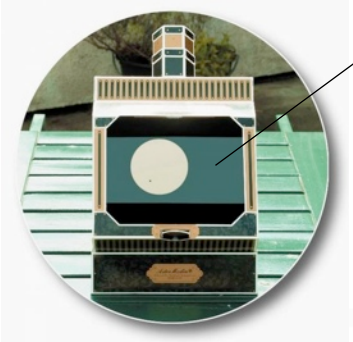
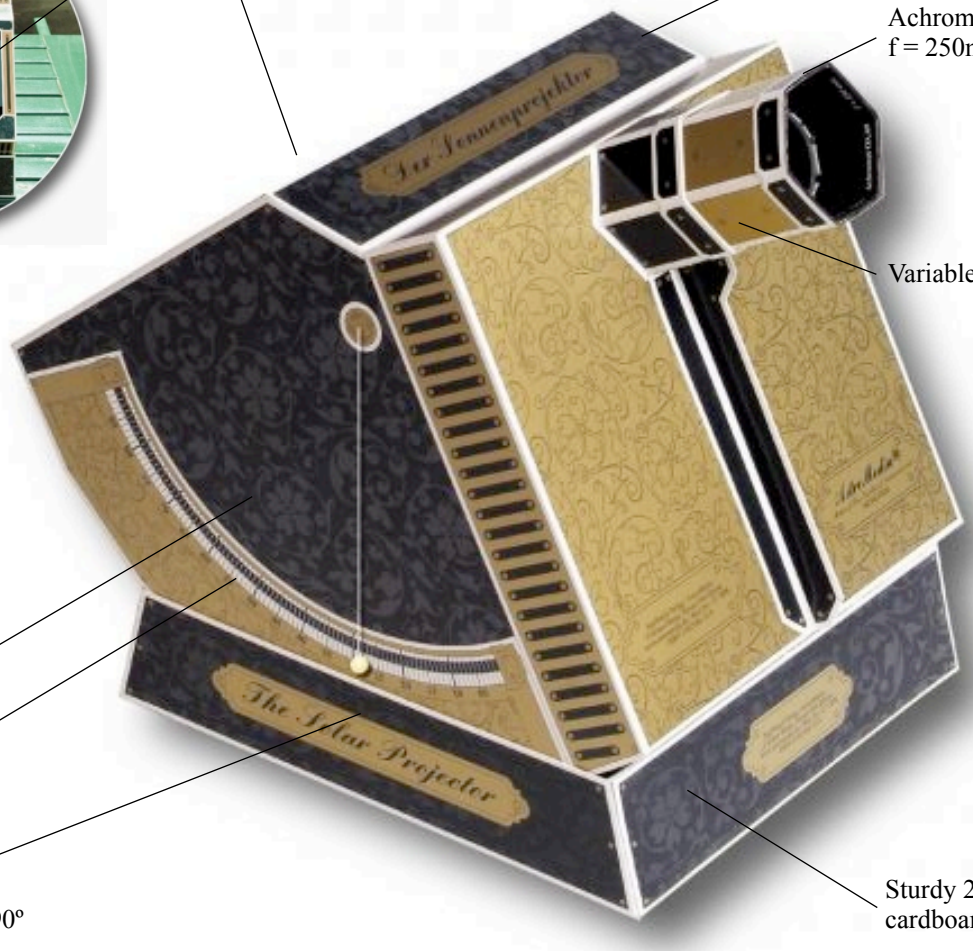
KLAUS HÜNIG

The Solar Projector

Cardboard kit for a projector that allows for safe observation of the Sun.
Size of the projected image: 55mm or 75mm





Comfortable observation from above

Plane mirror

Achromatic lens: f = 250mm

Variable blinds

Two convex mirrors: f = -10.2mm f = -14.0mm

Quadrant

Dobson mount adjustable from 0º to 90º

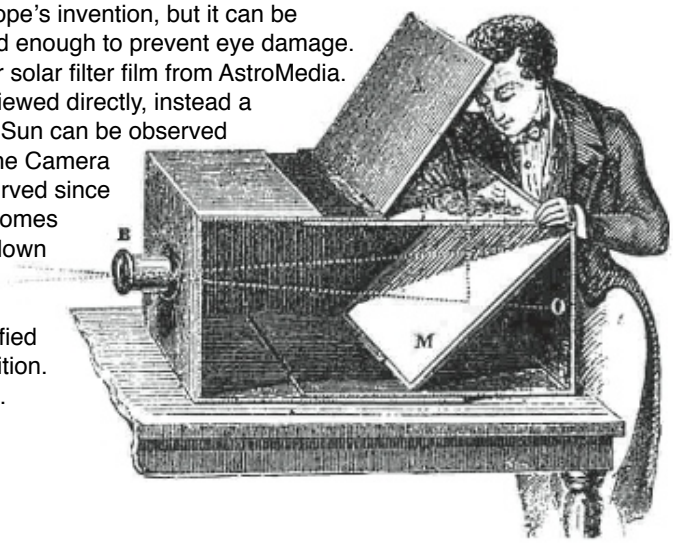
Sturdy 275g cardboard

AstroMedia

Revised Version: Andreas Schröer

The Solar Projector

The Sun has been observed with a telescope almost since the telescope's invention, but it can be dangerous. Only by using a strong filter can the Sun's light be dimmed enough to prevent eye damage. Today there are many suitable solar filters, for example the AstroSolar solar filter film from AstroMedia. The Solar Projector gets round this problem because the Sun is not viewed directly, instead a projected image is formed by the optical system. This means that the Sun can be observed safely without a solar filter. The Solar Projector uses the principle of the Camera Obscura (pin hole camera), with which solar eclipses have been observed since the 11th century and which is still used today in every camera: Light comes through a small opening into a dark chamber and creates an upside-down image of the outside world on the opposite wall. Instead of a simple opening, the Solar Projector has a lens and a convex mirror, which together work like a Galilean telescope and produce a strongly magnified image. A plane mirror reflects the image to a comfortable viewing position. Nevertheless, the main principle remains that of the Camera Obscura.



Klaus Hünig

Contents:

- 8 pre-punched sheets of cardboard
- 1 achromatic glass lens OPTI Media 569.OAL, 30 mm diameter, *f* = 250 mm
- 2 convex mirrors 16.5 mm diameter, *f* = -10.2 and -14.0 respectively
- 1 acrylic glass plane mirror 54 x 90 mm

You will also need for assembly:

- Standard solvent based all purpose glue, e.g. UHU, Evo-Stik Impact, B&Q All Purpose Glue. **Do not use water-based glue**: it softens and warps the cardboard, and doesn't stick properly to the printed surfaces. Solvent based glues also dry much faster.
- Double sided sticky tape for the plane mirror. **Some solvent based glues can damage its reflective coating.**
- An elastic band for mounting the glass lens.
- Two pieces of thin thread and two glass or metal beads for the quadrants.
- A sharp knife with a fine point (thin carpet knife, craft knife, scalpel), to cut the thin holding tabs of the pre-punched parts.
- A cutting board or mat, made from hardboard, plastic, or wood. Self healing cutting mats are ideal as the material re-closes after each cut.
- For perfectionists: a black felt tip pen to blacken the white edges of the inner apertures, lens holder, etc. before construction.

Tips for successful construction - Please read before commencing!

- In order to ensure good results and for straightforward construction, the building instructions have been broken down into Chapters A to D, which are broken down further into smaller steps. Do not be worried by the long text - it is simpler and faster than it appears and helps to avoid mistakes. Read each step from the beginning to the end before commencing and allow yourself a few hours for the construction (depending on experience). The more care you take, the better your Solar Projector will work and look.
- Every part has its name and part number printed on the front. The part number consists of a letter and a number: the letter denotes the chapter it belongs to, the numbers denote the order of construction (apart from parts [A6] and [A7], which are used in Chapter C). The part number can be recognised by its rectangular frame, e.g. B1. Only remove the parts as you need them.
- Places needing glue are marked in grey. Please keep in mind that the glueing areas are slightly smaller than the parts that will be glued to them. This ensures that grey areas will be completely covered.
- We recommend that you do not tear the parts out of the cardboard sheet, but cut through the thin connecting tabs to make sure that the edges stay smooth. Frayed edges can be cleaned with a nail file or with our AstroMedia File Set.
- All folding lines are prepared by groves or perforations. If they are to be bent "forwards", you have to fold them towards you when looking at the printed side of the part. If they are to be bent "backwards", you need to fold them away from you. You get a straighter fold if you position the folding line over a sharp edge.
- The mirrors: The surfaces of both convex mirrors made of acrylic glass are coated with aluminium and a protective layer of quartz. Nevertheless they are very delicate. Do not touch them with your fingers and only clean them, when necessary, with a cotton bud and some alcohol. The surface of the rectangular acrylic glass plane mirror is covered with a protective film. Only remove this after mounting the mirror.

Chapter A

The Housing

The projector housing is a box, which is open at the top and holds the objective lens at the front. Its back wall and base form a stepwise rounded surface. This shape allows the Solar Projector to be set to any solar altitude in its base.

Step 1: Remove the right side wall [A1] from the cardboard sheet and fold the flap on its top surface backwards. Do the same with the left side wall [A2].

Step 2: Remove the cardboard hexagon from the front wall [A3]. The front wall is divided by several long perpendicular scores into differently sized segments. Fold the top segment, on the back of which is a white field for the plane mirror, forwards and all other grooves, including those for the side flaps, backwards.

Step 3: Fold both trapezium shaped flaps of the plane-mirror holder [A4] backwards and glue the piece onto the grey glue mark of the top segment of the front wall [A3]. The two trapezium shaped flaps will then jut out beyond the front wall. Press the pieces against your worktop until the glue has set, using a book or similar weight, to make sure they don't warp.

Step 4: Remove the small cardboard piece at the top of the back wall [A5]. Fold all grooves, including those for the side flaps, backwards. This creates the segments which form the curved back and base. Glue the long tag of the bottom behind the bottom segment of the front wall [A3], which actually belongs to the curved base, so that the printed decoration continues without a break from one part to the next.

Step 5: Glue the long edge of the left side wall [A2] onto the equally long glue tag, which (seen from the front) is on the right hand side of the front wall [A3]. It should be immediately clear how the segments of the curved back wall will fit to the angular rounding of the side wall.

Step 6: Apply glue to the 7 glue tags on the back wall segments, lay the half-finished housing onto the left side wall and press the glue flaps firmly into position. For this press down from the inside of the housing and check at the same time from the outside that the edges of the back wall segments are exactly aligned with the angular edges of the side wall.

Step 7: As in Step 5, glue the right side wall [A1] onto the long glue tag of the front wall and then, as in Step 6, glue the flaps of the back wall segments onto the round edge of the side wall.

This completes the basic construction of the housing.

Chapter B

The Optical System

The optical system consists of the objective lens, a convex mirror and a plane mirror. The objective lens focuses the incident sun light. The convex mirror is located just before the focal point and reflects the rays, which fan out and are magnified. Finally the light hits a tilted plane mirror that deflects it to the bottom on the inside of the housing.

The Objective Lens

The Solar Projector's objective lens, OptiMedia 569.OAL, is an achromatic lens: it is colour corrected. It consists of two lenses made of glasses with different refractive indices, optically cemented together. A simple lens would create a colour fringe at the edges of the image. The achromatic lens 569.OAL has a focal length f of 250 mm, so its focal point is 250 mm from the centre of the lens.

Step 8. Fold the 6 long grooves of the objective guide [B1] backwards so that you get a hexagonal tube and glue the thin flap on one side of the tube onto the back of the opposite side. Finally fold the 5 short tags on one end of the tube forwards. Do not fold the long tag.

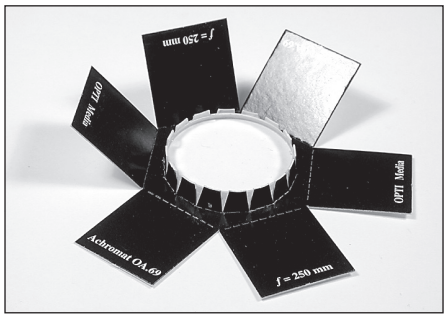
Step 9: First without glue, test that the objective guide fits from the inside through the hexagonal hole in the front wall of the housing, with the long flap pointing upwards. When the cardboard section between the housing front wall and the plane mirror holder is pushed downwards, it will touch the long, unfolded flap of the objective guide. First glue only the short flaps of the objective guide to the inside of the front wall of the housing and make sure that the guide remains at right angles to the housing.

Step 10: Put glue on both side flaps of the housing section mentioned in Step 9, as well as on the long, not folded flap of the objective guide. Stick this section onto the side wall of the housing and onto the long flap of the objective guide. Take care that its edges are flush against the edges of the side walls of the housing. The last section of the front wall, the holder for the plane mirror, should not be stuck on yet.

Step 11: Fold and glue the objective tube [B2] to form a hexagonal tube.

Step 12: Remove the disc from the middle of the objective lens holder [B3], fold the 16 small teethed tags carefully forwards without tearing them, and lay the piece on your work surface, so that the small tags create a round crown-like fence. The objective lens should be glued with its flat side facing downwards into this crown of small tags. This is best done as follows: Clean dust and finger prints from the objective lens, then carefully apply glue onto the inside of the teeth tags (perfectionists can first paint the top cut edges of the small teeth with a black felt tip pen). Place the lens in and wrap an elastic band around the teeth tags while the glue sets. Check that both the objective-lens holder and the lens itself are lying flat on the work surface. This will make sure that the lens is not offset or sits at an angle in its holder. It's not a problem if some glue gets on the edge of the lens because a 3.5 mm wide rim of the lens will be covered by an aperture. Glue that gets on the main part of the lens must be removed with solvent.

Step 13: Fold the 6 right-angled flaps of the objective lens holder forwards and push forwards the part with the lens in the opening of the objective tube [B2], which has the grey marks for gluing on the inside. The flaps must be absolutely flush against the edge of the objective tube. You are making a 24 mm deep black chamber, at the bottom of which the lens will sit. Glue the flaps firmly in this position.



Step 14: Fold the parts of the objective glide sleeve [B4] and the objective tube sleeve [B5] backwards and stick them on the marked areas around the opening of the objective guide and the objective tube.

Step 15: Fold the short and long score of both supports for the objective guide [B6] and [B7] forwards. The folds divide the two parts in a small and a large glue flap and an even larger main part. Glue the main part of both supports together. Finally glue the spread apart glue flaps onto the marked area on the front of the housing and both the small glue flaps directly under the objective guide. This makes sure that the objective remains perpendicular to the front wall and that it can't bend.

Step 16: Remove the card disc from the hexagonal 23 mm objective aperture [B8] and reinforce the fold lines marked with perforations with some sticky tape on the white back side. This will stop the flaps from ripping when the objective aperture is continuously removed and replaced with another aperture. Then fold all flaps forwards and push the aperture from the inner side into the objective tube, the side with the hexagon first. The aperture is not glued in and can always be removed later, using tweezers or a similar tool. Remove the card discs from the hexagonal apertures [B9], [B10], [B11] and [B12] and put them aside.

Step 17: Try pushing the objective into the objective guide. It should be easy to move, but shouldn't slip by itself. To get the right friction, you can stick one or more layers of 23 x 36 mm paper onto the inside surface of the objective guide. Perfectionists will prefer black paper.

The Objective Lens

In order to project the image onto the bottom of the Solar Projector it has to be reflected downwards by a tilted plane mirror. This ensures that the projected picture, while laterally inverted, remains vertically correct. After completion you can check this by observing a sunset.

Step 18: Glue the plane mirror with its grey side onto the inner side of the plane mirror holder. Glue it in place so that it lies concentrically under the mirror holder and its ends are flush with the upper edge of the latter. Because it is slightly wider than the mirror holder, it will stick out by about a third in the inside of the projector. Wait till the glue has set completely before carrying on.

Warning: *Some glues can damage the reflective coating of the mirror. It's a good idea to test the glue on a corner of the mirror first, or use double-sided sticky tape.*

Step 19: Glue both side flaps of the plane mirror holder firmly into the housing and make sure that the edges of the plane mirror holder are exactly parallel to the edge of the housing. This is very important, because it ensures that the plane mirror has exactly the correct angle to reflect the picture downwards. Both the trapezium-shaped flaps on the left and right will be glued down later. Do not remove the protective film yet.

Chapter C

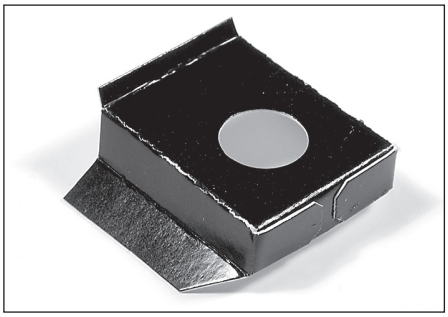
The Convex Mirrors

The two convex mirrors (the two mirrors with the domed reflective surfaces) have negative focal lengths of -10.2mm and -14mm. This means they don't collect the light as a concave mirror with a positive focal length would, but they fan it out. The shorter the negative focal length, the bigger the solar image is. The mirrors sit on the two sides of a removable cassette which can be swapped around.

Step 20. Remove the discs from the front [C1] and rear [C2] parts of the mirror cassette and fold the three surrounding narrow flaps forwards. Glue the parts onto the front and back of the middle part [C3] of the cassette so that the three rounded edges are flush with each other.

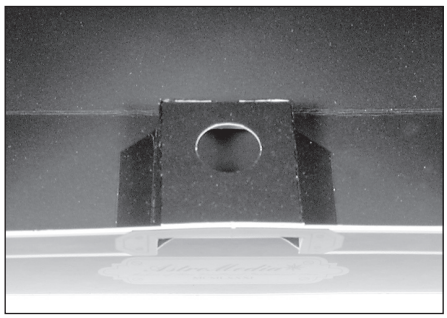
Step 21. Fold the edge strip [C4] of the cassette and glue it around the outside of the folded-up flaps of the front [C1] and back [C2] cassette parts. This edging strip should not be wider than the flaps. If necessary you can remove any excess cardboard carefully with a knife or file. Don't glue in the two convex mirrors yet.

Step 22: Remove the round disc from the slip case for the cassette [C5] and lay the slip case with the white back side down on your working surface, so that the two small pieces with sloped corners point away from you and the 4 mm narrow flap points towards you. Fold the 4 mm narrow flap forwards and the other three flaps around the central rectangle backwards. Fold the two protruding flaps backwards, so that they lie flat against the glue marks on the other flap. Finally fold forwards the two flaps with angled edges on the right and left. Now the slip case looks like this:



Step 23: Glue the two small flaps with sloped corners onto the top flap to form a flat box. Wait until the glue has set. Now hold the box, without applying any glue yet, onto the glue markings on the inside of the projector just under the top edge of the back wall, behind the round cutout. It should abut against the folded edge of the back wall. The two angled flaps should lie on the glue marks. Check whether the cassette can be pushed in from the outside through the round opening. Glue the two angled flaps of the slip case in this position onto the inner side of the back wall. After the glue has set, also stick the folded edge of the back wall onto the thin flap of the slip case.

Step 24: Look at the curved side of the two convex mirrors. You should see an image of your head, bigger in one of them than in the other. The mirror with the smaller image is the one with the focal length of -10.2mm. Glue it onto the cassette, on the side labelled "*f* = 10,2 mm". Glue the other mirror onto the other side.



Now you have mounted all optical elements.

Housing, finishing touches

Step 25: On both sides of the housing there is a quadrant, a quarter circle with a degree scale. In order to determine the height of the Sun with this, you need two thin threads, at the end of which you attach a weight by gluing or knotting. For a weight you can use a bead made of metal, glass, or stone. Make a hole in the centre of the small circle at the centre-point of the quadrant, insert the end of the thread with a needle and attach it firmly on the inside of the projector. The weight should hang low enough that the thread is clearly visible against the scale.

Step 26: Glue the edge reinforcement of the housing [A6] onto the folded lip of the back wall. The right angled cut-out should be flush with the cut-out for the cassette. Now glue the two protruding ends of the reinforcement and also the two trapezium shaped flaps of the plane mirror holder onto the folded rims of the side walls. This gives the Solar Projector a remarkable stability, despite the fact that the top is almost completely open.

Step 27: Fold the two side flaps of the projection surface [A7] backwards at a right angle. The projection surface should not be glued in, so that it can be replaced

with highly reflective paper or a grid template, if necessary (see notes below). Lay the projection surface with the flaps downward into the bottom of the housing, so that it touches the front wall and the two flaps fit snugly into the corner of the housing curvature.

Step 28: Remove the protective foil from the plane mirror. It might be necessary to slightly lift a corner with a knife.

Now the Solar Projector is complete.

Chapter D

The Base

In order to adjust the altitude of the Solar Projector between the horizon and the zenith, the base has a curved surface which holds the rounded back of the housing. This simple but efficient way of fitting the projector is known as a Dobsonian mount, after its inventor, and is often used for astronomical telescopes.

Step 29: Fold the flaps of the trapezium shaped left outer side [D1] backwards and the many small flaps of the left inner side [D2] forwards. The top edge of the outer side is exactly as long as the straight edge of the inner side. Glue the inner side and the outer side back to back (with the printed sides outwards) so that these two equal edges are flush.

Step 30: Do the same with the right outer side [D3] and right inner side [D4].

Step 31: Fold the two flaps of the curved surface [D5] backwards and gently curve the surface by holding one of the flaps and dragging the part over a straight table edge or similar, with the printed side facing downwards: the printed side should be the inside of the curvature. It should be curved enough to fit approximately the line of the flaps of the inner sides [D2] and [D4].

Step 32: Take one of the two outer sides, with the glued-on inner side and apply glue to the printed side of the small flaps. Lay the outer side face-down on your work surface, stand the curved surface [D5] on the inner side and stick the flaps to the back of the curved surface. Take care that the ends of the curved surface do not stick out beyond the ends of the inner side. Stick the other inner side on the other edge of the curved surface in the same way.

Step 33: Fold all the flaps of the base plate [D6] backwards and place it, printed side downwards, on your work surface. Stick first one, and then the other flap to the back of the two side pieces that are joined by the curved surface. It is best to do this as follows: Put glue on one of the two flaps and place the curved surface with the side pieces onto the base plate, so that the side pieces line up with the two flaps. To glue it in place it you can push against the pieces on the outside with your hand and on the inside with a pencil or similar. Glue the second flap in the same way.

Step 34: Finally, you need to glue the front side [D7] and the rear side [D8] of the base onto the flaps of the two remaining openings. Lay the base on a flat surface for this and ensure that the base plate stays square against all the edges while glueing.

Congratulations! Now you've put it all together and you are ready for your "First Light", as astronomers call the time of the first observation with a new piece of equipment. We wish you many interesting hours with your self-built Solar Projector!

How to use your Solar Projector:

1. Place the objective in the objective guide and put the cassette in the slipcase.
2. Place the Solar Projector in the Dobsonian base and put it up to the Sun so that the little bright point from the objective hits the convex mirror, somewhat above its centre.
3. Put the objective in focus by pushing it forwards or backwards so that a clear image of the Sun appears on the projection surface.
4. The Sun moves, so the image of the Sun will also move. Rotate and tip the projector so that the image is once again easy to see. The focussing of the objective will only need to be changed when you swap the convex mirrors.
5. **Important:** Do not leave the Solar Projector unmonitored with the objective in the direction of the Sun. The focussed light from the Sun could move away from the mirror and burn a hole into the cardboard.

Frequently asked questions:

1. **Why doesn't the Solar Projector need a solar filter?** Looking directly at the Sun, whether with or without a telescope should always be done with a solar filter. But with the Solar Projector you are not looking at the Sun, but at a projected image. This image is no more dangerous than a piece of paper with the Sun shining on it.
2. **What can I observe with the Solar Projector?** Most importantly sun spots, but also solar eclipses and planet transits. Under good conditions it is even possible to observe the landscape.
3. **Are there always sun spots visible?** The number of sun spots changes during a cycle of approximately 11 years. The last minimum was in 2009, the next maximum is expected in 2013. When near a minimum, sun spots are only visible with a very powerful telescope (with solar filter). You can find more information about sun spots on the internet at www.wikipedia.org.
4. **Can sun spots change in size and position?** Yes, sun spots (which often consist of groups of smaller spots), grow and shrink, and move over days from left to right over the solar surface. The reason for this is the rotation of the solar sphere around its own axis (the rotation period is 25 days on the solar equator, 35-40 days at the poles). If you follow the position of a regular round spot near the centre of the solar disk over a few days it will get ever thinner because of perspective distortion.
5. **How often can I see solar eclipses?**
   Approximately twice a year somewhere on Earth, but usually only in very specific, and often very inaccessible places. Lists of solar eclipses can be found on Wikipedia as well.
6. **What is a planetary transit?**
   The orbits of Mercury and Venus around the Sun are within the orbit of the Earth. Therefore occasionally Mercury or Venus are exactly between the Earth the Sun, so that for a short time they move past the solar disk. Such a planetary transit is a rare occasion, because the orbits of the planets don't lie in the exact same plane.

7. **How can I tell if what I'm seeing is a sun spot or a piece of dust in the optical system?** Move the Solar Projector a bit forwards and backwards so that the solar image moves around the projection surface. If the spot moves as well, it belongs to the Sun. If it doesn't, it is probably on the plane mirror. Dirt on the lenses don't cause spots, they just make the image poorer.
8. **What are the grids below for?** The grids correspond to the sizes of the two solar images. You can put them on the projection surface to record the exact position of sun spots and thus by making observations over a period of time, see how they have changed.
9. **How can I determine the height of the Sun?** The height of the Sun is the angle between it and the horizon. It can be read directly from the two quadrants. The Solar Projector must, of course, be placed on a flat horizontal surface. You can check this with a spirit level (for example the mini-spirit level from AstroMedia, order number 410.WAS) or by rotating the Solar Projector by 180°. If you get the same angle again, the surface must be horizontal.
10. **What happens if I hold a coloured filter in front of the objective?** Try it! The contrast of the image changes with the chosen filter. You can try similar experiments with coloured paper on the projection surface.
11. **What are the hexagonal apertures for?** You can put these behind the large aperture in the objective and therefore reduce the aperture opening. Smaller apertures make the image sharper, but dimmer. But that could be desirable, for example if you find the solar image too bright. It can sometimes be easier to make out sun spots in a dimmer image.