# PHOTOGRAPHING THE SUN

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## Abstract

Photography is a good way to record the Sun´s disk. A photograph can be taken in two minutes, and only a small gap in the clouds is needed for this. Its accuracy is not affected by the movement of the Sun or human interference, unlike drawing the Sun by projection. Later, the photographs can be examined and measured at ease.

Time-lapse photography or long exposure also reveals the movement of the Sun in the sky.

In this workshop, we will analyse some Sun photographs, finding the rotation period of the Sun with help of sunspots, and possibly (weather permitting) take some photographs of the Sun´s disk. The technical aspects of this kind of photography are discussed too.

For this you will need a single-lens reflex camera, long lens or telescope/spotting scope with an adaptor for your camera, a ND 5 solar filter and a sturdy tripod. Digital single-lens reflex (DSLR) cameras are very good for the purpose, and you can use a compact digital camera too. If you use a film camera, slide film is best for classroom use, because the slides can be projected on a coordinate grid to be seen and examined by the whole student group at the same time. With a digital image, you can use a beamer for the same purpose.

### The lens

The Sun's diameter (D) is about 1.4 million kilometres and its distance from the Earth (a) is about 150 million kilometres (Fig. 1.). By photographing it with a lens of focal length f we get an image of diameter d of the Sun on film. From similar triangles we get

$$(1) \qquad \frac{d}{f} = \frac{D}{a} \Rightarrow d = \frac{D}{a} * f = \frac{1{,}4 * 10^6\, km}{150 * 10^6\, km} * f \approx \frac{f}{110}$$

So, by dividing the focal length of the telescope or camera lens by 110 we get the approximate diameter of the Sun's image on the film.

If we want to see details such as sunspots in our pictures, we have to use a long focal length lens or a telescope, preferably 1000 mm or more (d >9mm). Focal lengths in excess of 2600 mm will give too large an image of the Sun for the 24 mm high frame of 35 mm film. Most DSLR cameras have a sensor smaller than a 35 mm film frame. Use the crop factor of your camera to find how the focal length of your lens compares with a lens used in a 35mm camera. The crop factor for an APS-size sensor is about 1.6 and for a micro four-thirds sensor it is 2. So, a 500 mm lens in an APS-sensor camera is equivalent with a 800 mm lens in a 35mm camera. The same lens in a micro four-thirds camera works like a 1000 mm lens in a 35mm camera.

In this workshop, we will concentrate on photographing sunspots and finding their coordinates in the photographs in order to calculate the rotation period of the Sun and finding the movement of sunspots in latitude. For this we need lenses (or telescopes) with focal lengths under 2600 mm (35 mm equivalent). In order to get the whole solar disk in one frame, 2000 mm (35 mm equivalent) is ideal, giving a Sun image diameter of 18 mm.

With a telescope, it is possible to achieve more magnification using an eyepiece and projecting the image in its desired scale on the film, but with most telescopes having a focal length of over 900 mm, this is not usually necessary. Instead, the telescope objective is used as a long focus lens and the camera body (without the lens) is attached to the eyepiece end. There are adaptors for different camera mounts. You can buy them in camera or astronomy shops, but remember to check your telescope and camera mount before shopping.

For a compact digital camera you need an adapter to attach the camera over telescope's eyepiece. Astrophotographers call this afocal method; birdwatchers call it digiscoping (Fig. 4.). You can use a spotting scope as well as an astronomical telescope. One problem with the afocal method is that the field of view is too narrow for the whole Sun. Use the eyepiece of longest focal length (smallest magnification) you have, and don't zoom out the camera lens more than necessary, i.e. use a the greatest $f_e$ and smallest $f_c$ (Fig. 4.). Use the camera monitor to find a suitable combination of focal lengths.

The long focus camera lenses are fine too. Their focal length (as well as a telescope´s) can be doubled with a teleconverter (astronomers call it a Barlow lens). A barlow lens is often included in the equipment of a telescope.

Some digital so-called bridge cameras have a built-in superzoom lens with a longest focal length of 600 mm (35 mm equivalent) or more, long enough for Sun photography.

**Filtration**

The Sun is dangerously bright. DO NOT LOOK AT THE SUN WITHOUT PROPER FILTRATION - YOU CAN DAMAGE YOUR EYESIGHT. This caution is even more important when using any optical aid (binoculars, telescope, or camera). With their larger lenses they collect much more harmful radiation than the eye alone, and immediate blindness may result if the eye is exposed to this radiation. Even if you do not look trough the camera´s viewfinder, the heat of the Sun can burn your camera!

The best place for a Sun filter is over the objective lens. In any other place inside the lens or telescope a filter is liable to overheat and crack. When the excess of Sun's radiation is filtered out before it enters the lens, you and your equipment are safe. But do not use home-made filters as you can not be sure they filter out infra-red or ultraviolet radiation not seen by the eye. These are even more damaging than the visible light.

There are many kinds of Sun filters on the market, many of them very expensive, but the most practical and affordable solution for our purposes is a specially coated Mylar filter, a thin foil aluminised on both surfaces, with transparency about 1/100 000 (logarithmic density 5), for example Baader AstroSolar™ filter. The foil is fastened on a cardboard ring and taped securely on the lens, possibly equipped with a cardboard mask with a round opening smaller than the diameter of the objective lens to diminish the amount of radiation entering the lens. When working with students, take care to ensure that nobody tries to play a practical joke by removing the filter or piercing it.

Do not leave your camera pointed at the Sun for a prolonged time. When not taking photographs, cover the objective lens to avoid accumulation of heat inside the lens or camera.

**Exposing the Sun pictures**

The best material for Sun photography is a low-speed, very contrasted film like the old Agfaortho (nowadays a similar film is made under the name Macophot ORT 25). This is a special orthochromatic (insensitive to red) black and white negative film, and it is best self-developed. Of course, slide films will do too, the slowest (smallest ISO number with finest grain and often high contrast) being best.

A digital camera is a modern way to record the image of the Sun. With a digital image, you can use an image processing program to combine the image with a coordinate grid (see below). Of course, you can scan your slides to get a digital image.

The exposure depends on many non-predictable factors like the atmospheric haze combined with the height of the Sun, and you must bracket (make longer and shorter exposures around the estimated value) to get the best possible picture. As a starting point you can use the exposure time given by the formula

$$t = \frac{N^2 D}{ISO * K} \qquad (2)$$

K = constant of solar light intensity, approximately $70*10^6$
ISO = film sensitivity in ISO
D = reduction number, for example for a Mylar filter D = $10^5$
N = aperture number = focal length divided by lens diameter (the f-stop in a lens)

Example: N = 20 (a 100 mm diameter lens of 1000 mm focal length equipped with a 2x converter, resulting in a 2000 mm focal length; 2000 mm: 100 mm = 20), D = $10^5$, ISO = 100 and K = $70*10^6$. The exposure time is

$$t = \frac{20^2 * 10^5}{100 * 70 * 10^6} s = \frac{1}{175} s$$

This time is not found in an ordinary camera, so you can try 1/125 s and 1/250s to begin with.

The calculated exposure time can be used for the first exposure and then additional exposures are made using 2, 4, 1/2 and 1/4 times the first exposure time. In any case, before using a new film-lens (or telescope) combination for important photographs, it is wise to make and develop trial exposures, bracketing widely, and then use the best exposure as a starting point for bracketing the next time.  If you use a digital camera, you see the result immediately on the camera monitor.

The camera´s own exposure meter or auto exposure can be used too, but usually a correction is needed. The necessary correction depends on the type of the meter’s metering pattern (spot metering works best here), so again, you must make a trial series of exposures.

Due to movement of the Earth the Sun seems to move 15 arc seconds per one second or 1 arc second in 1/15 s, so there is a upper limit for exposure time that depends on the accuracy required. 1/30 s  or shorter exposure will give photographs sharp enough for our purposes without tracking, if the steadiness of the air is good.

**Sunspot photography in practice**

The air is often steadiest in the morning, about 2 hours after the sunrise, when the Sun has not yet heated the air very much. Short exposure times (around 1/1000 s), if possible, will help too. Focusing with long focal lengths is difficult: the viewfinder image looks dim and coarse, and the split-image and microprism focusing aids or auto focusing mostly do not work. There are special screens for this kind of photography, but they are expensive, and changing the screen is possible only with professional-level SLR-cameras, so you mostly have to make do with the standard ground class image. Remember to check the focusing every time before making an exposure. A DSLR camera with live-view makes focusing easy and accurate.

The tripod must be as sturdy as possible. Try to tap your camera lightly, looking into the viewfinder. If the image dances wildly, the tripod is not sturdy enough. If you use some extra support, like a monopod, and support the camera-lens combination at two points, the wobbling will be greatly reduced - but take care not to bend your camera's lens mount!

Use a cord release or self-timer to avoid vibration when firing the shutter. If your camera has the facility to lift the mirror up before exposure, use it. In some cameras the mirror goes up in advance, when the self-timer is activated.

You have to know the celestial north in your Sun pictures. The Earth revolves 15 arc minutes in one minute, so in two minutes the movement is about the diameter of the Sun (about 30´). By making two exposures on the same frame at an interval of about two minutes without moving the camera, you will get two images overlapping a bit. The direction of Sun´s apparent movement is from east to west, and north-south-direction is perpendicular to the line combining the centres of the two images - or better still, the line combines two images of the same sunspot (fig. 2.).

If your camera has no double exposure facility, take two images at an interval of two minutes without moving the camera and combine them afterwards in an image processing program. For this, you must first scan the images exposed on film. Don't crop them before combining!

The Sun rotates about $13^o$ in a day, so 1 - 3 day intervals between pictures will give good material to enable you to calculate the Sun's rotation period.

## Sunspot coordinates and Sun´s rotation

The rotation axis of the Sun is not perpendicular to the orbital or equatorial plane of the Earth. If you want to determine the real coordinates of sunspots, you have to place the axis of the coordinate grid or sphere correctly in relation to the celestial north in your pictures. The angle between celestial north and Sun´s axis is called position angle and varies between $+-26{,}4^o$ during the year, + meaning the solar axis inclined to the east from celestial north and - to the west (tables 2 and 3).

The north pole of the Sun is tilted from $7.25^o$ to $-7.25^o$ towards or away from the Earth, respectively, and for our purposes three different grids ($0^o$, $4^o$ and $7^o$) are sufficient (Fig. 3.). For non-critical work, a $0^o$ grid will be accurate enough. You can enlarge the grids with a copier, but remember that some copiers can distort the drawings. For use with digital images, scan the grid. There are professional grids for more accurate work, but they are expensive.

The tilt and position angle of the axis are found in astronomical almanacs or a good planetarium program.

The pictures are framed and projected with a slide projector on a white styrofoam sphere of the same size as the image of the Sun. Thus the sunspots fall on their real places, transforming the two-dimensional projection seen into a three-dimensional "real" picture. If the styrofoam sphere has a coordinate grid drawn on it, the sunspot coordinates can be read directly, provided the sphere has its tilt and inclination set correctly.

If you project the slides with a photographic enlarger on a plane, the grids in Fig. 3. are large enough. Working with an enlarger is more convenient than with a slide projector, because the image is horizontal, but of course this works only with small groups.

| Day | Position angle/deg | | Day | Position angle/deg |
|---|---|---|---|---|
| 1.1. | -4 | | 1.7. | +4 |
| 15.1. | -10 | | 15.7. | +10 |
| 1.2. | -17 | | 1.8. | +16 |
| 15.2. | -21 | | 15.8. | +20 |
| 1.3. | -23 | | 1.9. | +23 |
| 15.3. | -25 | | 15.9. | +25 |
| 1.4. | -24 | | 1.10. | +25 |
| 15.4. | -23 | | 15.10. | +23 |
| 1.5. | -19 | | 1.11. | +20 |
| 15.5. | -15 | | 15.11. | +15 |
| 1.6. | -8 | | 1.12. | +9 |
| 15.6. | -2 | | 15.12. | +3 |

| Day | Position angle/deg | | Day | Position angle/deg |
|---|---|---|---|---|
| 8.7. | +7 | | 11.7. | +8 |
| 9.7. | +7 | | 12.7. | +8 |
| 10.7. | +7 | | 13.7. | +9 |

Tables 2 and 3. Position angles of the Sun's axis.

The tilt of the Sun's north pole toward (+) or away (-) from the Earth is zero on June 6 and December 7, and reaches a maximum value around March 6 ($-7.25^o$) and September 8 ($+7.25^o$)

The position angle can be found by the apparent movement of sunspots, but finding the tilt with this method is not practicable as its effect on the apparent sunspot movement is too small for our method. Galileo, a diligent observer, however, found this effect with his primitive telescope. The real sunspot movement on the solar disk causes errors too.  You can begin the work on the photographs without the coordinate grid and the students will soon find that sunspots seem to move obliquely on the Sun´s disk, if the photographs are not all taken at the time, when the position angle is near $0^o$ .

To find the rotation period of the Sun we need a series of photographs taken at intervals of one to three days. The positions of sunspots are determined by projecting the Sun pictures in the right scale on a grid drawing. The grid must be in right position angle, determined using the tables and the celestial north in the photographs, as described earlier. The most distinctive sunspots from successive photographs are marked on the drawing. Their coordinates are read with the help of the coordinate grid, interpolating when necessary.

The rotation period of the Sun is found by

$$T_{rot} = \frac{360^0}{\frac{\Delta\alpha}{\Delta t}} \qquad (3)$$

where $\Delta\alpha$ is the longitude difference of a sunspot in two photographs taken at time interval $\Delta t$ .

By making the measurement for sunspots at different latitudes you may find that the rotation time depends on the latitude, the period being shorter at lower latitudes. This is not an easy effect to find because sunspots are concentrated in middle latitudes, and there will not be very much material at other latitudes.

The calculated rotation time is the synodic rotation period (as seen from Earth). The sidereal rotation period (in relation to the stars) can be calculated by taking the orbital movement of the Earth into account.

If you want to find the movement of sunspots in latitude, you have to take photographs over a longer period, preferably over a month, and locate some big sunspots you can recognise, when they come back into view again with the Sun's rotation.

You can use the sunspot photographs for determining sunspot numbers and collecting statistical material of course, but finding the rotation period of the Sun is the simplest and possibly the pedagogically most awarding use of Sun photography.

## Conclusion

In time you will accumulate a good collection of Sun photographs to be used in the lessons, but the best way is to take the photographs with students and then analyse those photographs together. But do not let the students photograph the Sun without supervision: the dangers are too great!

## Bibliography

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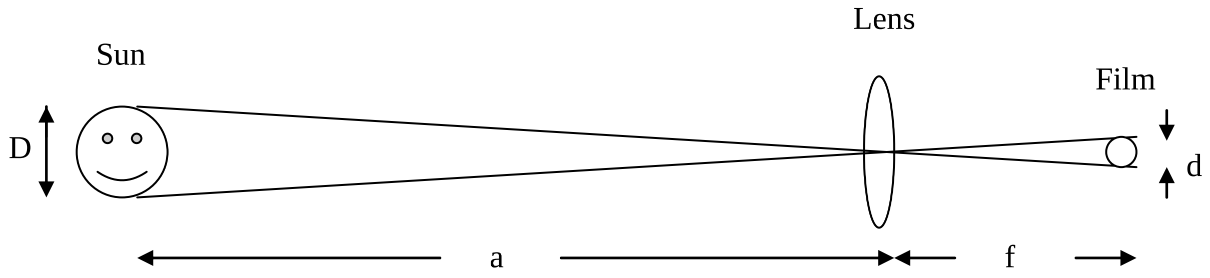


Fig.1. **D** is the diameter and **a** the distance of the Sun, **f** is the focal length of the lens or telescope and **d** the diameter of the Sun´s image on film.

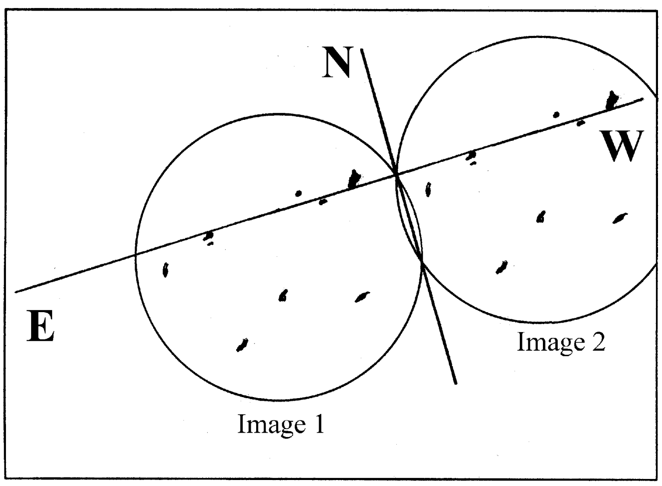


Fig. 2. Finding the celestial North in Sun pictures.

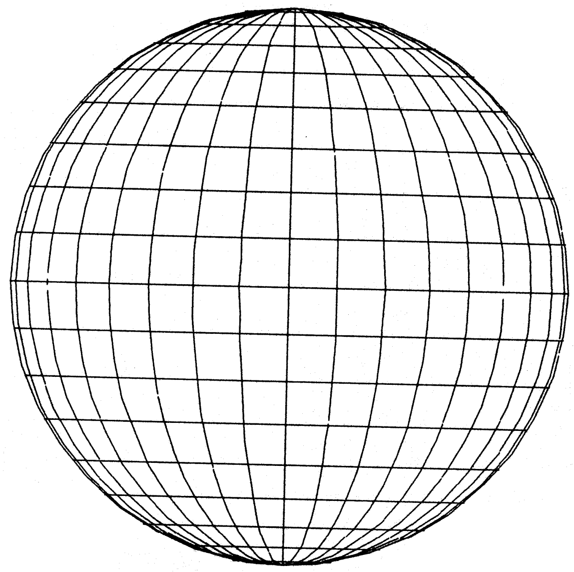

Fig. 3a. $10^o$ grid for $0^o$ tilt.

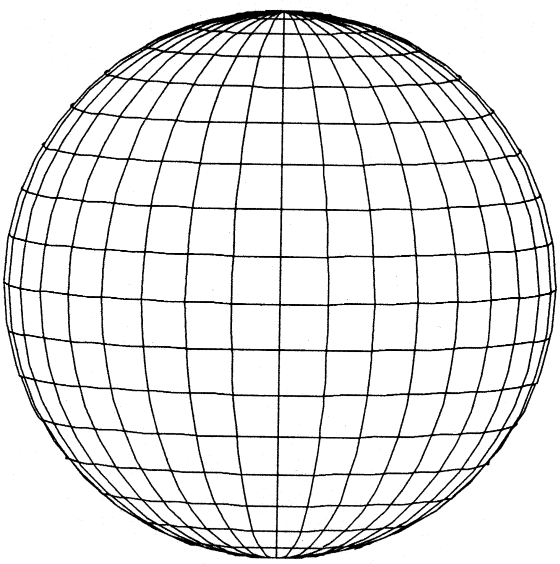

Fig. 3b $10^o$ grid for $4^o$ tilt.

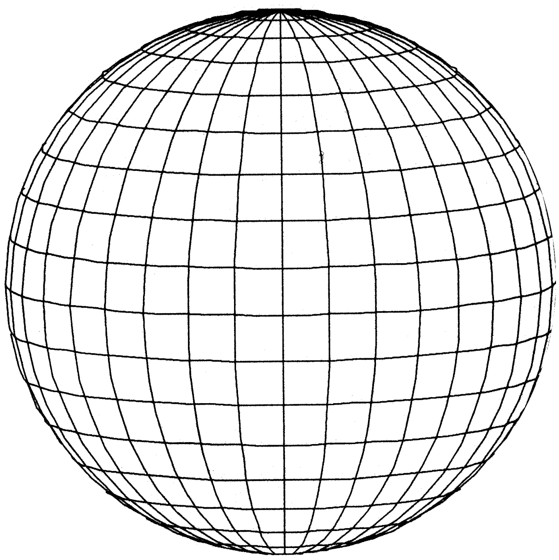

Fig. 3c $10^o$ grid for $7^o$ tilt.

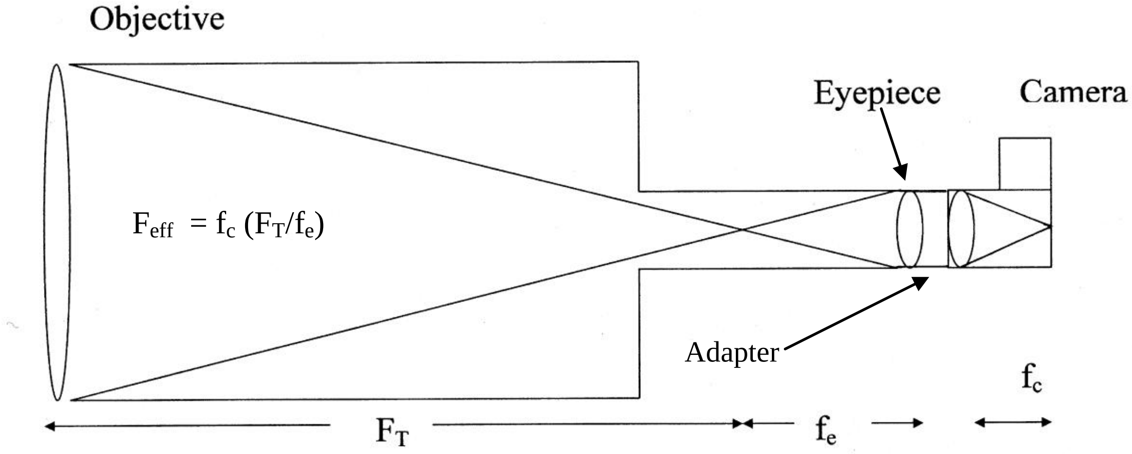


Fig. 4. The afocal method. $F_T$ = focal length of telescope, $f_e$ = f. l. of eyepiece, $f_c$ = f. l. of camera lens, $F_{eff}$ = effective f. l. $F_{eff} = f_c (F_T/f_e)$