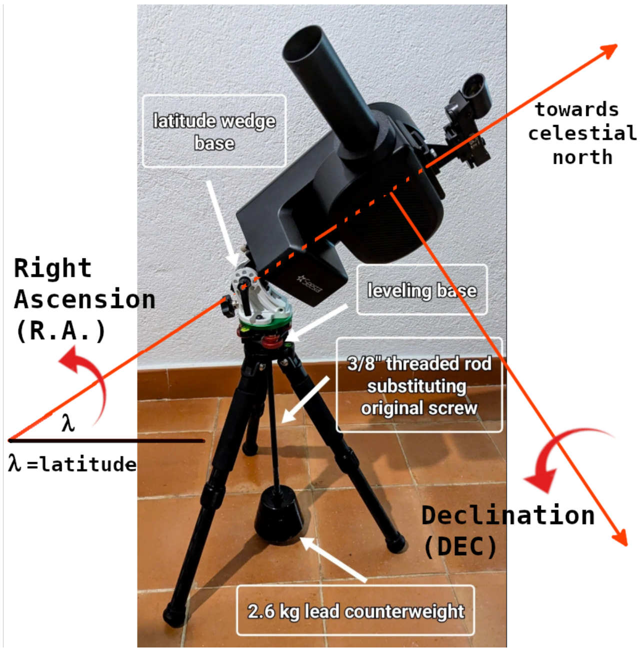

Figure 3: *Seestar adapted to be used with an equatorial mount*

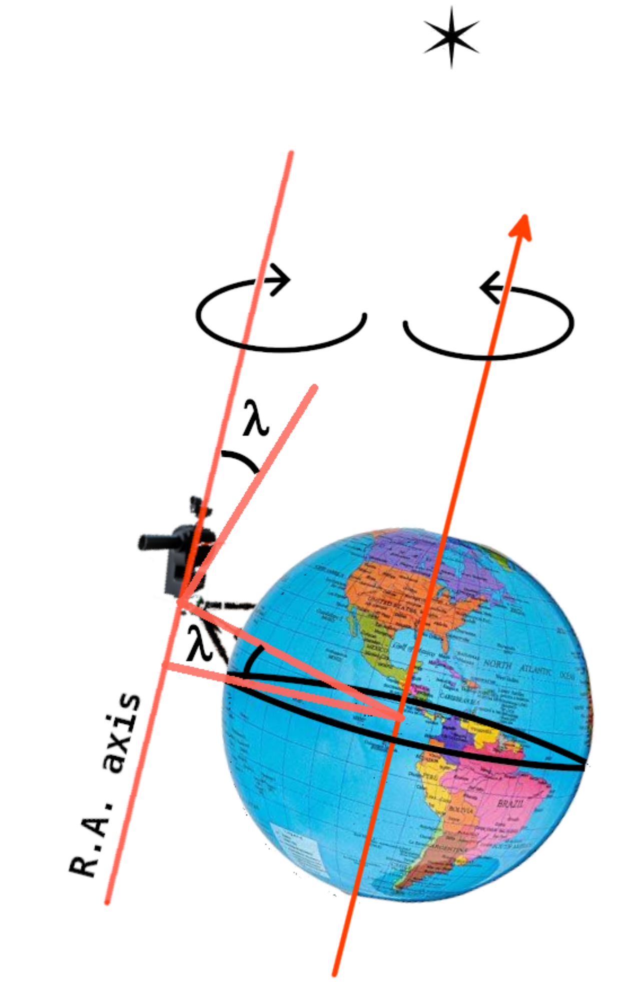

Figure 4: *Compensation of the Earth's rotation by orienting the RA axis parallel to the Earth's rotation axis*

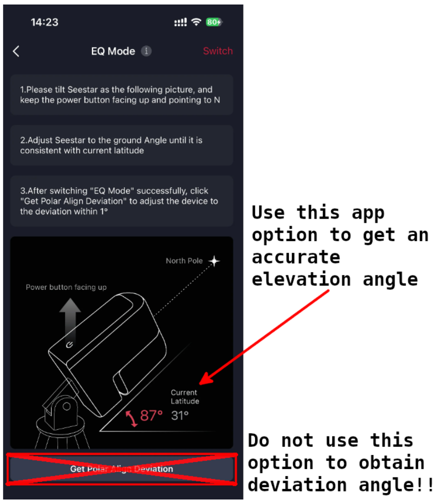

Figure 5: *How adjust the elevation angle in the Seestar's app*

Figure 6: *Mounting the smartphone-Seestar system to point to the North Star*

north. Additionally, any metallic structure close to the compass will interfere with the measurement.

Method 1.- One of the simplest methods to determine true north is to hang a weighted rope and wait for the sun to reach its highest point in the sky. At that time, the shadow of the rope will be oriented north-south. Mark this line on the ground to use as a guide for pointing the telescope in that direction as needed. You can find the Sun's transit time (or solar noon, around midday UTC) through programs like **Stellarium** or directly from the **U.S. Navy website.** This is a good method if you plan to observe the Sun from the same place, such as your home, but it is not practical if you move to the countryside to perform the observation.

Method 2.- The second method involves smartphone apps like **Stellarium** that provide the position of the stars in real time. This method (Figure 7) involves placing your smartphone perpendicular to the RA axis to search for Polaris (the North Star). Note that, like the previous method, this method can also be used in the southern hemisphere because such programs can be used to find the celestial north or south.

Figure 7 shows the new scheme for observing a star

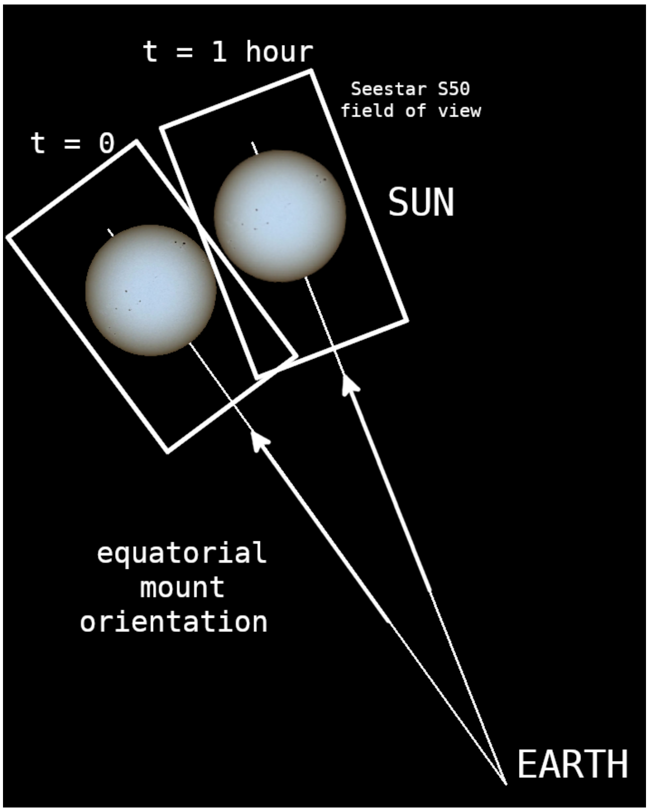

Figure 7: *Scheme of observation of the Sun using an equatorial mount*

using an altazimuthal mount. If we have correctly oriented ourselves to Polaris, the effect of the Earth's rotation should be mitigated.

Repeating the first try

After pointing the telescope at the North Star, we can create a new time-lapse video of the Sun over the course of one hour. Video 2 shows the comparison of both observations. Note that the equatorial mount has removed the effect of the Earth's rotation.

Video 2. *Comparison of 1-hour time-lapse observation using altazimuth mount or equatorial mount (click on the icon or here to see the video)*

However, it is not possible to observe the Sun's rotation when using the equatorial mount. Therefore,

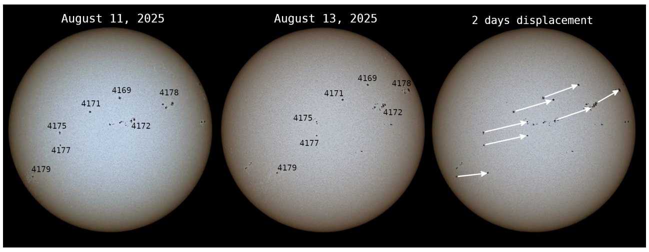

Figure 8: *Sunspot differences between 2 days*

we can conclude that one hour is insufficient time to clearly observe its rotation. Nevertheless, the differences in sunspot positions between the videos taken on August 9 and August 11 are evident. Thus, differences in photographs taken two days apart should suffice for calculating the Sun's rotation period.

Sun's rotation period computation

We take a new photograph 2 days later using the equatorial mount (Figure 8). The sunspots are numbered according to the **NOAA/SWPC 4-digit region number**, and the displacement is clear. Note that all sunspots have moved in the same direction. Therefore, we can assume that the movement is mainly due to the Sun's rotation, rather than the movement of the sunspots themselves.

We can now calculate the displacement. However, it will be very useful to project a spherical grid over the image to provide the displacement in degrees. The first thing to note is that the Sun's rotation axis is tilted around 15°. Additionally, the Sun tilts about 7.5° out of the ecliptic, which means that throughout the year, we do not see the same face: the Sun's North Pole tips most toward Earth in September, and six months later (in March), the Sun's South Pole tilts maximumly toward Earth (see **tychos.info**).

We can try to plot a spherical grid adapted to the displacement lines that are shown in the right plot of Figure 8. However, there is a program (sorry, only available for Windows systems) that can help us a lot: **TiltingSun**. Introducing our latitude, longitude, date, and time, it shows the orientation of the Sun. In our case, it provides a value of 15.46° for the angular tilt and a latitude of 6.55° for the center of the visible Sun. Figure 9 is the result of superimposing the 5° resolution grid provided by the program on the 2-day displacement plot.

Based on Figure 9, we can create a table 1 with the data corresponding to the seven measured data points

Throughout the year, the Earth orbits the Sun in the same direction as its rotation. Therefore, we must add the Earth's angular movement around the Sun to the measured displacements. The eccentricity of the Earth's orbit around the Sun is very small, so we will assume a circular orbit for our computations. In this case, the Earth's angular displacement in one day is approx-

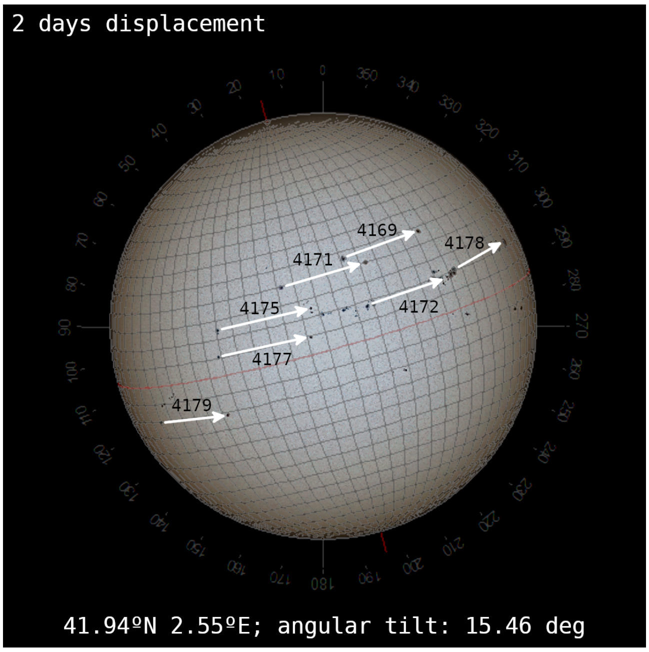

Figure 9: *Angular displacement of the sunspots in 2 days. Grid resolution: 5°*

Table 1: *Measured data for 2-day displacement*

region number	latitude (°)	displacement (°)
4169	~ 25	25 ± 5
4171	~ 20	25 ± 5
4172	~ 10	25 ± 5
4175	$\sim 10 - 15$	25 ± 5
4177	~ 5	25 ± 5
4178	~ 10	25 ± 5
4179	~ -10	25 ± 5

imately 1° (360° in 365.24 days). Thus, adding a daily degree to the measurements, we obtain a daily mean solar rotation of **d=(12.5+1.0)±2.5°**. The complete period covers a displacement of 360°, then the Sun's rotation period in days will be **T=360°/d.** Taking into account the error propagation (Δ**T**=Δ**(a/x)=a**Δ**x/x**^{2}) obtain for the period a value of

T = 26.6 ± 4.9 days

Is this an acceptable value?

First, we should mention that the Sun's rotation period depends on latitude because it is not a rigid solid. **To obtain a more accurate value, we should get more measurements and have more variety in the latitude of the sunspots**. The latitudinal distribution of the sunspots depends on the time inside the 11-year solar cycle. However, sunspots rarely appear beyond 40° latitude (Ian Ridpath & Wil Tiriton *Guide to stars and planets,* Ed. Collins and Sons, London 1984, also in **Spanish**).

The period as a function of the latitude varies from 24.47 days at the equator to 35 days close to the poles. Literature uses the definition of a Carrington rotation, a synodic rotation period of 27.26 days. This chosen period corresponds to a rotation at a latitude of 26 degrees (source: **Solar project 2010**)

Therefore, our estimate of solar rotation seems good enough as a first approach to the problem.

Animation of the complete process (click on the icon or here to see the video)