

## Introduction


Sunpass can transform any smart phone into an accurate solar compass which will give you the orientation of the true-North (i.e. the geographic North) wherever you are in the world (up to the poles), provided the Sun is present in the sky.

The compass accuracy is not influenced by ferromagnetic materials nearby the compass, nor by solar storms. It ranges from 1-2 degrees when using the “Fixed” Method (see “METHOD” parameter), down to 0.1-0.2 degrees when using the “Slit” method. Anyway, the Sun ephemerides algorithm has an accuracy as small as 0.01°; hence, in case you need a super-accuracy, beside the use of your phone alone, you can add few additional tools (a ruler and a plumb) to measure the absolute orientation of any building with the same accuracy of Ephemerides (0.01°), as explained in the “Theodolite Azimuth” Function.

No internet connection is needed for the compass working and no tabulated numbers are used for the Sun ephemerides. Hence, you can get the Sun ephemerides (see “Ephemerides” Function”) not only for the present day but also for any date, although the error increases by 0.02° for each century from present date.


Most of the Functions, labelled with “F”, are free, but some Functions specific for professionals, labelled with (P), can be used only after paying a few euros of royalties.


## Let's start with the “Orientation Function” (F).


After installation, before using your new solar compass, you must check the “Parameters Menu” by pressing the  icon on the top (right hand). In particular, you must verify that the “Time zone” is the right one”, that the “METHOD” is selected on “Fixed”, and that the “Daylight Saving Time” is set on “YES” (or “NOT”) if applied (or not) in the period of the year of present time.

Then you can press the “Compass” button (on the bottom at right hand), wait for your GPS connection (the Latitude and Longitude indication must appear in green colour) and point at the Sun you phone: the compass icon will indicate the true North (as well as all the other cardinal points) while the true North direction angle, with respect to the longer side of your phone, appears at the bottom. You are now in the “Orientation” Function with the “Fixed” Method.

You can see that the compass icon (with its four cardinal points) slowly turns in the direction opposite to the Sun one and at the same speed, so that if you maintains you phone oriented toward the Sun, the compass icons maintains always the same orientation (the true North). But if you point the phone to other directions (different from the Sun one), the compass icon will not move with respect to the phone. Hence, when the “Fixed” method is used, the compass accuracy is the same of your ability to point your phone toward the Sun (let's say 1-2 degrees).

In case you can't receive the GPS signal, you can manually insert your geographic coordinates: go to the Parameters menu (by pressing the  icon) and then switch off the “waiting for GPS”

condition by pressing the  icon (at the top of the page): this icon will turn from “G\_GPS” to “M-Manual” and the geographic coordinated in the Orientation Function page will be in red colour rather than green. Note: this switch, as well as all other settings of Sunpass, is not reset when you close the Sunpass App. Hence, if you forget this switch in the “M\_Manual” state and then close the Sunpass, at the next opening of Sunpass you will not get the automatic reading (from the GPS) of


the geographic coordinates and of the time until you switch the  icon to the “G\_GPS” state.

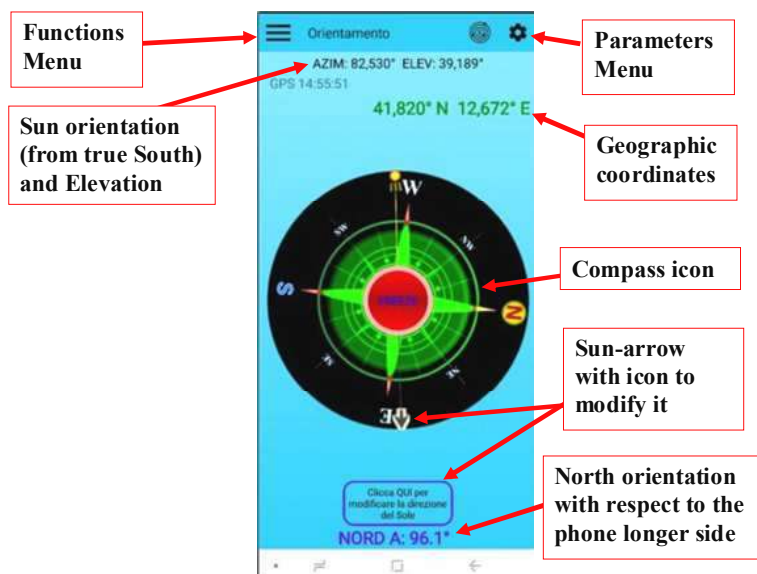
In case you need to orient your phone along a direction different from the Sun one (for example you want to align your phone along a wall of which you want to know the azimuth), you can turn the Sun-arrow on your display and orient toward the Sun just such arrow rather than the full phone

(for frontward, backward, leftward, and rightward settings of the Sun-arrow, just press one of the for corresponding arrows).

In order to reach the best alignment between the Sun direction and the Sun-arrow setting, you can place a small cube or a cylinder (like for example a middle size 1.5V battery) over your phone display and shift it until one of the borders of the shadow generated by the cylinder passes through the center of the compass icon.

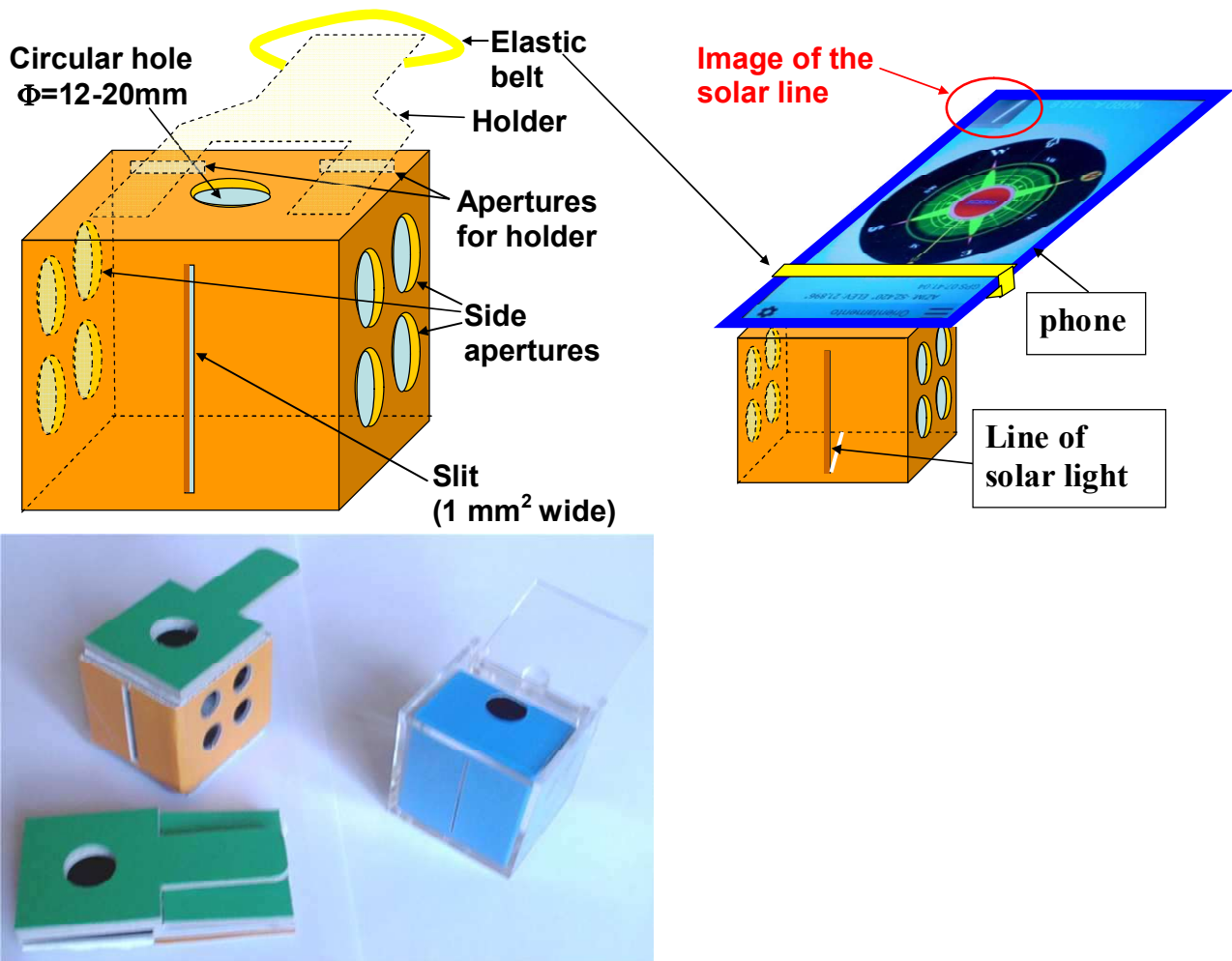
**Let’s improve the compass accuracy using the other Methods of the Orientation Function.**

You can significantly improve the accuracy of your compass (up to 10 times) by selecting a Method different from the “Fixed” one (go to “Parameters Menu” by pressing the  icon and adjust the “METHOD” selection). In this case your mobile phone will use it’s camera in order to individuate the Sun direction in place of you. You can not point your camera directly toward the sun (it might be damaged by an excess of light intensity), but you can frame your camera to the shadow of any vertical bar (selecting the “Gnomon” Method) or to the shadow of a building edge (selecting the “Edge” Method) or to the shadow from a slit (selecting the “Slit” Method).



**Figure 1: The phone display when the “Orientation” Function is used in the “Fixed” Method.**

This last solution is the best because it doesn’t require the horizontality of your phone (provided you have selected “YES” at the “Use Accelerometer” switch on the “Parameters menu”), but you need to place below your phone a box (approximately a cubic one) with a hole on the ceiling (for the phone camera) a slit on one side to get the projection of a line of solar light on a plane (the floor of the box) parallel to your phone one. The box can have any size (starting from a minimum of 4 cm i.e. the minimum focal length of your phone) and you can make it by yourself (see Figure 2) or buy it for few Euros at [www.gruppodm.com](http://www.gruppodm.com) .




**Figure 2: Examples of “Orientation KIT”, i.e. of the box for the “Orientation” Function using the “Slit” Method: self-made KIT (top) and the 4x4x4 cm<sup>3</sup> commercial KITs sold by D.M. Packaging of Rignano Flaminio (Rome, Italy). On the right, the complete compass is shown during operation.**

The floor and the ceiling of the box should be white colour while all the other internal faces should be black. Some side-apertures (approximately 20% of the lateral walls area) can gently illuminate the floor, thus avoiding the phone camera to saturate when the bright solar line is projected on the floor.

Two small apertures on the rear wall allow a holder (a plastic or metallic or wooden plate shaped like in Fig. 2) to enter the box and help you to hold the box when using your solar compass. Alternatively, the holder might be glued over the box. You can keep the holder in contact with your phone rear by hands, by elastic belts (as shown in Fig. 2) or by any other structure (like for example the holders for self-photos).

When using the “Slit” Method, don’t mind to orient your phone toward the Sun, nor to orient the slit in the same direction of the phone: just orient the slit approximately toward the Sun, no matter what the phone orientation is, and shift the box until the bright line approximately crosses the phone frame center. The only important point is the parallelism between the mobile plane and the box floor. In case the cover of your phone limits such parallelism, just remove it.

In case you need to hold the indications on the display after an orientation measurement, just press the button “Freeze” at the center of the compass icon: the compass icon and the displayed numbers will be kept frozen until you press “Release”. This possibility can be useful when you want to know the orientation of a pointing means (like a binocular or a telescope) by approaching the phone to the telescope tube: in that moment your eyes are busy at the telescope but you can press the “Freeze” button and read later the orientation value.

Verify the good quality of the line of the solar light on the bottom of the display (see Fig. 2): in case it is too bad, the compass icon stops to work and it loses its normal contrast and brightness. You can also change the level of minimum acceptable line quality: go to “Parameters Menu” by pressing the  icon and adjust the “Accuracy” selection among “Low”, “Medium”, and “High”; according with the resolution of your phone camera and with the quality of your box, you can choose the “accuracy” parameter at the minimum level required for the software to accept the line image.

There is also a fifth method called “Magnetic”. This method is very similar to the “Slit” method, but the “Freeze” button is substituted by the “Magnetic” button. In this case the compass goes on working even if the Sun disappears: it exploits the magnetic sensor of your smartphone (if present) and assumes that the local difference between the geographic north (measured by your solar compass at the moment in which you press “Magnetic”) and the magnetic north (measured by the magnetic sensor) keeps constant.

This method can be useful when the Sun direction is too different from orientation you want to give to your phone (for example for the “Install Solar Panels function”, as explained in the following). Note: when using this method, limit the movements of your phone as much as possible (just rotations), otherwise you will lose too much the compass accuracy. Return to normal operation by pressing the “Solar” button in place of the “Magnetic” one.

### Using the Orientation KIT of D.M. Packaging.

The D.M. Packaging s.r.l. of Rignano Flaminio (Rome, [www.gruppodm.com](http://www.gruppodm.com)) delivers the two types of Orientation KIT shown in Fig. 2c: a cardboard KIT and a Plexiglas KIT.


For the use of the cardboard KIT we suggest to follow these instructions:

- a) Open the cardboard parallelogram so that it makes four right angles.
- b) Refold the side walls (each one has 4 holes) so that their thicker part (40x40 mm<sup>2</sup>) enter the parallelogram and make a complete cubic box. The friction should be enough to keep the box closed. If not, add a piece of scotch.
- c) Verify that the slit is free from dust or glue residuals.
- d) Hang up the box under your smartphone using your finger or a clothes peg (insert a piece of wood in your clothes peg fulcrum so that the aperture of the clothes peg better fits with your phone thickness) and orient it approximately toward the Sun. The box is ready for use.
- e) In order to close the box, insert your thinner finger in the upper hole and push the side wall centre. The refold the two side walls as in the origin.

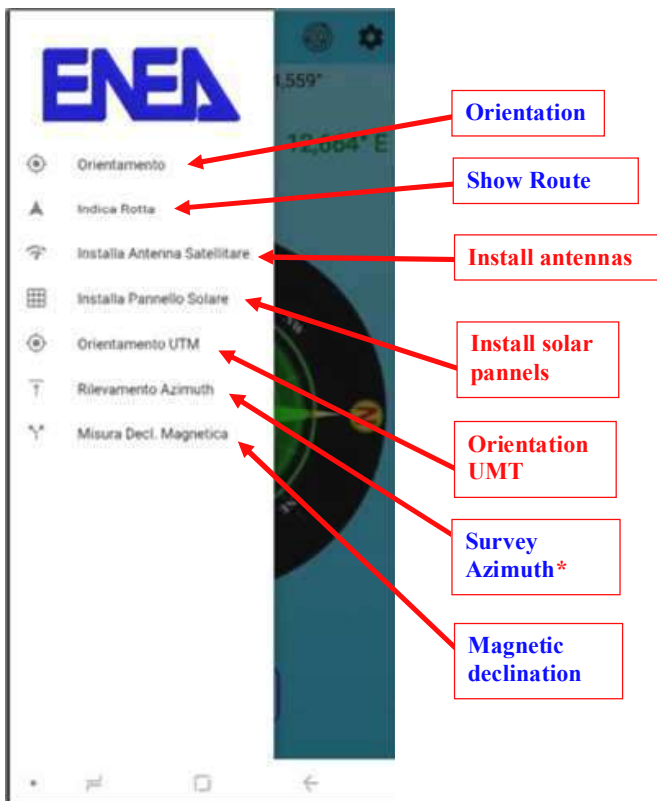
For the use of the plexiglass KIT we suggest to follow these instructions:


- a) Open the cover of the box and turn it by almost 180 degrees (overcome the friction that you encounter around 100 degrees) so that the cover becomes the handle of your box.
- b) Hang up the box under your smartphone (as for the cardboard box case) and ensure that the upper border of the box is parallel to the rear of your phone).
- c) After using, close again the cover (to keep always clean the slit).


### Other Functions

Beside the Orientation Function which transforms your smart phone into a compass, similar to conventional magnetic compasses but much more accurate and insensitive to nearby ferromagnetic materials, Sunpass exhibits other useful Functions which exploits the mathematical algorithms in a slightly different way from the Orientation Function. You can select the other Functions by pressing the “Functions Menu”, that is the  icon on the left-top of your display. The available Functions are those shown in Fig. 3. Most of them (those in blue colour in Fig. 3) are for educational or

general purposes and are free, while some of them (those in red colour) are for professionals and their use is accessible only by paying a small royalty.



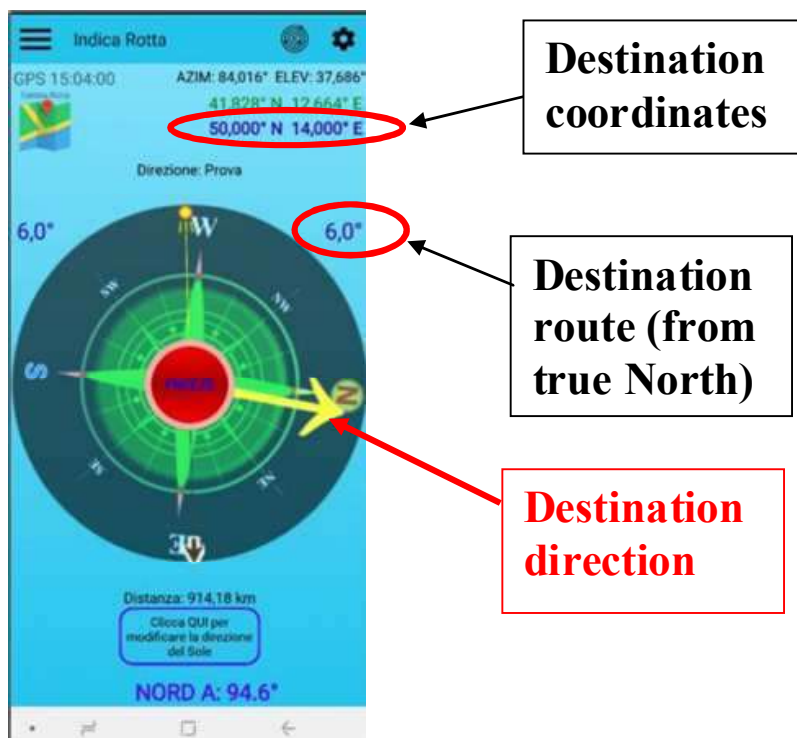
**Figure 3: The list of different Functions which appear on the display after pressing the  icon for Functions selection. Those in blue colour are free while those in red colour require royalties payment.**

A further function, called “Sun ephemerides” can be called at any time just by pressing the “” icon at the top of all pages.

**The “Show Route Function” (Free).**

This function is similar to the Orientation Function but in this case, in addition, a yellow arrow overlaps the compass icon indicating the direction that you need to follow to reach your destination; furthermore, an additional azimuth angle appears on the display, indicating the angular value of the orthodromic route which leads to your destination.

You can insert the geographic coordinates of the destination by digitizing them, or by selecting them from your personal list or from Google Maps (provided the internet connection to Google Maps is available). An example of the Display of your compass in the “Show Route” Function is shown in Fig. 4.



**Figure 4: The display of the phone when the Show-Route Function is used. In this example the destination coordinates which have been digitized as INPUT are 50° North and 14° East of Greenwich.**

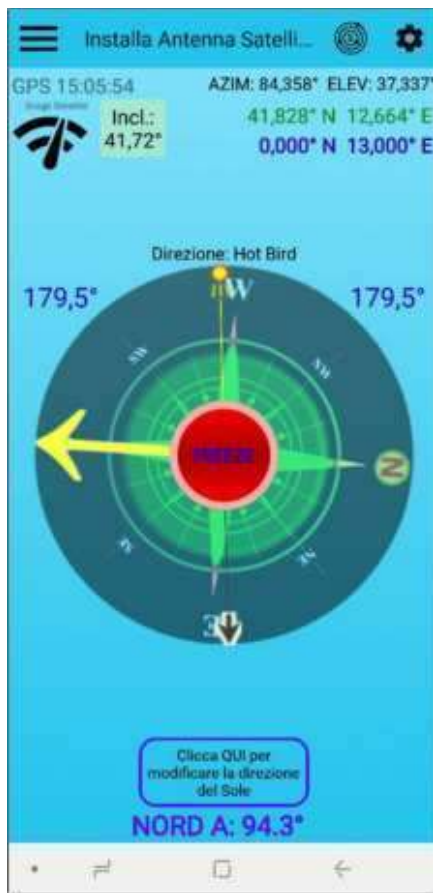
Furthermore, the display of your phone shows also the geographic distance of the destination in Km units: it should be intended as the distance along a straight line for short distance values (<50 Km) or as the length of the orthodromic route for the case of large distance values (>50 Km).

### **The “Install Antennas Function” (Pay)**

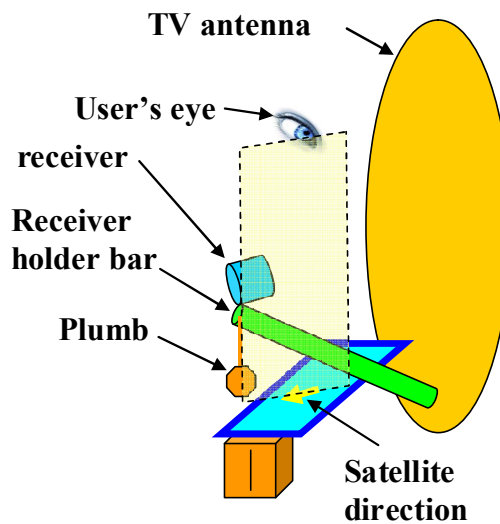
This function is for parabolic antennas installers. The function is rather similar to the “Show Route” Function, but in this case you can select one of the television geo-stationary satellites rather than a geographic destination. The yellow arrow on the display will show you the direction of the satellite while, on the display, the satellite azimuth (both with respect to the true North direction as well as with respect to the longer side of your phone) and elevation angles appear.

After adjusting the vertical goniometer of your antenna at the angle indicated on the display of your phone, you can place the phone right below the bar which holds the detector of your antenna and, keeping your eye right over the bar, turn the antenna until the bar becomes parallel to the yellow arrow. To be sure that your eye is on the vertical plane which lies on the bar, you can add a small plumb at the antenna receiver (tangent to the holder bar) as shown in Fig. 4bis.

You can exploit your solar compass also for the installation of terrestrial antennas (like for example logarithmic antennas) rather than for satellite type. In this case you can use just the “Show route” function and insert as “wished destination” the geographical coordinates of the TV repeater antenna at which you wish to point your terrestrial antenna. Also in this case, you must turn your antenna until its main (longer) axis coincides with the direction of the yellow arrow displayed by your phone.



a)



b)

**Figure 4bis: Orienting a satellite TV antenna using the “Install antenna Function”:** the display when the “Hot Bird television satellite has been selected (a) and the smartphone positioning under the antenna (b). Ehen positioning the phone, the plumb, the user’s eye, the receiver holder border, and the yellow arrow on the phone display (indicating the satellite direction) must lie on the same vertical plane (here represented by the yellow dashed rectangle).

### The “Install Solar Panels Function” (Pay)

This Function is for solar panel installers. As well known, the indication of the true South/North direction given by any compass show you the best orientation of any solar panel. Even the “Orientation” function gives you this indication. The “Install Solar Panels” Function is similar to the Orientation Function but, in this case, it gives you important additional informations.

To use this function you need just an arbitrary cubic or parallelepiped box to be used as adapter between your phone and the solar panel you want to install.

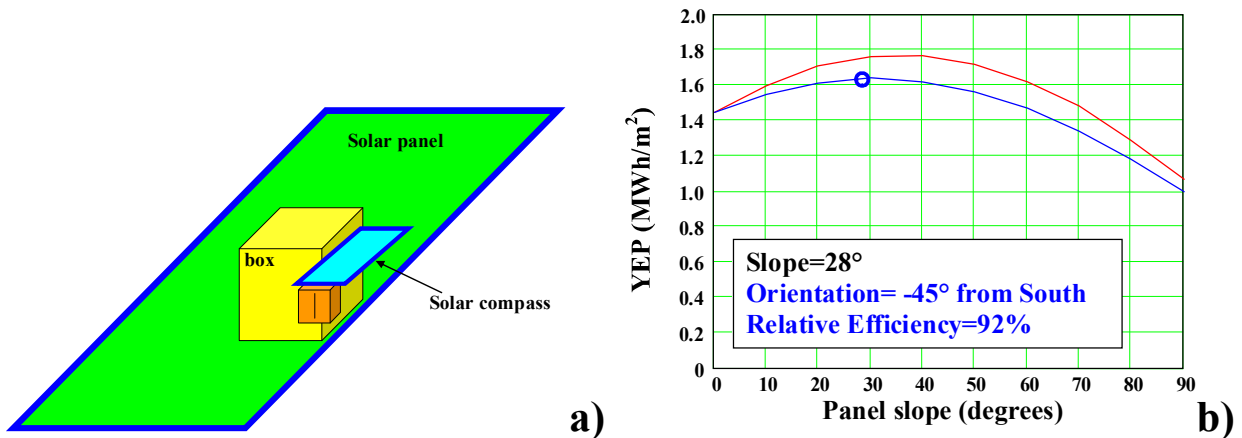
Place the box laying on the panel (same slope) and then put your phone over the box to acquire the panel slope (press the “slope” button to do it) as shown in Fig. 4trisA.

Then place your phone in contact with one of the two lateral walls of your box (you can keep the phone approximately horizontal for a suitable entering of the sun radiation through the slit) in order to measure the panel orientation (the box tilted side must be parallel to the panel border as shown in Fig. 4trisA). For this Function the “Slit” or the “Magnetic” methods (see Orientation Function) are mandatory. So, you are not allowed to select other “Methods” when using this Function. In case, during measurements, the panel orientation (P) differs too much from the Sun one (by more than 45°), you can use the “Magnetic Method” or you can place your phone on the upper face of the box, oriented to right (R) or to left (L) with respect to the (P) direction so that the angle between the Sun and your phone is reduced.

Press the “P”, or “L” or “R” button to start the orientation measurement; after few minutes, you will get on the display the result of the panel efficiency measurement: it gives you the value of the Yearly Energy Production (YEP) of your panel (circle) and it compares such value with that obtained for the same orientation (blue curve) or for the best orientation (red curve), i.e. the south orientation for positive latitudes and the north orientation for negative latitudes, as a function of the panel slope, as shown in Fig. 4trisB.

**Important:** these are the YEP values obtained for an ideal solar panel (100% conversion efficiency) and ideal weather (100% of sunny days during the year). In other words, these are not real YEP but are the yearly solar released energy per unit of surface.

Hence, in order to get the real YEP value of your panel, you must to multiply the YEP shown on the display by the conversion efficiency of your panel (typically between 10% and 20%) and by the average percentage of sunny days on your geographic area.



**Figure 4tris. Measuring the efficiency of a solar panel: during the measurement of the panel orientation for a “P” positioning of the smartphone (a) and the result of the measurement (b) for a panel at middle latitudes (+42° in this example) oriented to the South-East direction with a slope of 28° (blue circle), compared with that of any other slope maintaining the same orientation (blue curve) or adjusting the orientation at best (red curve), that is toward the South direction in this example. The panel slope, its orientation, and the relative efficiency are shown in the rectangle. The YEP corresponding to 0° is the so called “horizontal solar irradiation per year”.**

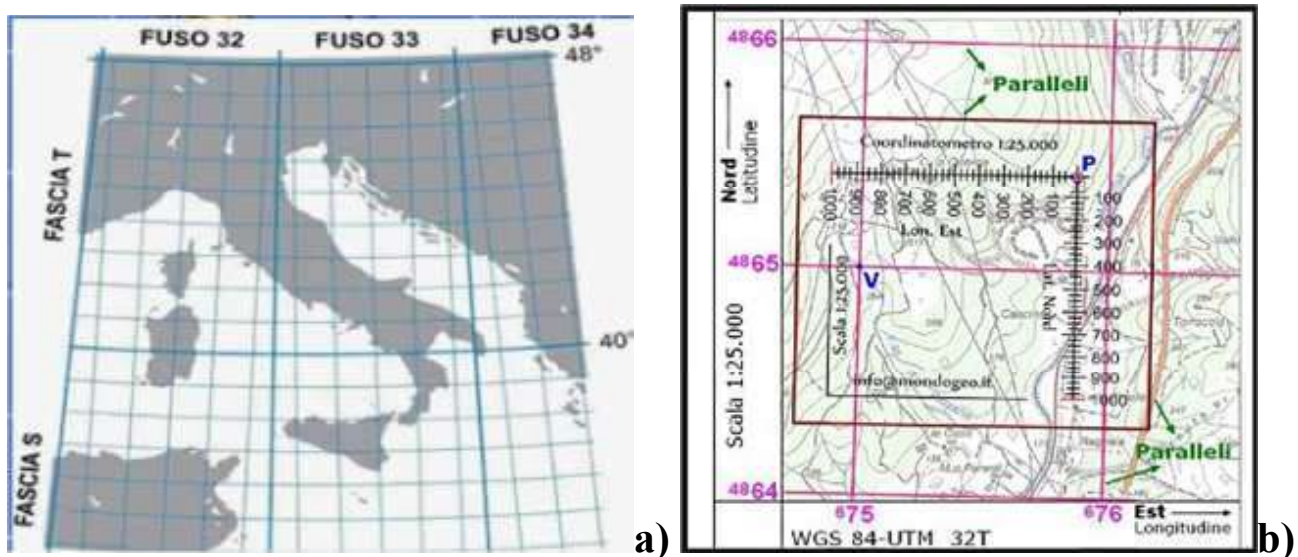
On the base of the Relative Efficiency, defined as the ratio between the panel YEP and the maximum YEP available in that place (i.e. the maximum of the red curve), the panel installer can decide if it could be convenient to change the slope (or the orientation) of the panel or just to maintain it as it is (for example maintaining the panels laying on the house roof) and to compensate for the efficiency reduction (with respect to the maximum one) by increasing the panels total surface.

### The “Orientation UTM Function” (Pay)

This Function is for engineers and for survey operators. It is similar to the Orientation Function but the azimuth angular indications as well as the North indication are referred to the UTM (Universal Transverse Mercator) meridians rather than to the geographic meridians. While geographic meridians are converging toward the North or South poles, the UTM meridians keeps parallel each other, within each of the 60 UTM Zone regions of the world, thus generating a differentiation of “North direction”, called “convergence angle”, which for some geographic places

can reach few degrees as shown in Fig. 5. UTM is generally used in topographic maps and cadastral maps.

When using this Function, the compass icon North-South direction is aligned with the UTM meridian (the red lines of Fig. 5) and the number of the Zone as well as the convergence angle appear on the display.



**Figure 5: UTM zones in Italy (a) and UTM meridians and Parallel in a topographic map, b), for a scale 1:25000. Purple colour numbers indicate the distance from Equator (in km units) and the distance from the reference central UTM meridian of that zone (the zone # 32T in this example) + 500 km (an offset of the UTM longitude to avoid negative longitude values). The tilt of the UTM meridians (due to the convergence angle, positive in this example) is well evident.**

### The “Survey Azimuth Function” (Free)

Also this Function is for professional people like engineers and survey operators. It is very similar to the “Orientation Function”, but in this case the smart phone is expected to be mounted over a “Survey KIT”.

Differently from the “Orientation Function”, in this case a list of four azimuth values, which correspond to the four pointers (separated by 90° each other) of the KIT, appears on the display.

The pointer azimuth is the orientation of the vertical plane which lies on the main axis of the pointer. Hence, the four azimuth values given by this function are separated by 90° each other only when the survey KIT is horizontal.

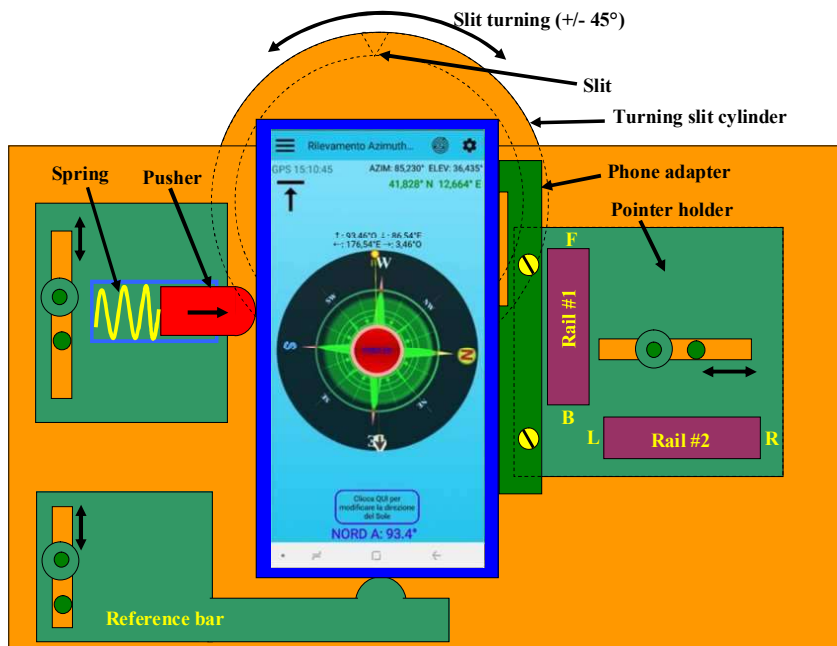
Such Survey KIT can be a professional one, like that shown in Fig. 6, or simply a hand made one, like that shown in Fig. 7.



The KIT is equipped with just one professional optical pointer (like those for guns) which can be fixed on one of two rails (orthogonal each other) in two opposite directions, so that four different orientations are allowed for the pointer: F, B, L, R, where F, B, L, R stand for Front, Back, Left, and Right with respect to the Sun direction.

After orienting the slit of the KIT approximately toward the sun, the KIT can be turned (together with the phone) up to +/- 45° until the pointer (mounted on the most suitable among the four possible FBLR positions) points at the object of interest.

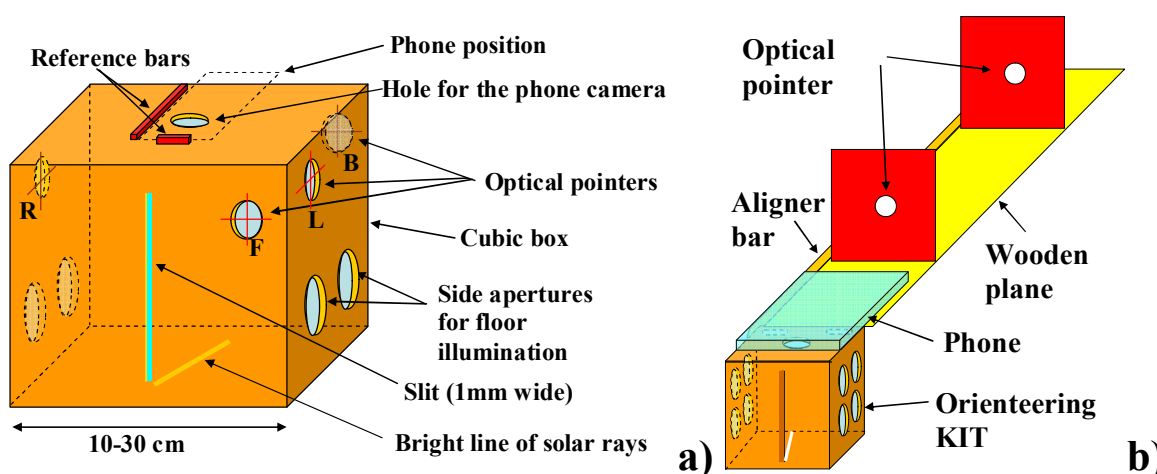
You will note that, in case the phone and the KIT are horizontal, the four azimuth values (which appear on the display) differ each other by  $90^\circ$ . Else case, the KIT tilt (revealed by the phone internal inclinometer) is automatically taken into consideration (provided you have selected “YES” at the “Use Accelerometer” switch on the “Parameters menu”).



**Figure 6: The professional Survey KIT.**

In the case of the professional KIT, the phone is pressed (by a spring) between the “Pusher” and the “Pointer holder” plate. An intermediate “Phone Adapter” allow to avoid the effects of side buttons of the phone, thus ensuring a good parallelism between the phone longer side and the Pointer holder.

The Pointer holder and the Reference bar can be shifted (once for ever) so that the phone camera is positioned at the center of the slit cylinder. In this way the bright line observed by the camera should cross the center of the camera frame and the best accuracy ( $0.1^\circ$ ) of the compass is achieved.



**Fig. 7: Examples of self-made “Survey KITs”:** large box with internal optical pointers (a) or large pointer combined with the Orienteering KIT (b). In the first case, the central hole at the box ceiling allows the phone camera to observe the bright solar line on the box floor. In the second case, the phone with the orienteeing KIT shown in Fig 2 is aligned along an optical pointer obtained just by placing a couple of twin holed screens on a wooden plane.

The four possible orientations of the pointer allow the slit tilt (as well as the bright line) to never exceed  $45^\circ$  from the phone main axis.

Also the pusher can be vertically adjusted (once for ever) so that it pushes the phone approximately on the center and far from buttons.

As above mentioned, even self-made survey KITs, like those shown in Fig. 7, can be used as a cheaper alternative, but, of course, in such cases the  $0.1^\circ$  compass accuracy is not guaranteed.

For the cubic self-made Survey KIT, any cubic box can be used. The optical pointers can be obtained simply by two couples of circular holes (same size and same distance from the box corners) with a cross of wires to help the pointing. Paint over the box the phone position so that the two lines joining the crosses are parallel to the phone sides; you could also glue two reference bars over the box at two borders of the phone (see Fig. 7a) in order to fasten the phone positioning (polish the bars where phone buttons touch it, so that the phone can be in full contact with the bar). Label the four holes of the optical pointers like in Fig. 7; each of the four pointing direction (F, B, L, R), which are at  $90^\circ$  each other, can be pointed just by approaching your eye to the cross at the opposite hole.

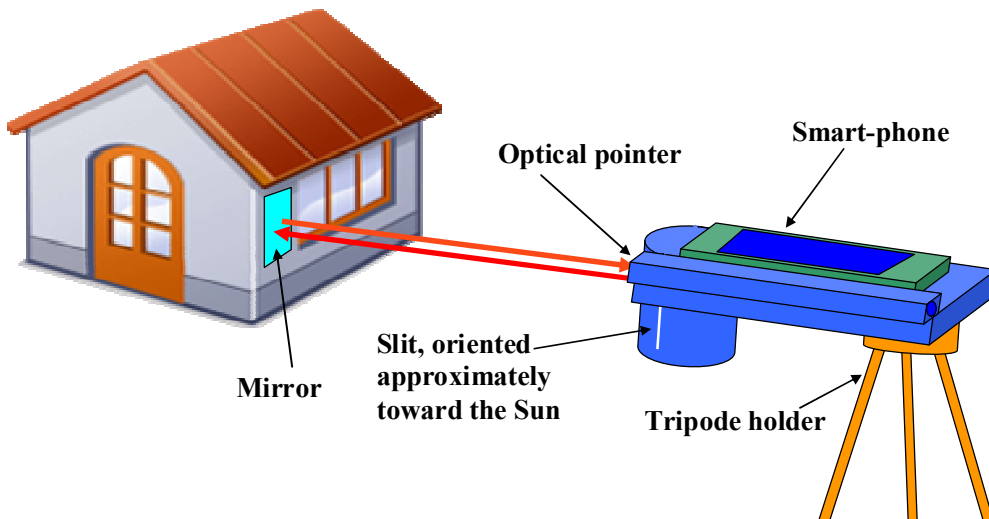
As for the case of the box for the “Orientation Function” (see Fig. 2), also in this case you should paint with black colour the internal walls of the box, leaving white colour just at the floor and at the ceiling (for a better uniformity of the floor illumination).

Since the software takes into account the inclination of the phone, the horizontality of the KIT plate (or of the box ceiling and floor) is not required (provided you have selected “YES” at the “Use Accelerometer” switch on the “Parameters menu”).

As an alternative, you can make a self-made Survey KIT just by aligning the orienteering KIT of Fig. 2 on a simple long optical pointer. For example, as shown in Fig. 7b, you can place on a long ( $\sim 1\text{m}$ ) wooden plane a couple of twin holed screens and hold it using a conventional tripod for photographic cameras. Ensure a good alignment between the wooden plane and your phone by adding an aligner bar on the wooden plane, as shown in Fig. 7b.

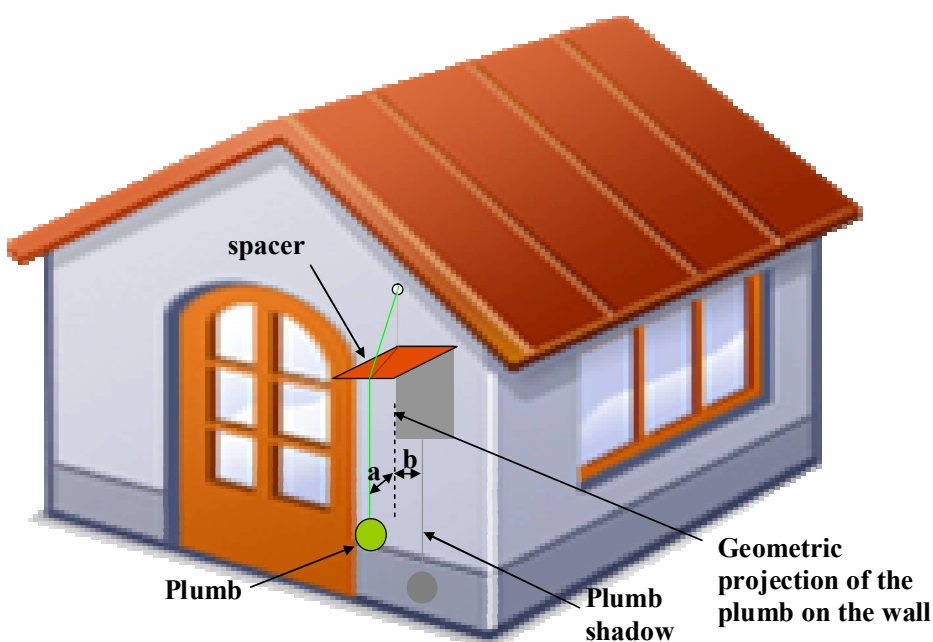
When your phone is equipped with the Survey KIT, the “Theodolite Azimuth Function”, you obtain a high precision solar compass which can be used for different professional purposes:

- 1) You can measure the azimuth of the view direction of any target,
- 2) You can get an absolute zeroing of any survey tool like theodolites, laser scanners or total stations (just by pointing with such tools the same target pointed by the compass, while positioning your compass over or below your tool).
- 3) You can measure the azimuth of any wall of a building, just by placing a mirror on the wall and pointing the optical pointer of the compass to the image of the pointer itself reflected on the mirror (see Fig. 8) or by observing the wall tangentially i.e. by placing the optical pointer of the KIT along the direction of the wall.
- 4) You can use it for archeo-astronomy purposes by joining this function with the Sun-rise and Sun-set values given by the “Ephemerides Function” as described in the following (Ephemerides Function description).



**Figure 8: Measurement of the azimuth of a wall using the Survey KIT and the Theodolite Function.**

As above mentioned, since the Sun ephemerides are calculated with an accuracy one order of magnitude better than that achievable by your Survey tool (limited by the phone inclinometer accuracy), in case you need to reach the same accuracy of the ephemerides ( $0.01^\circ$ ) you can directly point your tool to the Sun (using a solar filter, of course) and exploit your phone just as a calculator of the Sun ephemerides i.e. of the. Analogously, for a very high accuracy building-orientation measurement, you can directly measure the orientation of the building wall with respect to the Sun just using a ruler and a plumb, as above mentioned: fix the plumb at a distance “a” from the wall and measure with the ruler (kept horizontal on the wall surface) the distance “b” between the shadow of the plumb wire and the geometrical projection of the wire on the wall (“b” is negative when the shadow is on the right side of the geometrical projection, as shown in Fig. 9). The orientation of the wall with respect to the Sun is given by  $\arctan(b/a)$ . Add this angle to the Sun orientation (read it on the phone in the Ephemerides Function at the same time you read “b”) and you get the absolute wall orientation. For windy days it is convenient to keep the plumb bowl into a pot filled with water in order to avoid oscillations.



**Figure 9: Determining the orientation of a wall with respect to the Sun by using a plumb; in order to hold it at  $a=30-50$  cm from the wall, a wooden spacer can be helpful.**

Alternatively, you can wait for the moment in which the Sun is tangent to the wall: in this case the wall orientation with respect to the Sun is simply  $\pm 90^\circ$ .

Anyway, for a low precision measurement of the azimuth of a wall, you can just put your phone in contact with the wall with the phone longer side parallel to the wall (possibly interpose a long bar between the phone and the wall in order to smooth the effects of the wall irregularities) and use the Orientation Function as already explained in: Let's start with the "Orientation Function".

### **The "Magnetic Declination Function" (Free)**

This Function is Free. It is similar to the orientation Function but it measures the difference between the true North direction (given by your solar compass) and the magnetic North direction (given by the magnetic sensor of your phone, if present), that is the magnetic declination.

Compared with the "Orientation Function", this function gives two advantages:


- a) The magnetic declination can be stored so that the compass will continue to work (indicating the true North direction) even if the Sun disappears (assuming that the local magnetic declination remains stable and exploiting the magnetic sensor). In this case your compass becomes a magnetic compass (just corrected by the magnetic declination).
- b) As soon as the internet connection will be available, your phone will communicate (if you allow it to do so) the result of your magnetic declination measurement to a world wide data bank, so that you will become a scientific collaborator for the study of the changes of the magnetic field emitted by the earth.
- c) You can hold the "magnetic compass use" also for the other functions (like the show-route function, the install-antennas function, etc.), so that you can use them even in case of cloudy days. But remember: in this case you are using a magnetic compass (not a solar compass) with all its intrinsic limits (sensitivity to nearby ferromagnetic objects, accuracy limited to few degrees, usable only far from the poles i.e. at latitudes lower than 60-70 degrees, etc.).

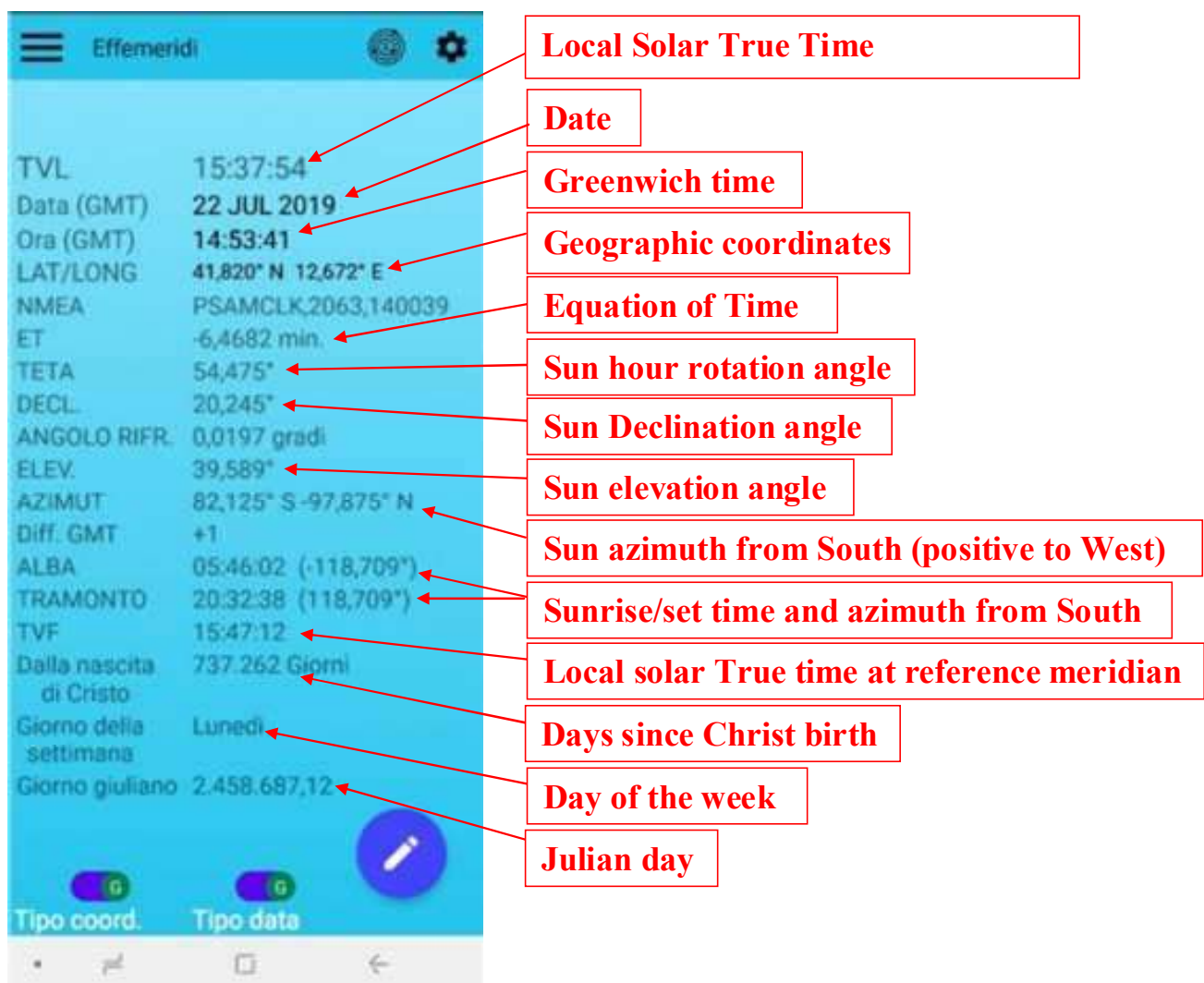
### **The "Ephemerides Function" (Free)**

This function is free and it gives many astronomical informations for education purposes, as shown in Fig. 10:






- 1) LTL= Local True Time . This is the time indicated by old sundials, according which it is 12 o'clock when the Sun is really in the middle of the day and it is exactly at noon (at the top of its elevation) and exactly in the South direction.
- 2) GMT= Greenwich Middle Time
- 3) Lat/Long= Latitude and Longitude
- 4) NMEA= the text received by the GPS of your phone
- 5) ET= Equation of Time. This is the difference between the True Time and the Middle Time due to the changes of the solar day durations (the time gap between two noon).
- 6) Theta=hour rotation angle of the Sun (around the earth axis) with respect to the local meridian (positive post meridian).
- 7) Decl.= Sun Declination angle; it is the angle between the equator plane and the Sun direction, positive for spring and summer periods in the northern hemisphere.
- 8) Refr. Angle= refraction angle given by the atmosphere in the direction of the Sun.
- 9) Elev= Elevation angle of the Sun over the Horizon
- 10) Azimuth= Direction of the Sun with respect to the geographic South and North directions
- 11) Sunrise= time and direction (" $\phi_{\text{sunrise}}$ " in brackets) of the appearance of the Sun over the Horizon (you can select if you means, as Sunrise time, the appearance of the first Sun ray, or of the Sun centered at the horizon or the Sun tangent over the horizon).


- 12) Sunset= time and direction (“ $\phi_{\text{sunset}}$ ” in brackets) of the disappearance of the Sun behind the Horizon (same setting possibilities as for the Sunrise).
- 13) TVF= Sun True Time at the reference spindle.
- 14) Days from Christ. This is the total number of days past since January 1<sup>st</sup> of year 1 A.C. assuming that the actual Gregorian calendar could be extended to any period of the history.
- 15) Day of the week
- 16) Julian day (useful for astronomers), that is the number of days past since Greenwich noon of January 1<sup>st</sup> of year 4713 Before Christ.

The Ephemerides Function can be called at any page just by pressing the  icon at the top of the page. The same icon can be used also to exit from the Ephemerides page



**Fig. 10: The ephemerides Function**


All these informations are normally given for the actual date, but you can change the date and get them for any date, in the past or in the future: press the  icon, at the bottom of the display, to insert the new date or the new geographic coordinate and then press the  or the  icon, respectively, to switch the ephemerides data-time-coordinates from the actual values to the desired newly inserted values: the “G” letter of the  or  icons has to switch from “G” (=GPS values) to “M” (=Manual values).

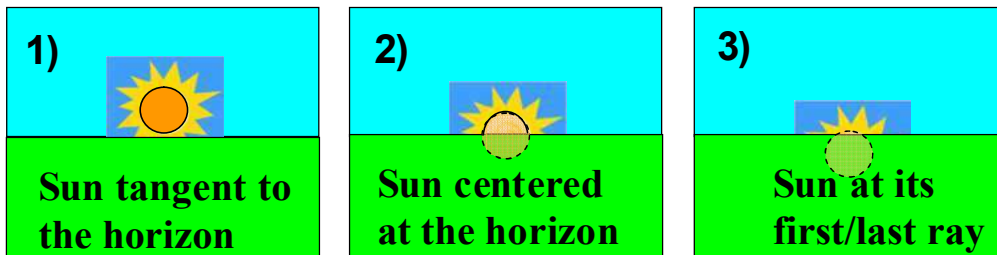
It is worth noticing that the elevation of the Sunset and Sunrise can be changed from the normal value (i.e. from zero). So, after reading on the display the direction of the sunset (for example), you can measure the horizon elevation angle “ $\theta H$ ” defined as the angular height of the hills in that direction (measured using a theodolite or calculated as  $\arctan(h/d)$ , where “ $h$ ” is the hill height and “ $d$ ” is the distance of the hill from you), insert it in the Horizon change menu (press the  icon) and get a new value of Sunset time and direction, adjusted to the disappearance of the Sun behind the hill rather than behind the normal horizon.

This possibility is particularly useful for archeo-astronomy purposes: you can measure the orientation of the wall of an ancient building and then compare it with the direction of the local Sunset or Sunrise for any day of the year.

You can also insert a negative value of “ $\theta H$ ” (for the cases in which you are over a hill). In case you insert “-10°” as elevation, the program assumes that you can see the sea below you toward the Sunrise or Sunset directions and automatically it calculates the true horizon elevation angle as  $-\arctan(\sqrt{2h/R})$ , where  $h$  is your height over the sea (given by the GPS of your phone) and “ $R$ ” is the earth radius ( $R=6378137m$ ). Since the error given on “ $h$ ” by your phone GPS is typically around 20m, you can efficiently exploit this automatic calculation of “ $\theta H$ ” only for height values over 200m (so that the relative error on “ $h$ ” becomes smaller than 10%). In case from your hill you see far horizontal lands rather than the sea, you can still calculate “ $\theta H$ ” as  $-\arctan(\sqrt{2h/R})$  by replacing “ $h$ ” as the difference between your height and the lands one.

As above mentioned, you can also insert your own definition of sunrise and sunset, different from the concept of first/last ray of sunlight (when the Sun is tangent to the horizon at its upper border):

press the  icon, then choose “Sunrise/Sunset” and finally select one of the three choices about Sunset/Sunrise definition. Remember that, from the astrophysical point of view, the time of the sunrise/sunset is defined as the time of the first/last ray of Sun light (case 3 of Figure 11), while the azimuth of the sunrise/sunset are defined as the direction of the Sun when it is centered at the horizon (case 2 of Figure 11).




**Figure 11: The three possible choices for the sunrise/sunset definition.**

### Archeo-astronomy application of Ephemerides

Archeoastronomia is a recent science which aims to discover the existence of special alignment of old buildings (castles, churches, etc.) with respect to the Sun. For example, it might happen to discover that at the building (or part of it) is perfectly aligned with the sunrise or sunset directions at the Sun solstices or at the equinox or at a special date like a holy day or an anniversary day of the original owner of the building.

Sunpass can be efficiently helpful for Archeoastronomia applications just by following this simple procedure:

- 1) First of all, Sunpass allows to measure the orientation (azimuth) of any wall of the building, that is the orientation of the direction perpendicular to the wall surface as already described in the “Survey Azimuth Function” section, with an accuracy and reliability much beyond that allowed by magnetic compasses. This allows also to

- know the direction “ $\phi_{wall}$ ” tangent to the wall, just by adding  $\pm 90^\circ$  to the azimuth of the wall.
- 2) Using a theodolite or other survey instrument, the user can measure the angular height “ $\theta_H$ ” of the horizon in the direction “ $\phi_{wall}$ ” and insert it in Sunpass as described here above (press the  icon in the Ephemerides page).
  - 3) Change the date in the Ephemerides page (see above) until the Sunrise direction or the Sunset direction equals “ $\phi_{wall}$ ”: that is the date you were looking for.

### **Accelerometer zeroing**

When using the SLIT (or Gnomon, or SHADOW) Methods generally it is convenient to activate the use of the phone internal accelerometer, so that the horizontality of the phone is not required because the phone inclination is automatically measured by the accelerometer and taken into account in all the calculations of Sunpass.

Anyway, the accuracy of phones accelerometers is not perfect and this mainly limits (to approximately  $0.1^\circ$ ) the performances of Sunpass.

Sometime accelerometers present not only casual errors but also systematic errors. You can remove the systematic errors of your accelerometer by following a simple self-calibration procedure: press the “CALIB” icon at the bottom of the “Parameters Menu page” and then follow one of the two calibration methods:

- a) if a horizontal table is available close to you, just place the phone over the table and then press “OK”: the two tilting angles (Roll and Pitch), shown on the display, should go to zero. Be careful: in case the camera objective of your phone is protruding, don’t place the phone directly over the table (it would be not parallel to the table), but interpose two twin pencils between the phone and the table so that the camera objective doesn’t touch the table and the phone results to be parallel to the table.
- b) If you have a non-horizontal table, place the phone over the table (again interposing the two pencils if the camera objective is protruding) and press the “+90” icon. Then turn your phone by  $180^\circ$  around a vertical axis, place it on the table (or over the two pencils) again and press the “-90” icon. The calibration is completed!

### **The language of Sunpass**

Sunpass automatically adjust its language to the selected phone-language.