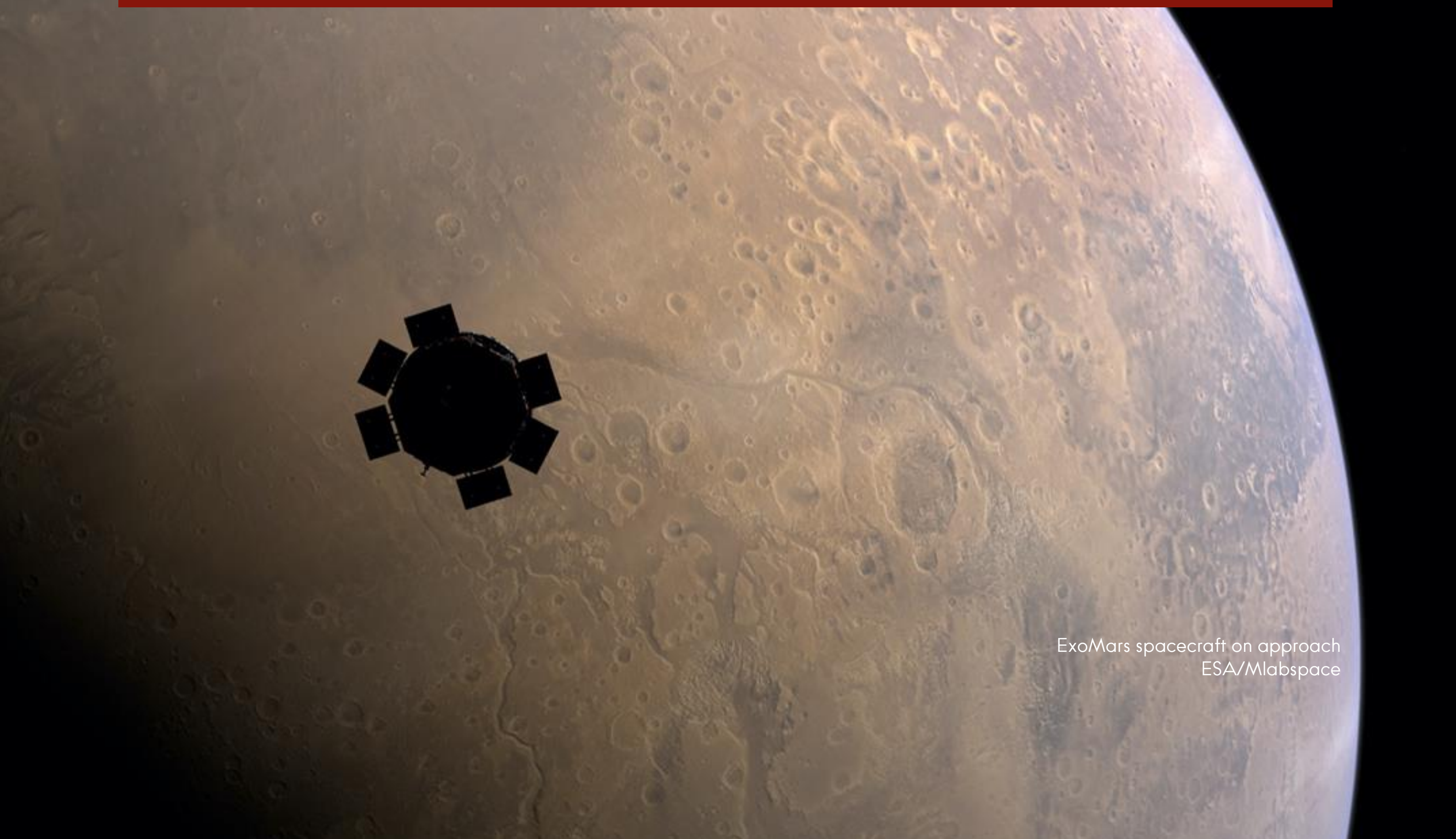
OMEGA

Speedmaster

# X-33 MARSTIMER

EXOMARS

# OPERATING INSTRUCTIONS



ExoMars spacecraft on approach
ESA/Mlabspace

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# INTRODUCTION

Congratulations on having received your OMEGA Speedmaster X-33 Marstimer, our first watch able to display Earth and Mars time.

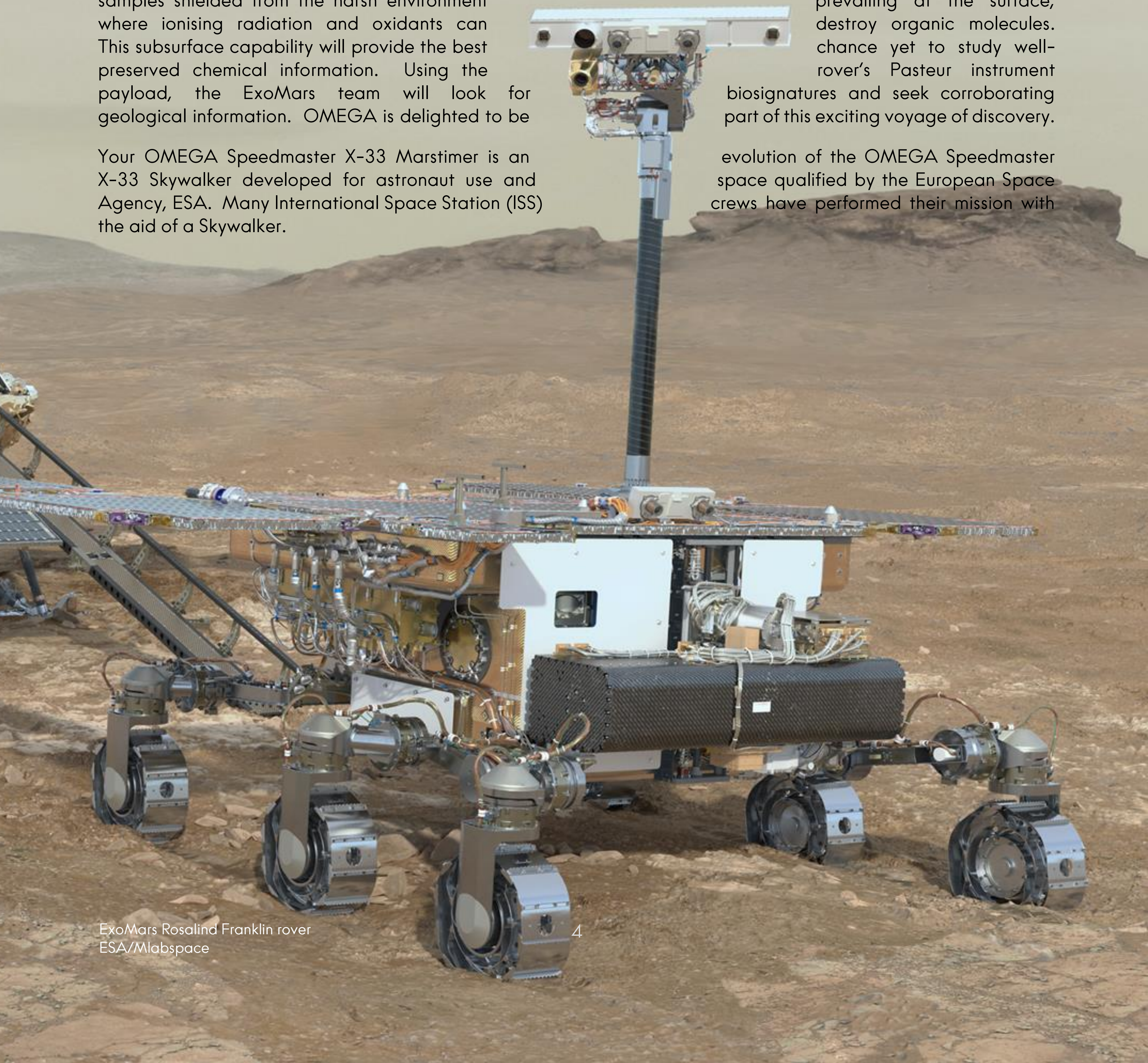
This precision tool implements special functions for conducting Mars surface operations. More specifically, the OMEGA Speedmaster X-33 Marstimer has been conceived to respond to the needs of scientists and engineers commanding ESA's ExoMars rover.

Conditions on early Mars, some 4 billion years ago, were similar to those when life appeared on the young Earth. This marks the red planet as a primary target to explore for signs of life in our Solar System.

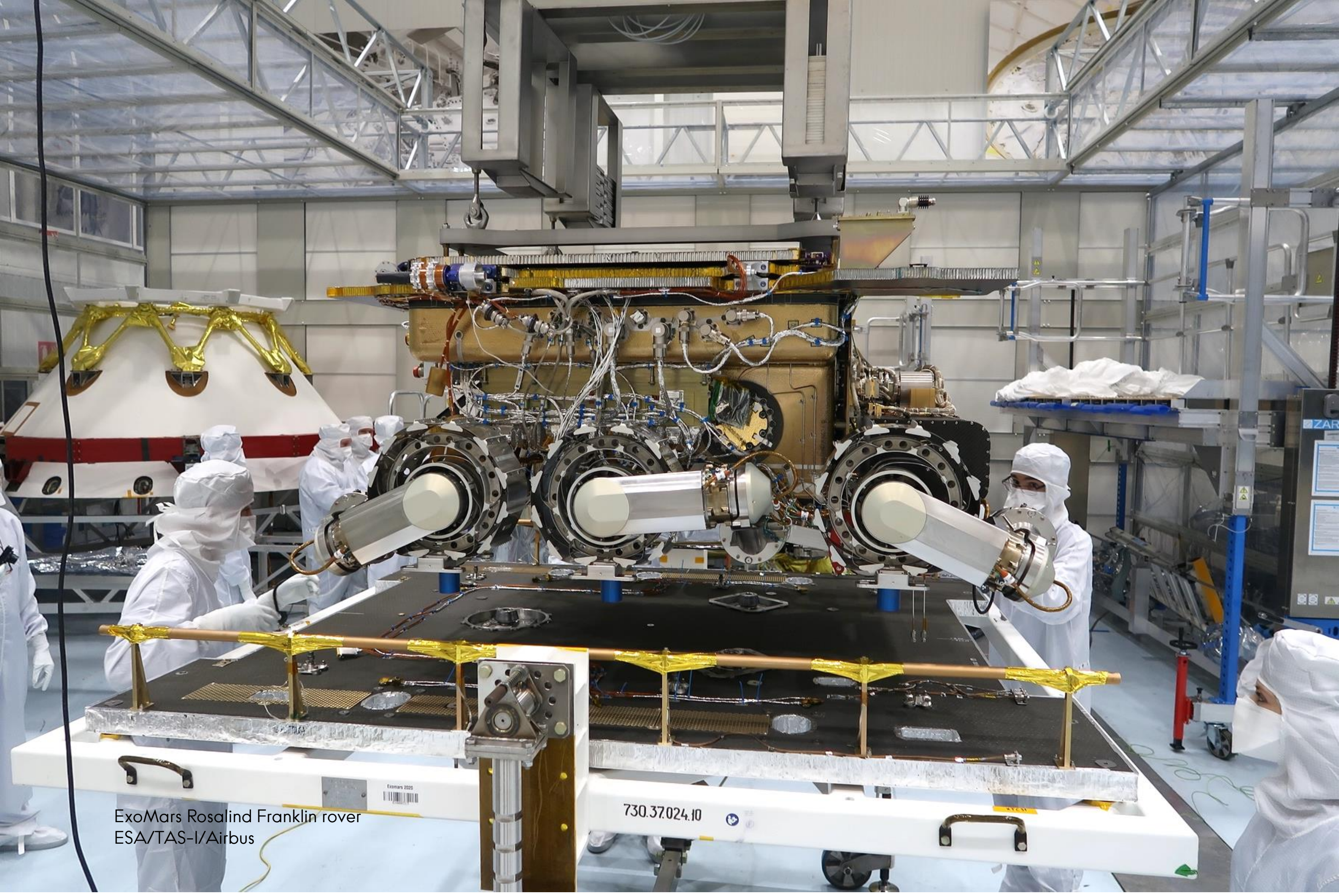
ExoMars will land at Oxia Planum, an ancient location believed to have been habitable in the distant past. The mission will deliver a rover—named after Rosalind Franklin—tasked with seeking traces of extinct life.

For the very first time, we will drill to depths of 2 m to collect and analyse samples shielded from the harsh environment prevailing at the surface, where ionising radiation and oxidants can destroy organic molecules. This subsurface capability will provide the best chance yet to study well-preserved chemical information. Using the rover's Pasteur instrument payload, the ExoMars team will look for biosignatures and seek corroborating geological information. OMEGA is delighted to be part of this exciting voyage of discovery.

Your OMEGA Speedmaster X-33 Marstimer is an evolution of the OMEGA Speedmaster X-33 Skywalker developed for astronaut use and space qualified by the European Space Agency, ESA. Many International Space Station (ISS) crews have performed their mission with the aid of a Skywalker.



ExoMars Rosalind Franklin rover
ESA/Mlabspace




ExoMars Rosalind Franklin rover
ESA/TAS-I/Airbus

# THIS MANUAL

Your OMEGA Speedmaster X-33 Marstimer is a surface exploration tool. Its functions require that you understand and become familiar with several planetary physics concepts. Please do not rush. Savour the complexity and density of the material presented. Invest the time necessary to master the various topics and you will be able to enjoy your watch to its full potential, which is considerable.

The first sections of this manual deal with relatively well-known Earth time zones; thereafter, they become slightly more technical to address Mars modes, and more specialised still when treating accurate solar navigation. We have included many information-rich diagrams. Please study them carefully. Examples illustrate how the various quantities are calculated, and how the associated functions are programmed and utilised. Some will require work on your part.

Once familiar with your watch, you will possess a powerful timepiece to help you through your daily tasks—whether at the office, the laboratory, on trips, the space station, or Mars.

# DESCRIPTION

Your OMEGA Speedmaster X-33 Marstimer is driven by the high-accuracy, thermally compensated OMEGA calibre 5622 movement. This 45-mm-diameter watch case has been crafted from lightweight, brushed grade 2 titanium. The matching bracelet incorporates two rows of brushed grade 5 titanium links to highlight a well-known Speedmaster design code. The bezel's aluminium alloy insert has been anodized with an oxalic acid solution to improve its hardness and durability. During the bezel manufacturing process, a colouring treatment was used to match the colour of the nanocrystalline red hematite fine layer that gives the surface of Mars its characteristic pale orange hue. The bezel features a numerical scale designed to facilitate the use of the solar compass. A scratch-resistant sapphire crystal, with anti-reflective coating on both sides, protects the jet-black dial and liquid crystal display (LCD) panel. When in low-light conditions, it is possible to manually engage an electroluminescent backlight function for reading the display information. Additionally, the hour and minute hands, as well as the hour markers, and bezel scales are coated with Super-LumiNova, a strontium aluminate photoluminescent pigment. The watch face has an ergonomical, clutter-free design. The layout of the digital numerals and minute markers allow an effortless visual management of the data that this timepiece can provide.



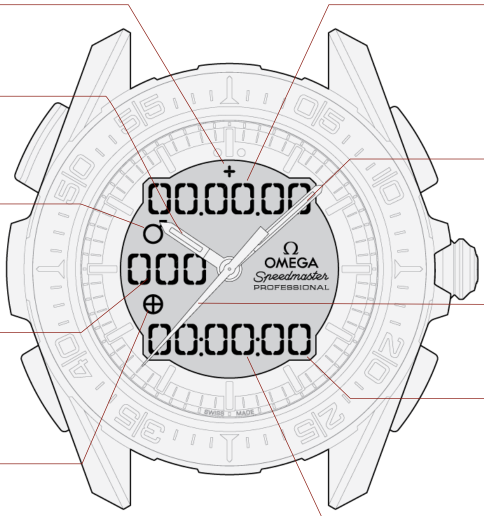
Arsia and Pavonis Mons volcanoes
ESA/DLR, Mars Express, HRSC

The caseback acts as a Hemoltz resonance cavity in order to implement a powerful alarm having low energy consumption. Its 80-dB level at 10 cm distance is an astronaut requirement. Since there is no convection in microgravity, numerous fans are needed to ensure good air circulation and avoid stagnation pockets, where humidity or impurities might collect. As a result, the ISS and most capsules can be pretty loud environments. Your watch alarms are set to be heard above the din of operating equipment.

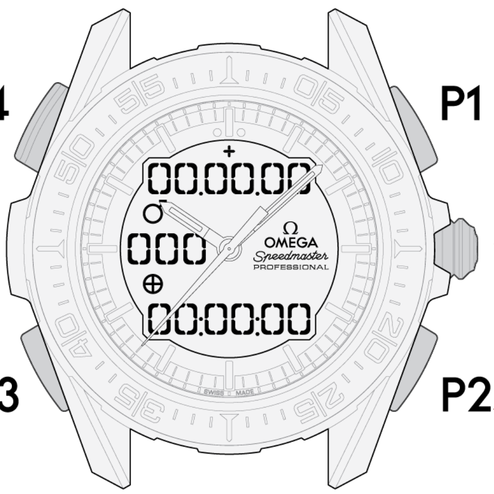
Your OMEGA Speedmaster X-33 Marstimer has been designed to cope with astronaut operations, which can include high acceleration, mechanical shock, low pressure, vacuum, a wide range of temperatures, and emergency procedures, such as pilot seat ejection and water immersion.


Dust on solar panels
NASA, Spirit rover

# ALPHANUMERIC DISPLAY




# PUSHERS AND CROWN




Press once

Press twice

Press and hold
(~ 3 seconds)

# FUNCTIONS

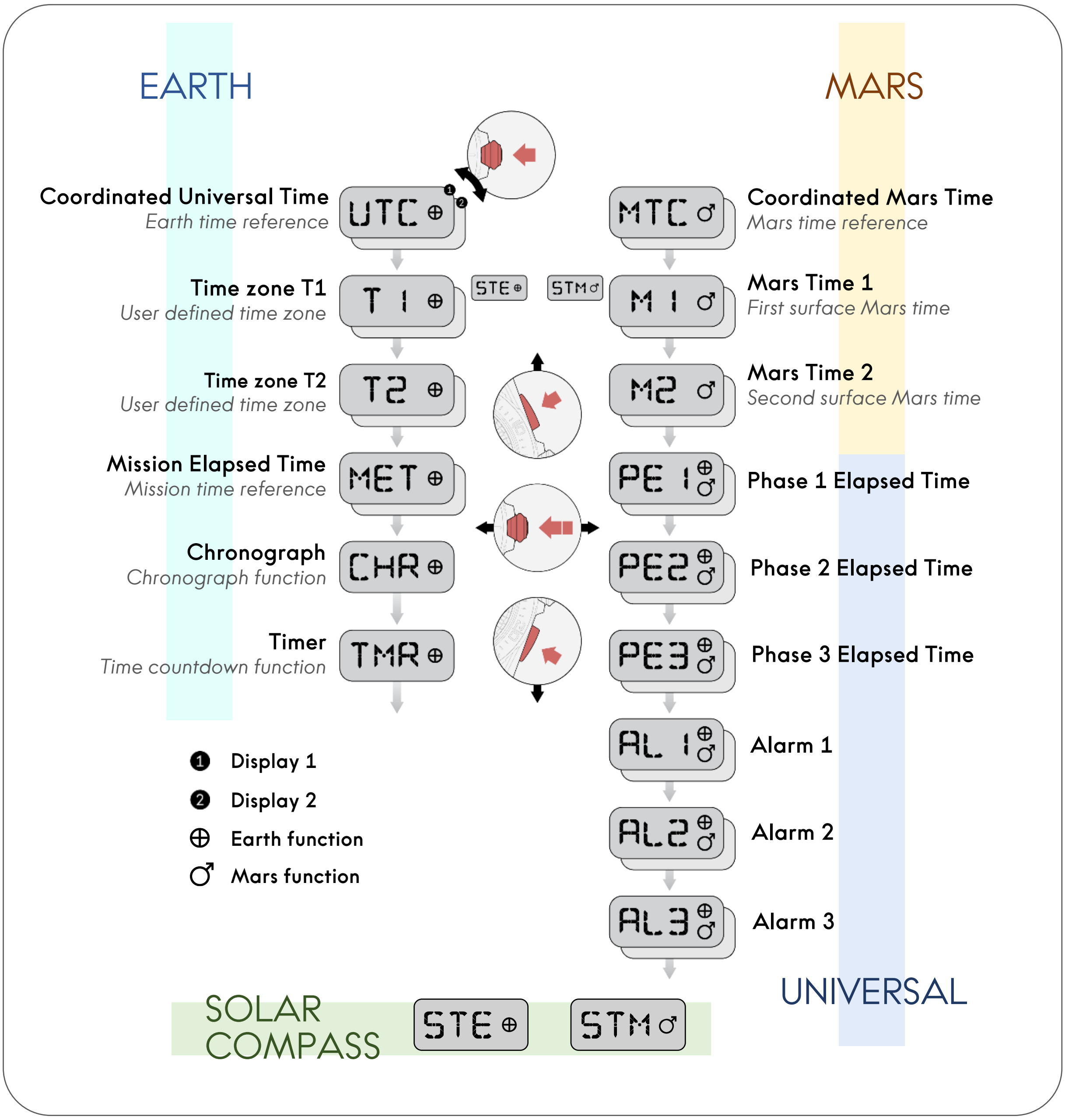
The OMEGA Speedmaster X-33 Marstimer functions are separated into **two groups**.

- **Earth** functions can be found in **Group 1**.
- **Mars** functions and **Universal** functions are in **Group 2**.
- **Solar Compass** is a special mode that engages several functions.

You can use pushers P1 and P2 to navigate vertically through a group's functions. **Press P2** for the **next function**. **Press P1** for the **previous function**.

**Press and hold the crown** to access the **next group** of functions.

Some functions provide information on two pages. When accessing these functions, you will first see **page 1**. A **short crown press** brings up **page 2**. The display returns to page 1 after 10 s, or by pressing again on the crown.



EARTH

# COORDINATED UNIVERSAL TIME (UTC)

**Coordinated Universal Time** (UTC) is the standard by which this world regulates clocks and time. It is never adjusted for daylight saving time and therefore can be used as a time reference always and everywhere, whether on Earth or in deep space.

Most space mission events are designated using UTC time stamps. To ensure there is no confusion with local time, mission time indications are often followed by a lower case "z". This z stands for Zulu Time Zone, a military time zone that coincides with UTC+0. For example, the ExoMars 2016 first Mission Operations Report reads: ***"The launch took place nominally at 09:31:42z."***

The official abbreviation for Coordinated Universal Time (UTC) came about as a compromise between English and French speakers:

- *Coordinated Universal Time* in English would normally be abbreviated CUT.
- *Temps Universel Coordonné* in French would typically be abbreviated TUC.

The International Telecommunication Union (ITU) and the International Astronomical Union (IAU) wished to minimize confusion. They hence mandated that a single abbreviation be used in all languages: UTC.

## UTC USES

### In Space:

The timing of all activities whose execution need not occur at a specific moment in the local day/night cycle can best be designated with Coordinated Universal Time.

For example, the orbital period of the International Space Station (ISS) at 400 km altitude is approximately 92 minutes. It would not be practical for astronauts to agree on how to share the physical exercise machines utilising the ~90-min "ISS day" as reference; therefore, they employ UTC. Likewise, on deep space missions, like ESA's Bepi Colombo traveling to Mercury, all critical events are exercised using UTC.

### On Earth:

In the ExoMars project we often need to set up teleconferences with colleagues in Europe, Russia, and on both coasts of North America. It would be tedious to have to inform every participant of when the event will take place in their local time. Instead, we can specify that a teleconference is scheduled to start at 14:00 UTC and everyone can work out what time that will be at their place.

If you have work colleagues or family based in other time zones, try setting up your next call or teleconference in terms of UTC.

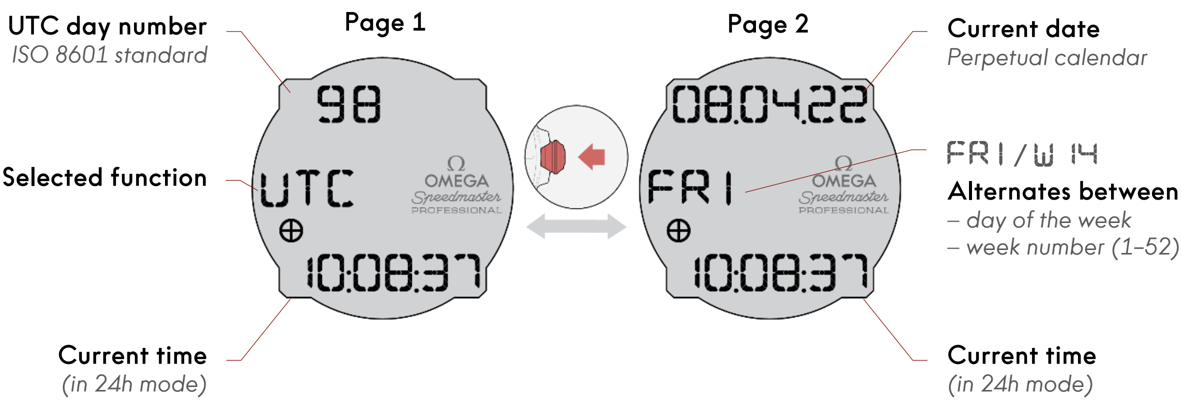
Other uses: UTC is the time standard employed in aviation for flight plans and air traffic control clearances. Weather forecasts and weather maps all use UTC to avoid confusion about time zones and daylight-saving time. Finally, amateur radio operators often schedule their contacts in UTC because transmissions at low frequencies can be picked up across many time zones.

ExoMars 2016, ESA-Stephane Corvaja

# UTC DISPLAY

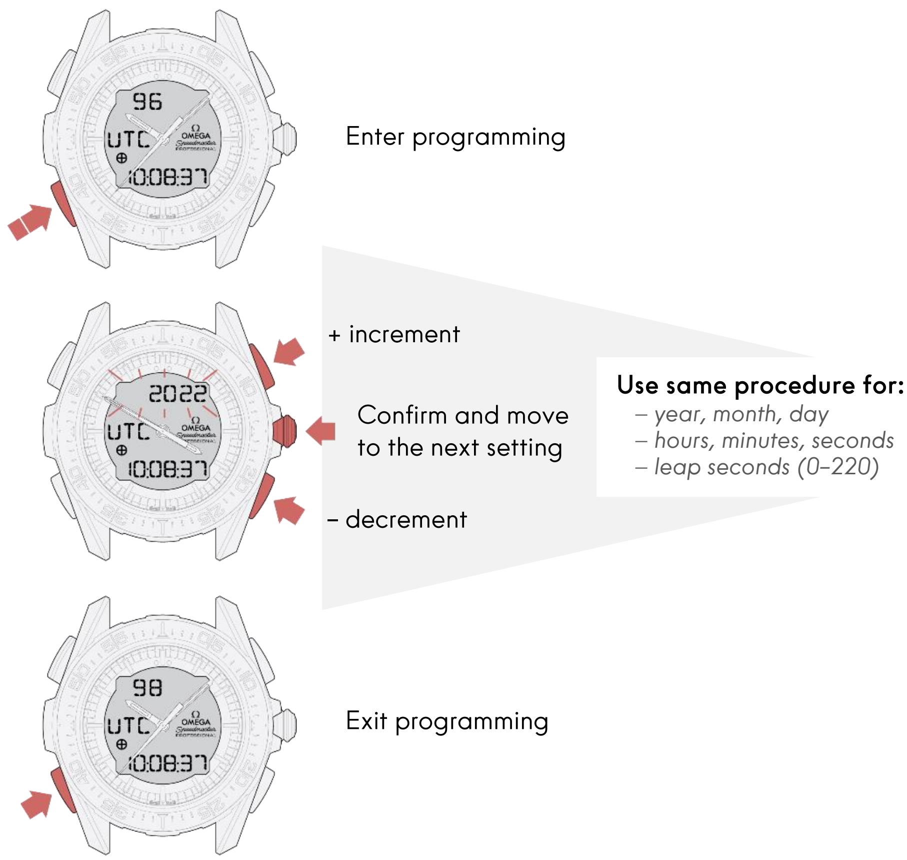
**UTC must be programmed first** as it is the time base utilised by all the other watch functions.

The UTC function presents information on two pages.




# UTC PROGRAMMING

Please navigate to the **UTC** function.



# PRECISION TIMING OF UTC AND ACCURACY

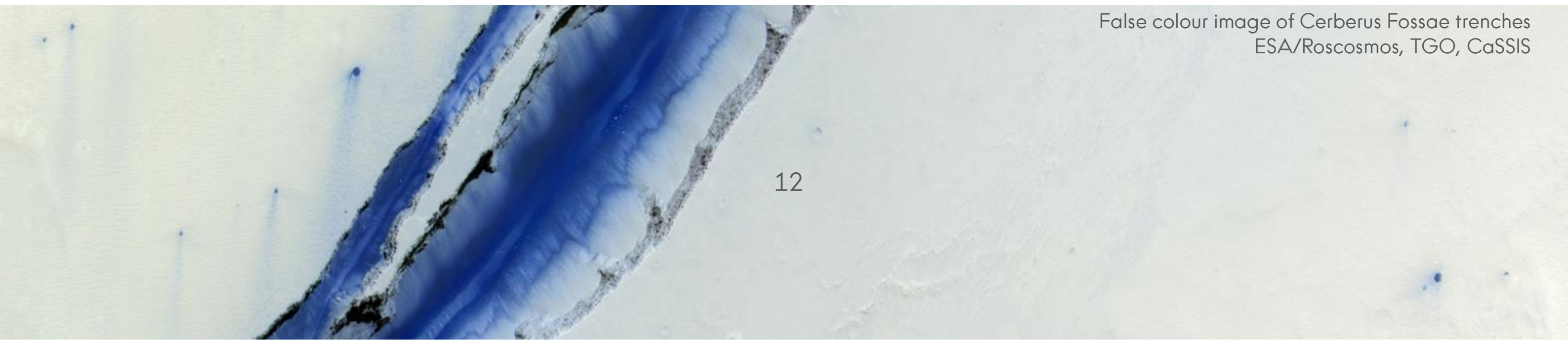
The foundation of the OMEGA Speedmaster X-33 Marstimer is the UTC time base. An internal microcontroller runs the complex mathematical algorithms required to implement all celestial mechanics functions.

Let us now explore 1) how to match the timing output of a mission control computer, or an atomic clock, to within 1 s, and 2) for how long you can expect this synchronisation to remain valid.

## Timing UTC

To achieve our first objective, it is important to programme UTC with sub-second precision. That is, be able to synchronise the beginning of the seconds count on your watch as close as possible with that of the reference clock. Hereafter we describe a pragmatic method for achieving this.

1. First, we need a reliable clock reference with 0.1 s accuracy (something that looks like XX:YY:ZZ.Z). For example, **time.is**, on the internet—please note, you need to type "." to get the display with tenths of s.
2. Next, we must concentrate on getting the seconds right. We will worry about the other quantities later. Please navigate to UTC. A long P3 press will put your watch in programming mode. Using P1, P2, and the crown, assign values to year, month, date, hours, and minutes.
3. Once you get to the seconds, you will see them ticking forward. Use P1 & P2 to assign a value; for example, 00. The seconds count has now stopped at 00.
4. We will now use a simple method employed by musicians to time rhythm and beat delays. You must find a way to hold the watch that is comfortable for what comes next. We suggest the following: If you are right-handed, keep the top band and watch back in your left hand. Place your right hand's thumb on the P3 pusher and your index on the crown.
5. Get close to the reference clock so that you can see both the reference time and your watch's display. The idea is to be able to press the P3 pusher to exit programming at the exact right moment. We will assume a 0.1 s delay between when you want to press P3 and when it is engaged—this is fairly typical for most people.
6. Look for the moment when the reference's decimal seconds reading is 9 and start marking a 1-s beat with your thumb on top of the P3 pusher (do not press). Continue. Wait until the reference clock's seconds count becomes 59.9 to fully press P3. If you timed it right, your watch's seconds count will be synchronised with that on the reference clock. You should see them cycle simultaneously to a new second.
7. Most probably you will have to repeat this a few times until you get it to work. By then the minutes count may be off. No problem. Go back to programming mode and set the correct value for the minutes. Exit with P3.

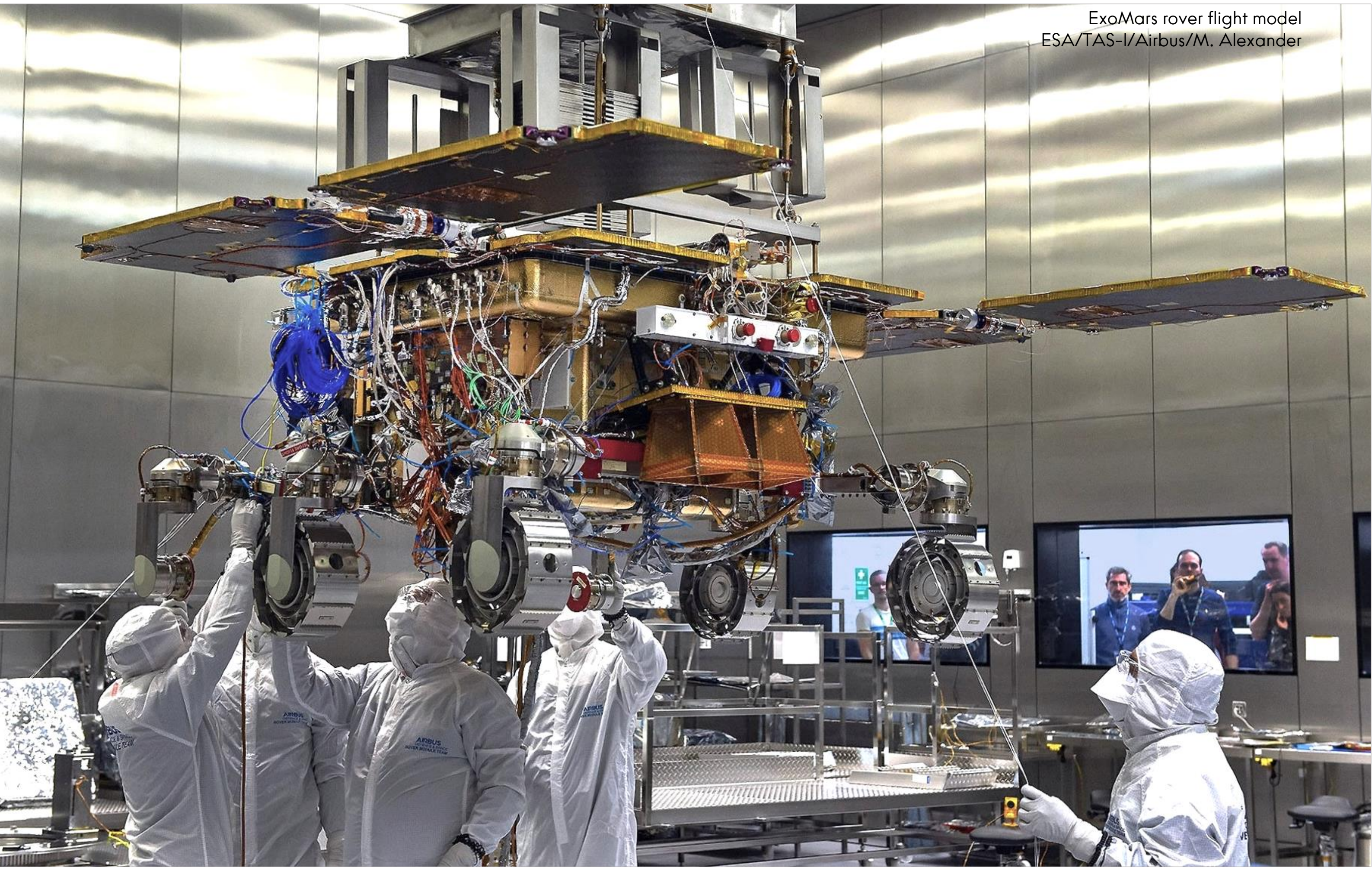


False colour image of Cerberus Fossae trenches
ESA/Roscosmos, TGO, CaSSIS

# LEAP SECONDS

A **leap second** is a one-second adjustment occasionally applied by the International Earth Rotation and Reference Systems Service (IERS) to ensure that UTC remains close to the mean solar time at the 0° meridian. This time modification is needed to compensate for the very gradual slowdown of the Earth's rotational speed, mainly resulting from tidally induced energy dissipation in the planet's body and oceans. UTC was introduced on 1 Jan 1972, initially with a 10-second lag behind International Atomic Time (TAI). Since then, 27 additional leap seconds have been inserted, the most recent one on 31 Dec 2016 at 23:59:60 UTC. As of 2020, UTC trails behind TAI by 37 seconds.

Please navigate to the appropriate leap seconds setting on the UTC function and programme in the required total number of leap seconds in the range 0–220. Once you confirm, this information will be propagated to all watch functions. At the moment, this value should be 37 s. Once a new correction becomes necessary, it will become 38 s, and so on.

ExoMars rover flight model
ESA/TAS-I/Airbus/M. Alexander

EARTH

# EARTH TIME ZONES (T1 & T2)

T1 and T2 are user-selected time zones defined as time differences relative to UTC.

UTC must be programmed first; only thereafter can you assign values to T1 and T2.

Please note: The **hands** on your watch **always display T1 time**. There are exceptions to this, but they require special manipulations to engage them. We will learn about them later.

## T1 & T2 USES

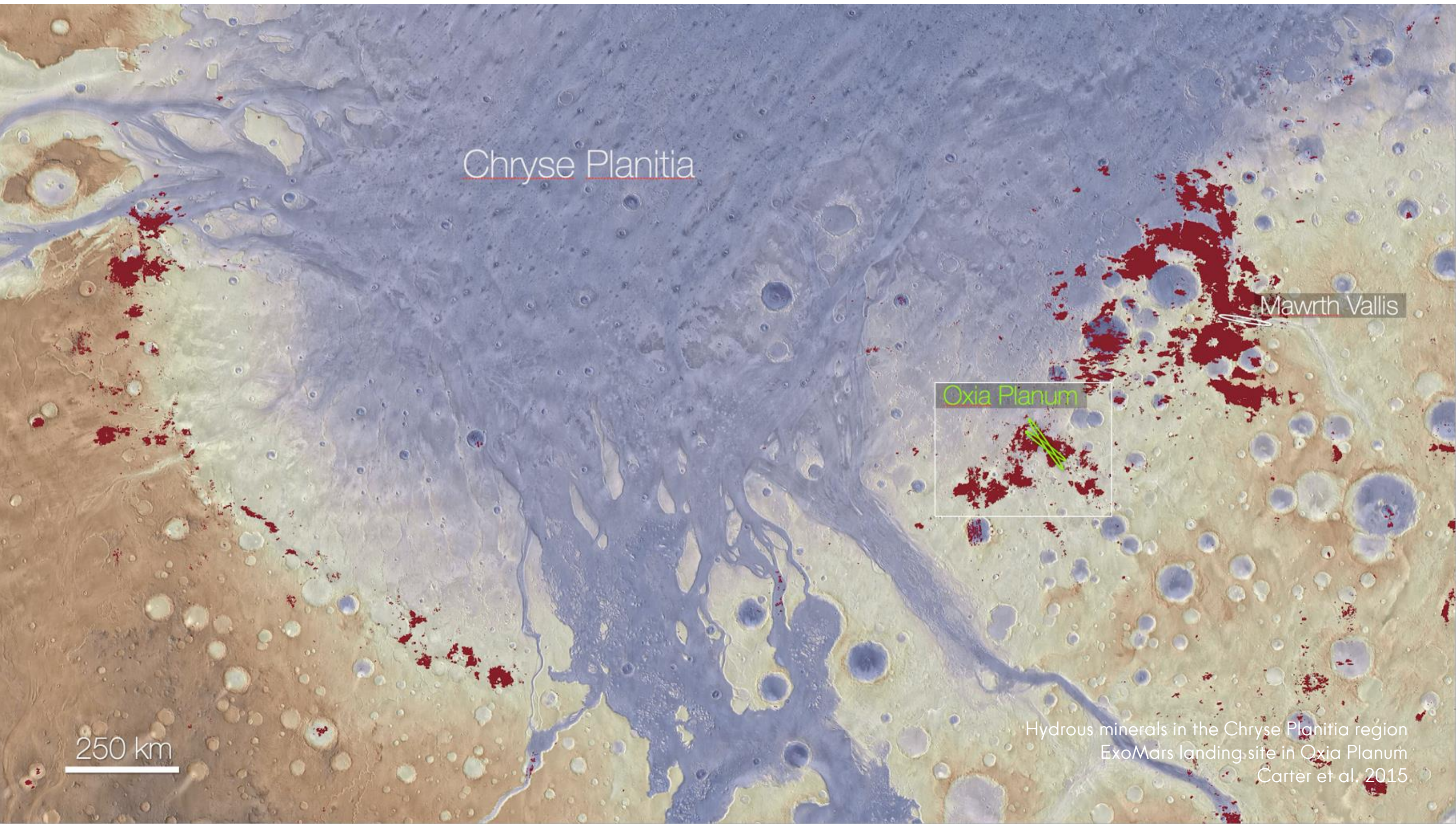
### On Earth:

**T1** should be set to your **local time zone**. You will then be able to determine the time at your current location, both by reading the hands' positions and the numerical display.

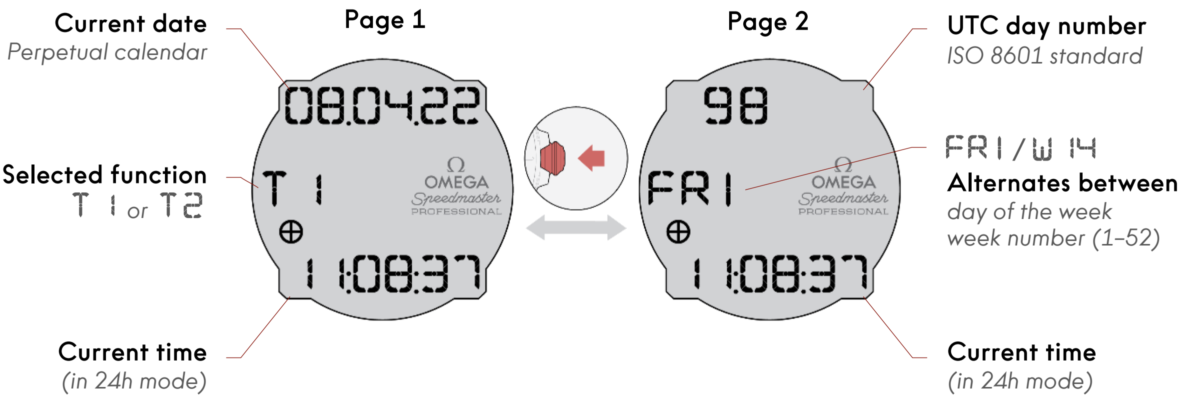
**T2** can be configured to show a **second time zone**. For example, the time zone where your family and friends reside.

### In Space:

For space operations we recommend setting T1 to UTC+0. In this manner, hands and display will both provide UTC information. You can programme T2 to show the time back at home.



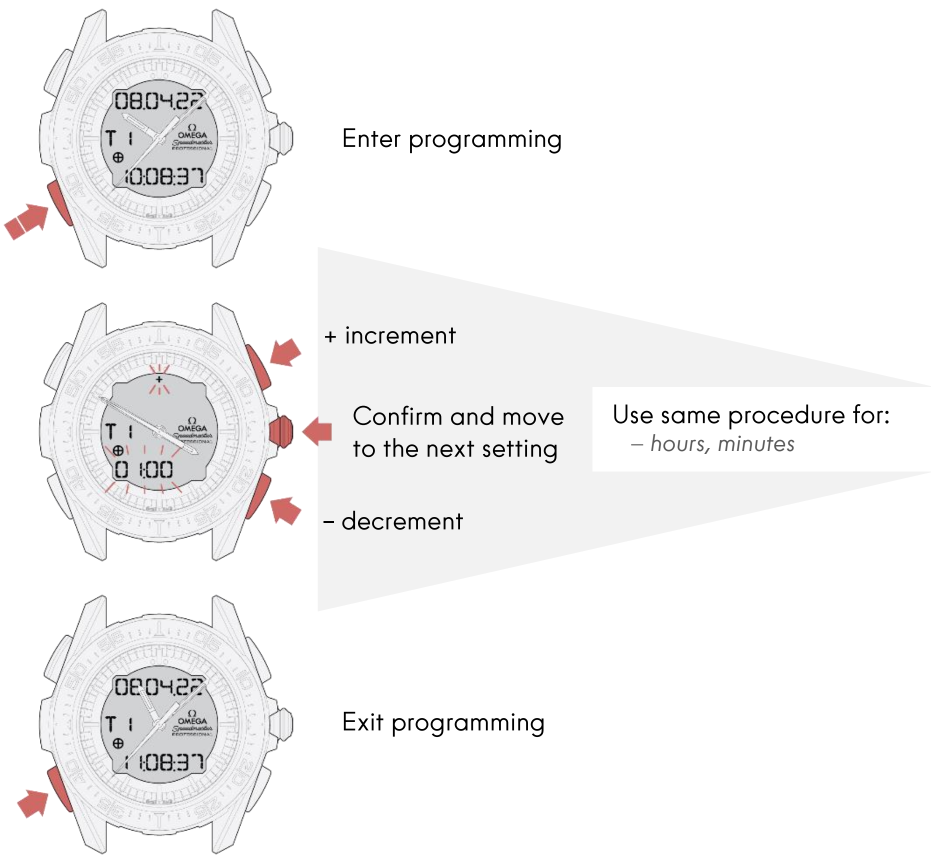
## T1 & T2 DISPLAY




## T1 & T2 PROGRAMMING

During programming, the "+" or "–" sign above the display indicates whether the time zone difference with respect to UTC is positive or negative. It is possible to programme time zone variations in hours (1-hour increments) and minutes (15-min increments).

Please navigate to the **T1** or **T2** functions.

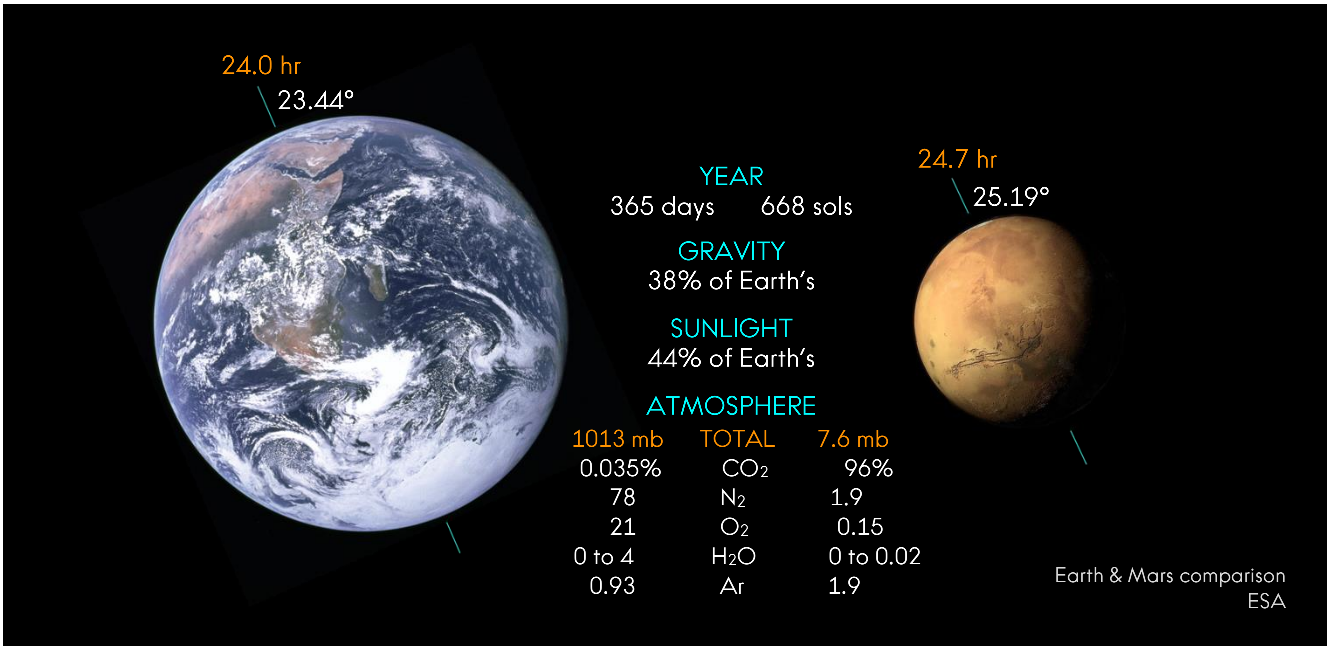


# COORDINATED MARS TIME (MTC)

**Coordinated Mars Time** (abbreviated **MTC**) is a proposed Mars standard analogue to Earth's UTC.

MTC is defined as the mean solar time at Mars' prime meridian (0° longitude), which passes through the centre of the Airy-0 crater, in Terra Meridiani. MTC is sometimes also denoted as Airy Mean Time (AMT).

At present, Mars' axial inclination and rotation period are similar to Earth's. The duration of a Mars solar day (called "sol") is 24 h 39 m 35.244 s (the corresponding value for Earth is 24 h 00 m 00.002 s). Thus, a Mars sol is approximately 2.7% longer than an Earth day. A sol is divided into 24 Mars hours of 60 Mars minutes each.



Earth & Mars comparison
ESA

As on Earth, it is possible to define "Mars time zones" to be exactly 15° wide, centred on successive 15°-multiples of longitude, at 0°, 15°, 30°, etc. By knowing in which Mars time zone a rover or a landmark are located, one can have an idea of the approximate mean solar time there. For example, Olympus Mons, the largest volcano in the Solar System, lies at 133.8°W. If we divide this value by 15°, we obtain 8.9. Hence, an astronaut standing on the rim of the Olympus Mons caldera could set his or her watch to Mars time zone MTC–9 (that is, nine hours ahead of MTC).

MTC-based time zones have yet to be employed for Mars time keeping, but this may change in the near future.

Another important piece of knowledge for Mars missions is date; or more accurately, Mars' position in its orbit around the Sun. On Earth we use the well-known 365-day calendar consisting of 12 months. A martian year, however, is 668.599 sols long.

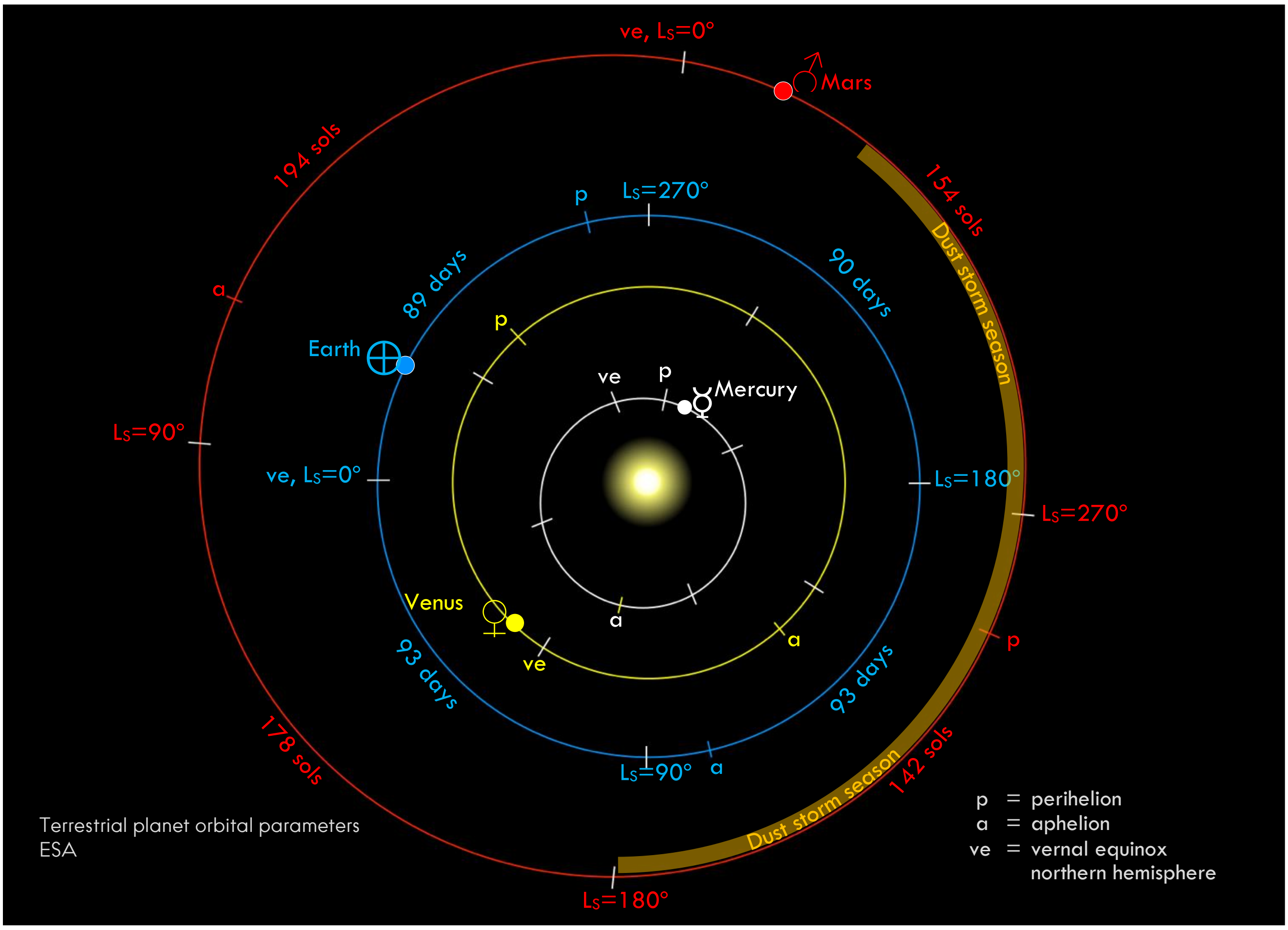
Whereas an Earth year can be divided into 52 seven-day weeks, a Mars year spans 95 seven-sol weeks.

Since no martian months have been agreed yet, scientists use Solar Longitude ($L_S$) to mark the passage of time within a Mars year. $L_S$ is the parameter that describes a planet's position in its orbital motion around the sun. It therefore constitutes the most accurate astronomical date.

For all planets, seasons begin at 90° $L_S$ intervals, on equinoxes and solstices.

| Solar Longitude ($L_S$) | Northern Hemisphere | | Southern Hemisphere | |
|---|---|---|---|---|
| 0° | vernal equinox | spring | autumnal equinox | autumn |
| 90° | summer solstice | summer | winter solstice | winter |
| 180° | autumnal equinox | autumn | vernal equinox | spring |
| 270° | winter solstice | winter | summer solstice | summer |

As we can see in the graph below, because Mars' orbit has higher eccentricity than Earth's (it is more elliptical), the seasons are not of equal length. Aphelion (a), the distance furthest from the Sun (249 million km), where Mars travels slowest, occurs at $L_S$ = 70°. Perihelion (p), the point closest to the Sun (207 million km), when Mars moves fastest, happens at $L_S$ = 250°. The near coincidence of aphelion with the northern summer solstice results in a temperate northern hemisphere climate—where ExoMars will land. The southern hemisphere, on the other hand, has short and relatively hot summers, but winters are long and very cold. The period during which Mars dust storms are most likely to occur begins at $L_S$ = 180° and ends at around $L_S$ = 325°. This is a critical time for missions that rely on solar panels for obtaining electrical energy, as dust uplifted into the atmosphere during a storm can obscure sunlight for weeks. Global scale dust storms are relatively rare, but their atmospheric effects can last for months—the last ones occurred in 2001, 2007, and 2018.



Terrestrial planet orbital parameters
ESA

The martian New Year (sol 1) is defined to coincide with the northern hemisphere vernal equinox, at $L_S$ = 0°. Thereafter, the year sol count increases by one at each successive local midnight transit.

We next discuss how we make assignments for the martian day of the week. For timekeeping purposes on Earth, astronomers use Julian date (JD)—a continuous, sequential count of the number of days starting with day 0 at noon UTC on Monday, 1 Jan 4713 BC. The equivalent for Mars is the Mars Sol Date (MSD), which provides a running count of sols since noon MTC on 29 Dec 1873. The watch assumes that MSD=0 occurred on a martian Monday and propagates the sols of the week since then to the present.

## MTC USES

### On Mars:

The MTC function on your watch provides a useful overview of Mars' orbital status. It displays the sol date, the season (solar longitude), and the time at the prime meridian.

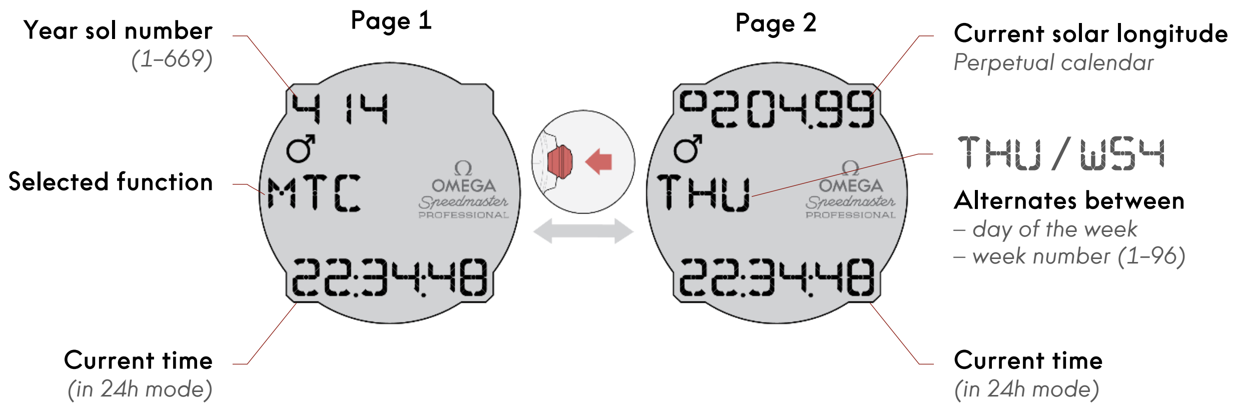
Although in principle it would be possible to synchronise Mars activities using MTC, in reality, since most actions performed on or near Mars are commanded from Earth, UTC is usually employed by ground control instead. However, MTC constitutes a practical time basis for calculating mean solar time at different locations on the martian surface (please see also M1 and M2 functions).

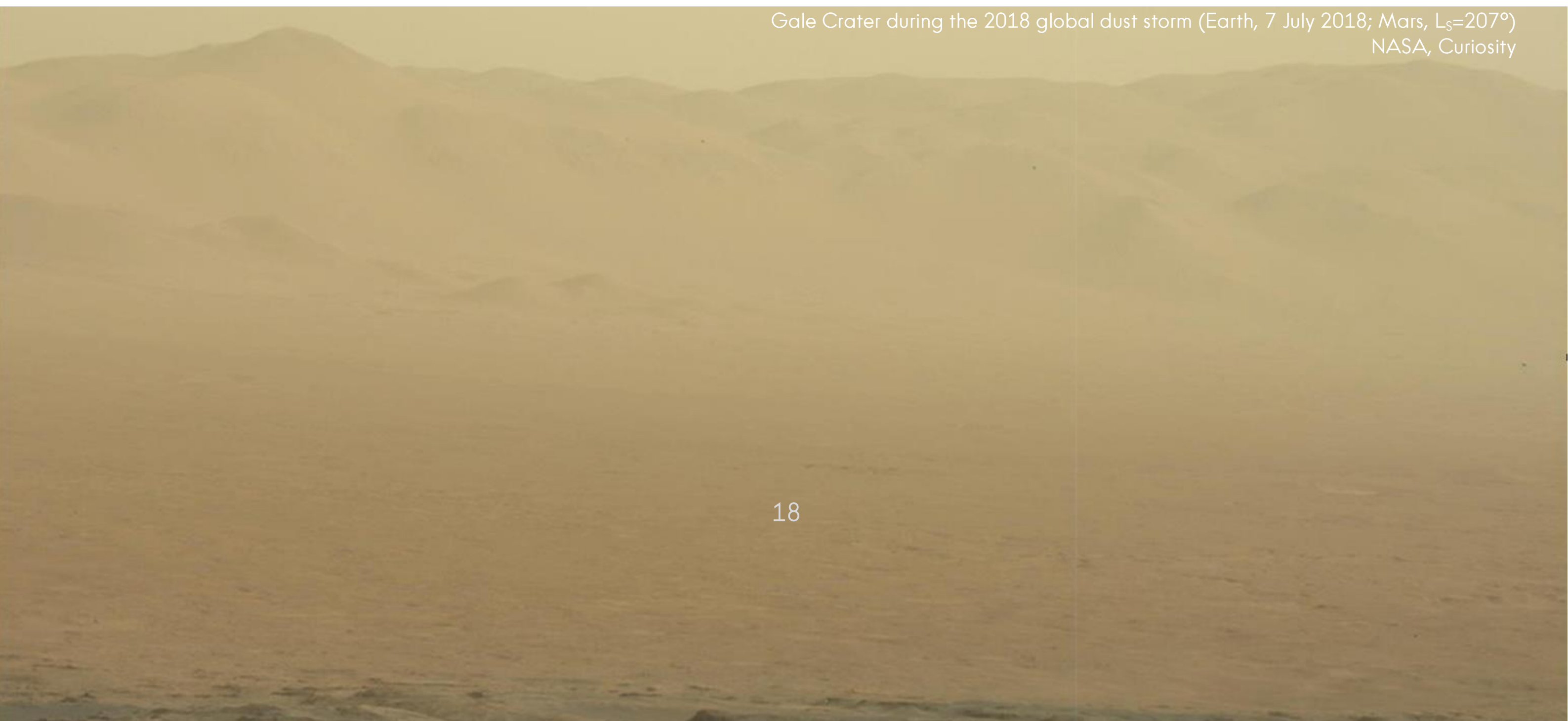
### On Earth:

As has been the case on all previous Mars surface missions, the Rosalind Franklin operations team will also begin their activities working on "Mars time."

## MTC DISPLAY

The MTC function presents information on two pages.





Gale Crater during the 2018 global dust storm (Earth, 7 July 2018; Mars, $L_S$=207°)
NASA, Curiosity

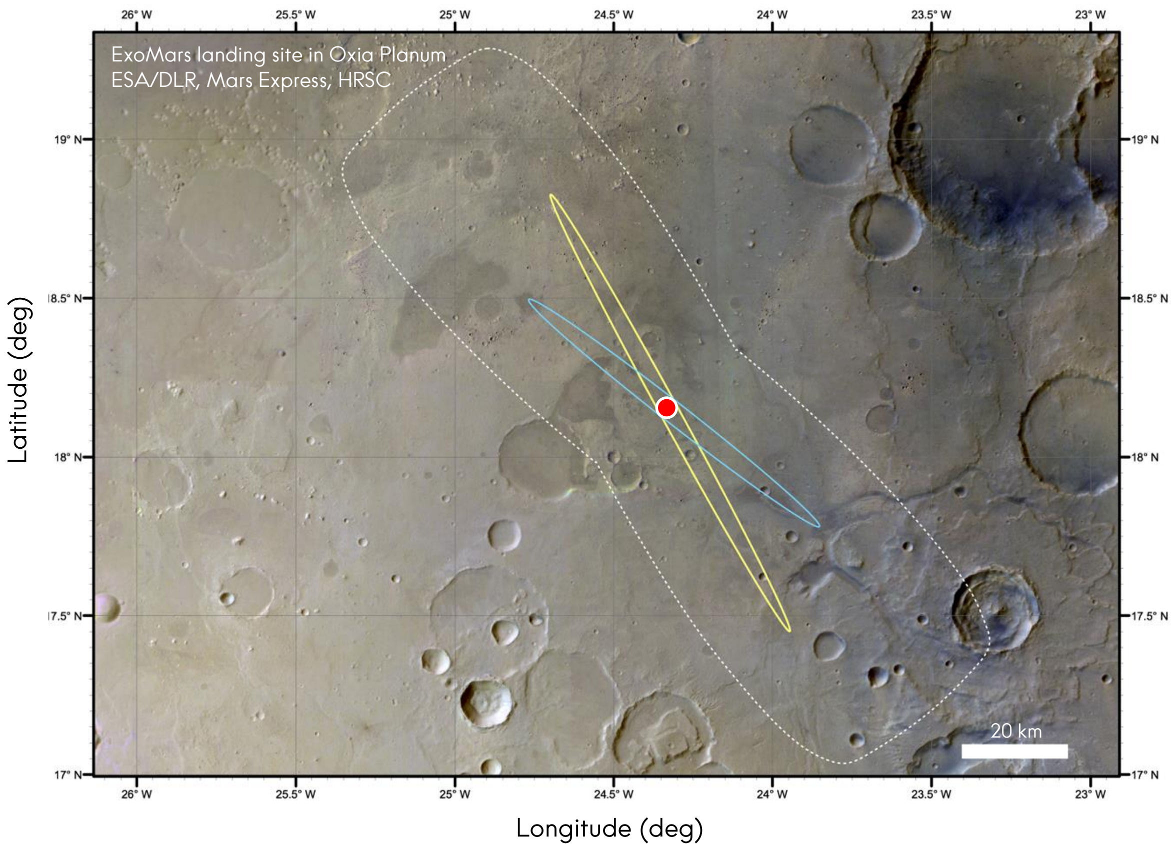
# MARS TIMES (M1 & M2)

**M1** and **M2** report Mars time at **two surface positions**.

Mars missions do not yet set their clocks to time zones. Instead, it is common practice to define "Mars mission time" to be the mean solar time at the intended touchdown location.

However, the effects of unpredictable atmospheric density variations and of winds always cause spacecraft to land several km away from the designated target. In theory, mission control could adjust their timekeeping to correct for this difference; that is, follow the mean solar time at the actual touchdown point rather than at the nominal one. In practice, they almost never do.

The diagram is a map of the ExoMars landing site at Oxia Planum. Depending on when the mission sets, different arrival inclinations are possible. Here, we show uncertainty ellipses (in yellow and blue) centred on a single desired landing point (indicated with a red circle), which has planetographic coordinates 18.159°N, 24.334°W.




We will now calculate the Local Mean Solar Time (LMST) at the centre of the ExoMars landing ellipse.

We start by recalling that MTC is defined as the mean solar time at 0° longitude (the Mars prime meridian). Since the landing site lies at 24.334°W, the mean solar time there will be advanced (be earlier) relative to MTC; thus, we will need to apply a negative offset. Landmarks due east of the prime meridian require a positive offset.

The LMST for a given planetographic longitude, $\Lambda_{pg}$, in degrees west, is: $\text{LMST} = \text{MTC} - \Lambda_{pg}\,(24\text{ h} / 360°)$.

Therefore, $\text{LMST}_{\text{ExoMars}} = \text{MTC} - (24.334° \times 24\text{ h} / 360°) = \text{MTC} - 1.622\text{ h} = \text{MTC} - 1\text{ h }37\text{ m }20.1\text{ s}$.

# M1 & M2 USES

## On Mars:

Please set **M1** to be your **local Mars time**. The hands of your watch will display T1.

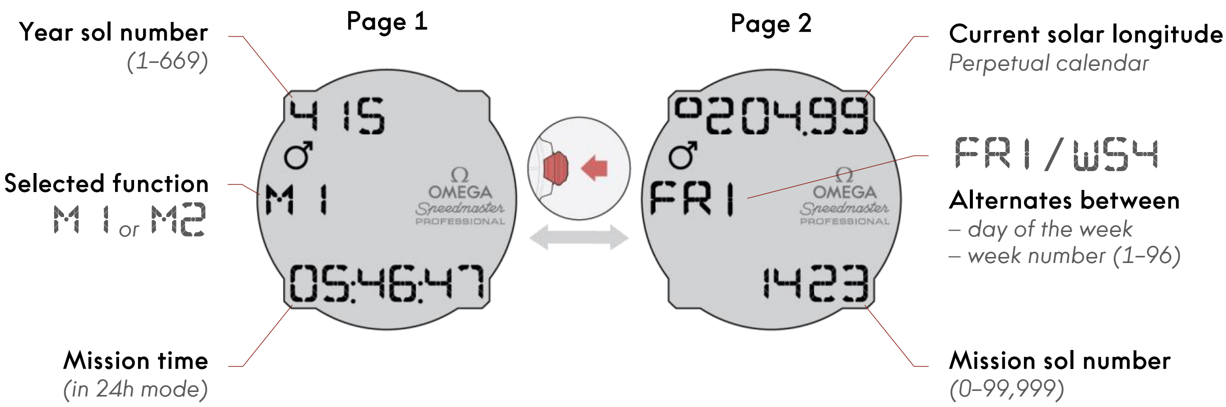
It is possible to have the hands report M1—press twice on pusher P2; repeat to make the hands go back to T1.

**M2** can be configured to show a **second Mars time**. For example, that of another mission.

## On Earth:

Members of the ExoMars operations team will set **M1** to follow the mission clock.

# M1 & M2 DISPLAY




# M1 & M2 PROGRAMMING

M1 and M2 are intended to be Mars mission functions. To programme them correctly you must specify three input parameters: landing site longitude, landing date, and the applicable number of leap seconds.

- To set **Mission Time**, you must first input the **planetocentric longitude**, $\Lambda_{pc}$ in degrees east for the site chosen by the project team to define their mission clock. In most cases this will be the designated touchdown point, rather than the actual landing location. Reference values for most active Mars missions are provided at the end of this manual.

  On Earth, we are familiar with *planetographic coordinates*. Longitude is defined in degrees west (–180° to 0°) or east (0° to +180°) with respect to the prime meridian. For Mars, however, the most widely used standard to specify locations is *planetocentric coordinates*. The 1970 International Astronomical Union (IAU) adopted the convention that longitude should increase in the direction of rotation. Thus, for planets rotating directly, like Mars, this results in longitude being measured from 0° to 360° eastward from the prime meridian.

  Configuring local time using a position's longitude provides a great deal of operational flexibility. For example, if ground control were to revise the mission clock, *e.g.*, as a result of the actual touchdown point being elsewhere than initially planned, all you need to do is provide the new longitude and your watch will calculate the correct mean solar time for the new landing location.

  In case you prefer to programme M1 or M2 to work on a given Mars time zone, please specify the corresponding time zone's centre longitude. This is easily calculated:

Let us first programme M1 for the Olympus Mons time zone. We saw previously that Olympus Mons lies on MTC−9. Since every time zone is centred on its respective 15° meridional band, the MTC−9 centre longitude is $\Lambda_{pc}$ = 360° − 9 x 15° = 225.00°E.

We next set M2 to work on the Elysium Mons time zone. This giant volcano can be found at 25.02°N, 147.21°E. As before, 147.21°E / 15° = 9.81, which can be rounded up to 10. Thus, Elysium Mons is in time zone MTC+10. For MTC+10 the correct band longitude is 10 x 15°E. Therefore, $\Lambda pc_{MTC+10}$ = 150.00°E.

It is always possible to check the longitude assigned to M1 or M2 by entering "programming mode".

- To enable **Mission Sol Number**, you must define the **UTC landing date and time**. Use the **P1** and **P2** buttons to specify year, month, day, and time. Your watch will designate the corresponding sol on Mars as "Mission Sol 1", independently of the local landing time. Sol 2 will begin at the landing site's mean solar time 00:00:00 on the subsequent sol.

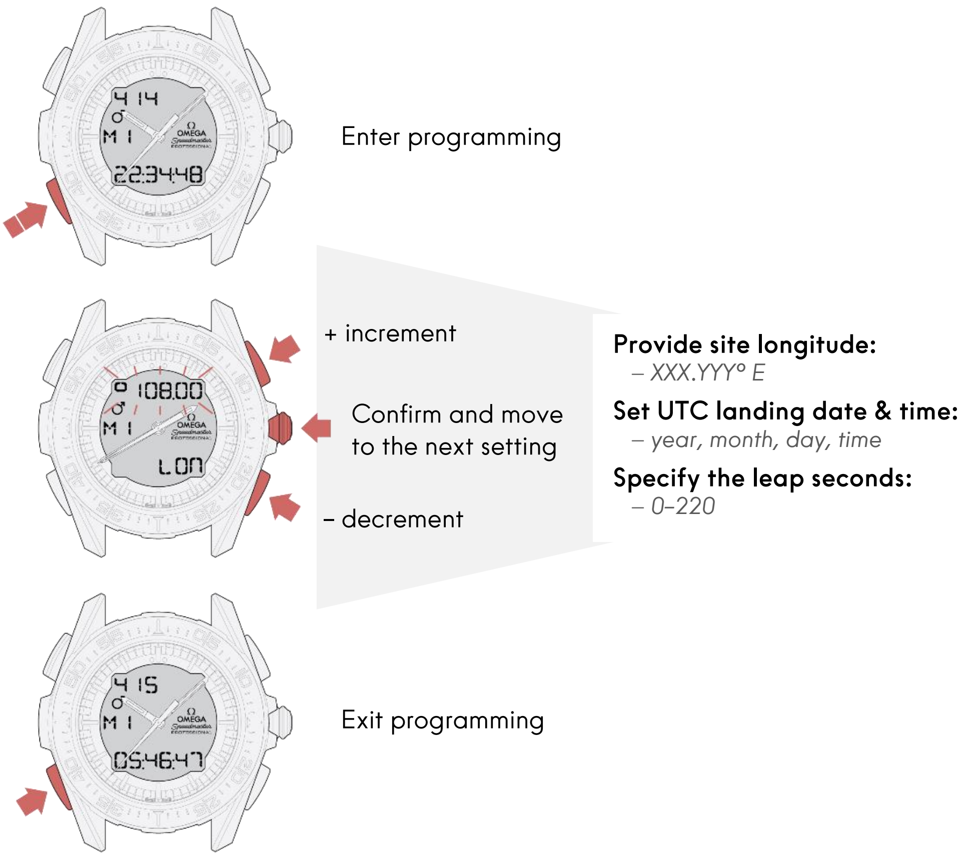
  Some project teams consider their touchdown sol as "Mission Sol 0". For such cases, please increase the UTC landing date you programme into M1 (or M2) by one day.

  You can also choose not to provide a UTC landing date—just "confirm" without any further inputs. The watch will then report the mean solar time at the longitude you have programmed.

- Finally, it is necessary to specify the **UTC leap seconds count at launch**, when the mission clock started, which may differ from the present one. For active missions, this can be found at the end of this manual.

  Important: If you need to adjust a mission's landing site longitude, remember thereafter to also confirm the touchdown UTC date, time, and leap seconds, otherwise the watch will not report mission sol number.

Please navigate to the **M1** or **M2** functions.



# MISSION ELAPSED TIME (MET)

**MET** displays the remaining time (–) until, and elapsed time (+) since, the start of the mission. MET works in Earth days and time, and can be specified using UTC, T1, or T2. Hence, MET is a different kind of time base, one relative to a certain programmed instance or deadline.

This function is very useful, whether on Earth, in space, or Mars.

## MET USES

### On Earth:

MET can be utilised to keep track of the time until, and since, the beginning of an important activity. This can be the initiation and subsequent development of a journey, the submission of an assignment and the period until receiving feedback, etc. For most personal or work-related "missions" you will select T1 (local time) as your reference.

### In space:

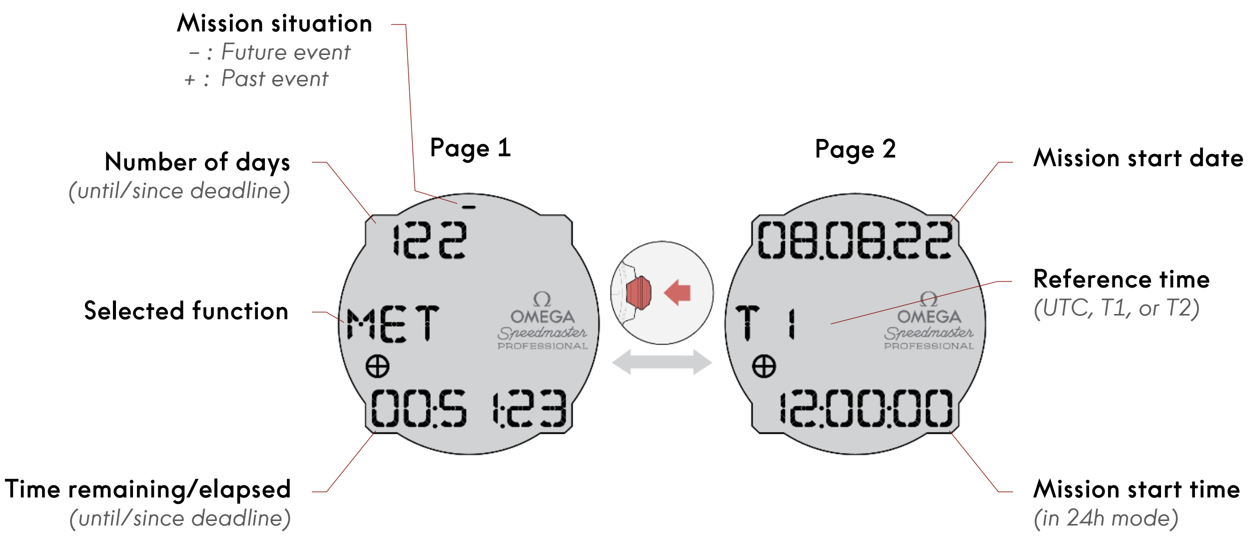
MET is fundamental. Missions are almost always journaled with respect to their launch. As the project team works in triple shift to verify spacecraft systems and software, complete launch campaign tasks, and fuel the rocket, the clock ticks: T–20 days, T–6 days, ... Immediately after takeoff, all mission milestones (*e.g.*, solar panel deployment, upper stage orbital burns and release into interplanetary trajectory) are recorded as T+h, m, s. During cruise, mission duration is tallied as T+XX days since launch.

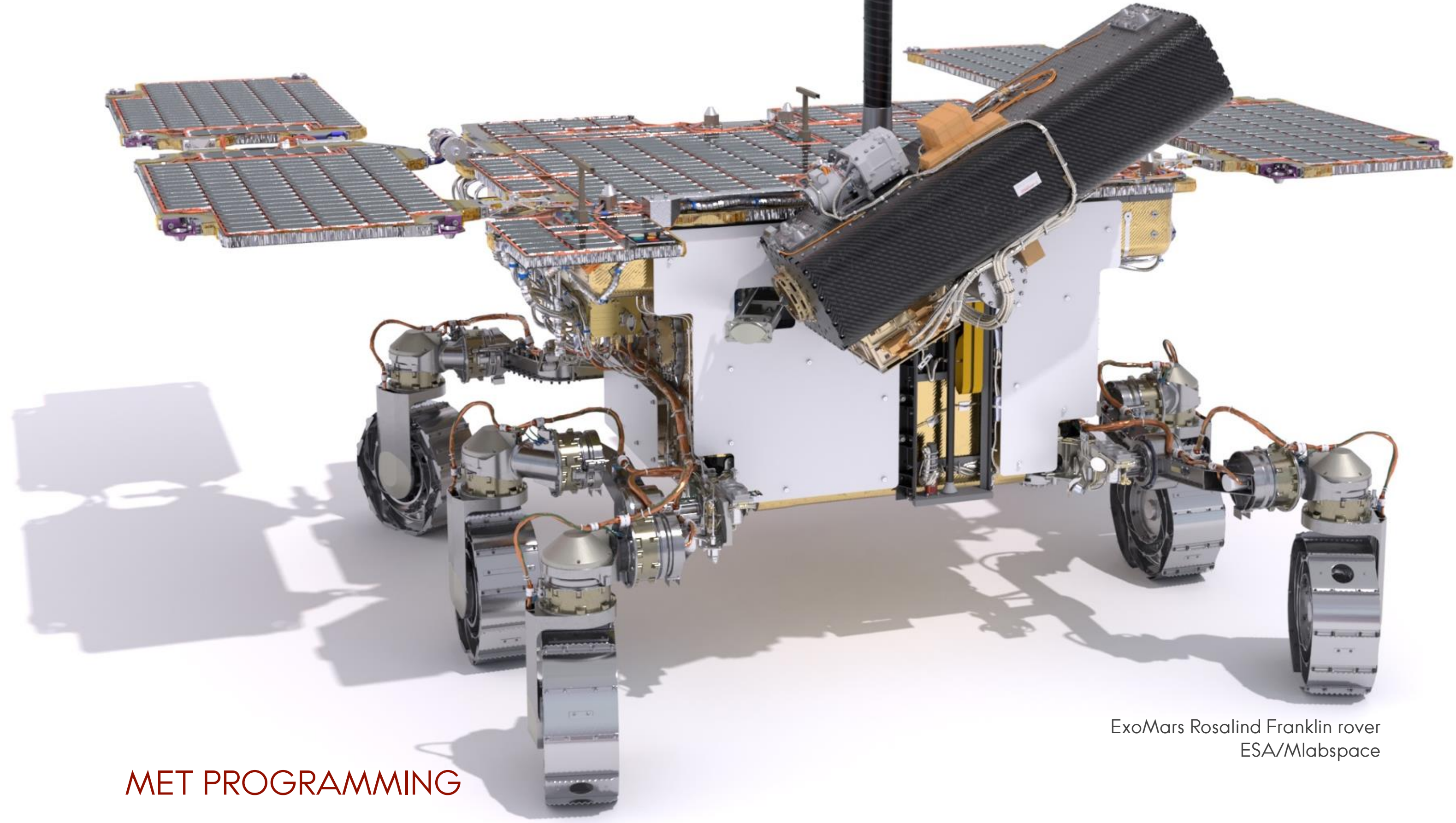
For space missions, please set MET to the launch time and use UTC as reference.

### On Mars:

We have seen how M1 (and M2) can be configured to keep track of mission sol number. This is fine, but you must surely also want to follow your mission in Earth days. Thus, for Mars missions, MET can be programmed with the UTC touchdown time and UTC as reference, to provide essential, complementary information to M1.

## MET DISPLAY



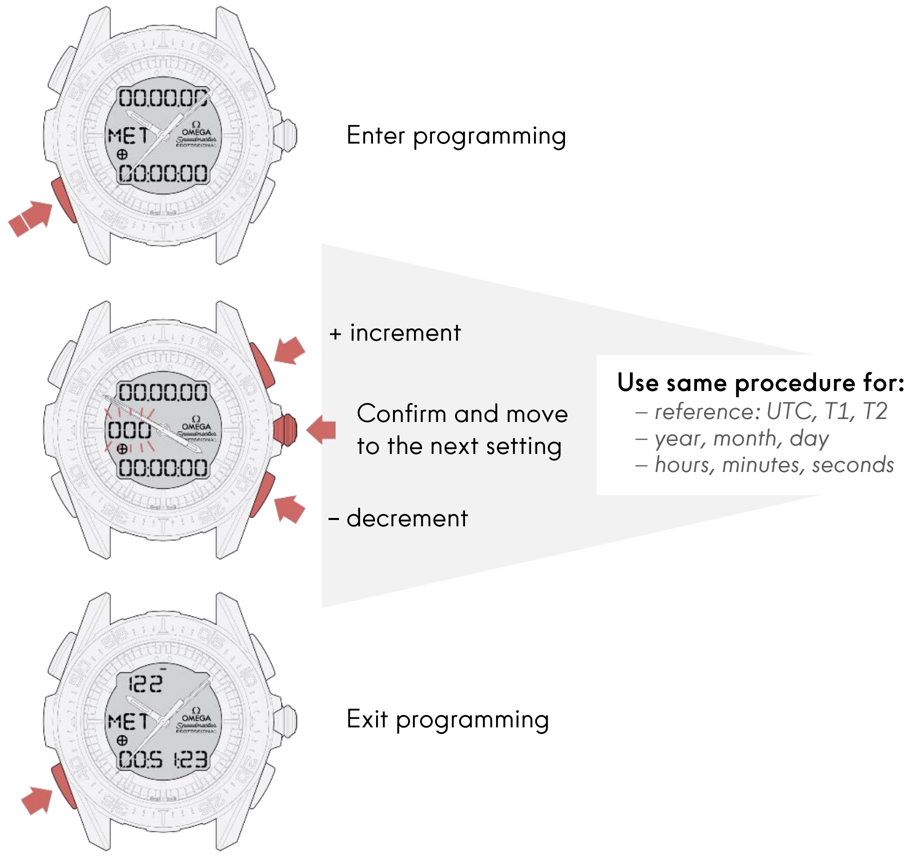


ExoMars Rosalind Franklin rover
ESA/Mlabspace

## MET PROGRAMMING

Please navigate to the **MET** function.

MET can track a maximum countdown time span of 999 days, 23 hours, 59 minutes, and 59 seconds.




Selecting as reference "000" resets the alarm to its factory settings.

UNIVERSAL

# PHASE ELAPSED TIME (PE1, PE2, PE3)

Three phase elapsed time (PET) functions are available, each with its unique chime. **PET** is a special type of alarm reporting the remaining time (–) until, and elapsed time (+) since, an event. PET may be programmed either according to MET (specifying an interval in days and hours since mission start), to a user-defined date and time (in UTC, T1, T2, MTC, M1, M2), or to a Mars solar longitude value (in MLS). "000" resets the alarm to its factory settings.

The PET function allows much flexibility regarding how events are designated. Hereafter, please find a table summarising all input parameters.

| PET Mode | Programming data |
|---|---|
| PET MET | Earth date and time offset compared to the mission time (MET)<br>Note: It is shown in the list of possible PET time bases only if MET is running |
| PET UTC | Earth: Count to and since a UTC date and time |
| PET T1 | Earth: Count to and since a T1 date and time |
| PET T2 | Earth: Count to and since a T2 date and time |
| PET MTC | Mars: Count to and since an MTC sol number and time |
| PET M1 | Mars: Count to and since an M1 sol number and time |
| PET M2 | Mars: Count to and since an M2 sol number and time |
| PET MLS | Mars: Count to and since a Mars solar longitude value |
| PET 000 | Reset alarm. |

## PET USES

### On Earth:

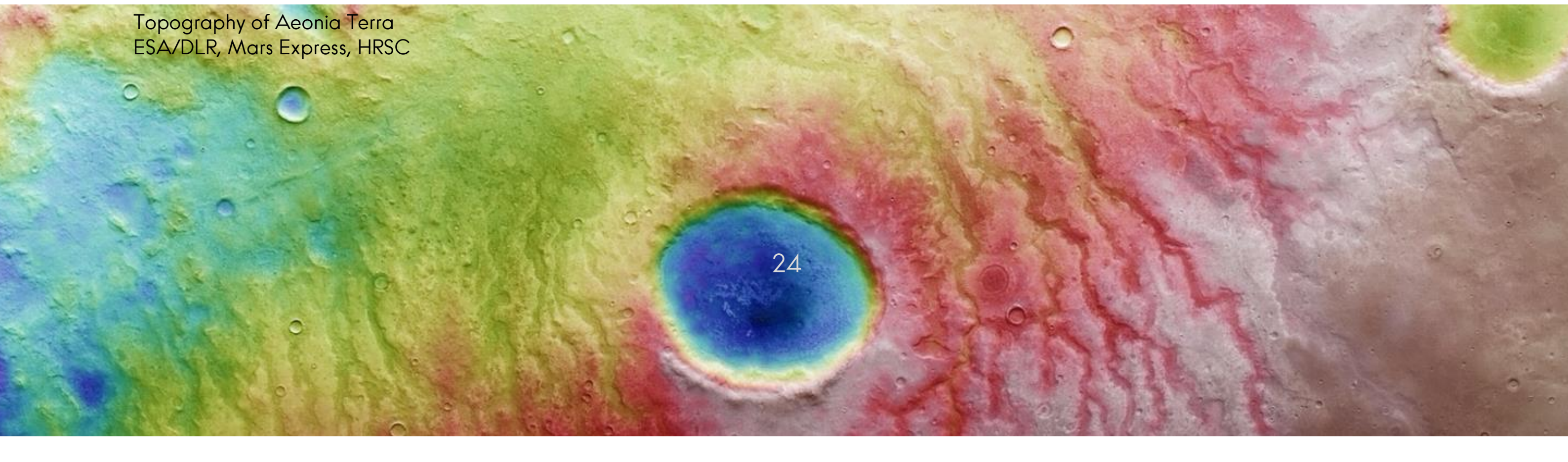
PET can be set to sound an alarm a certain time after the beginning of an important deadline programmed in MET. In this case PET behaves like an alarm relative to another alarm. For example, if I need to prepare a test sample and ship it to an industrial partner on a given date, I can programme this event using MET. I can also be reminded to check that it has arrived safely a week later by setting a seven-day count in PET relative to MET.

For space missions, PET is incredibly useful to count time to and from events specified in terms of mission elapsed time since launch.

### On Mars:

Likewise, PET can be set to count time to and since an event using a Mars time base—that is, how many sols, martian hours, minutes, and seconds.

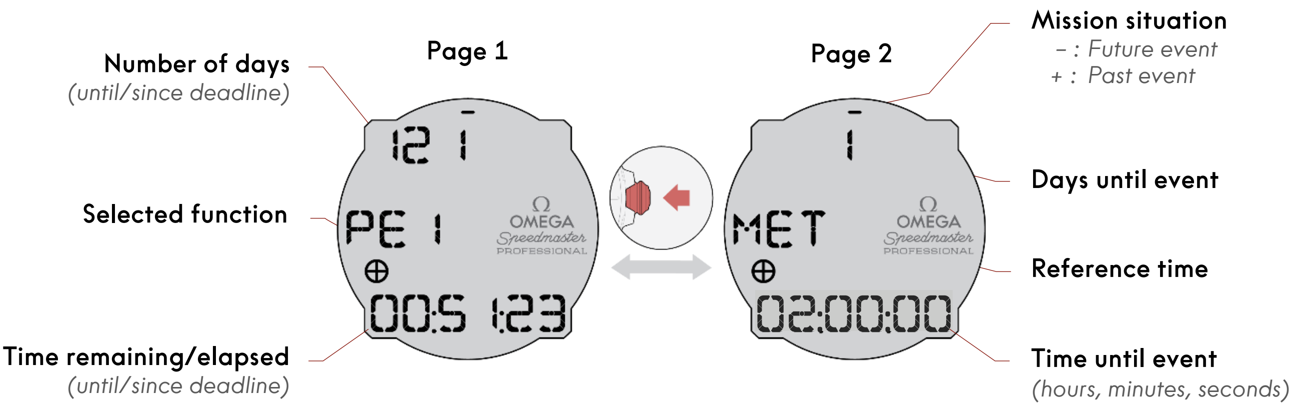
An interesting possibility is afforded by the MLS (Mars solar longitude) mode. The statistical dust storm season begins at $L_S$ = 180° and ends around $L_S$ = 325°. We could therefore set a PET alarm in MLS mode to count how many sols the rover has until the onset of dust storms becomes more probable.



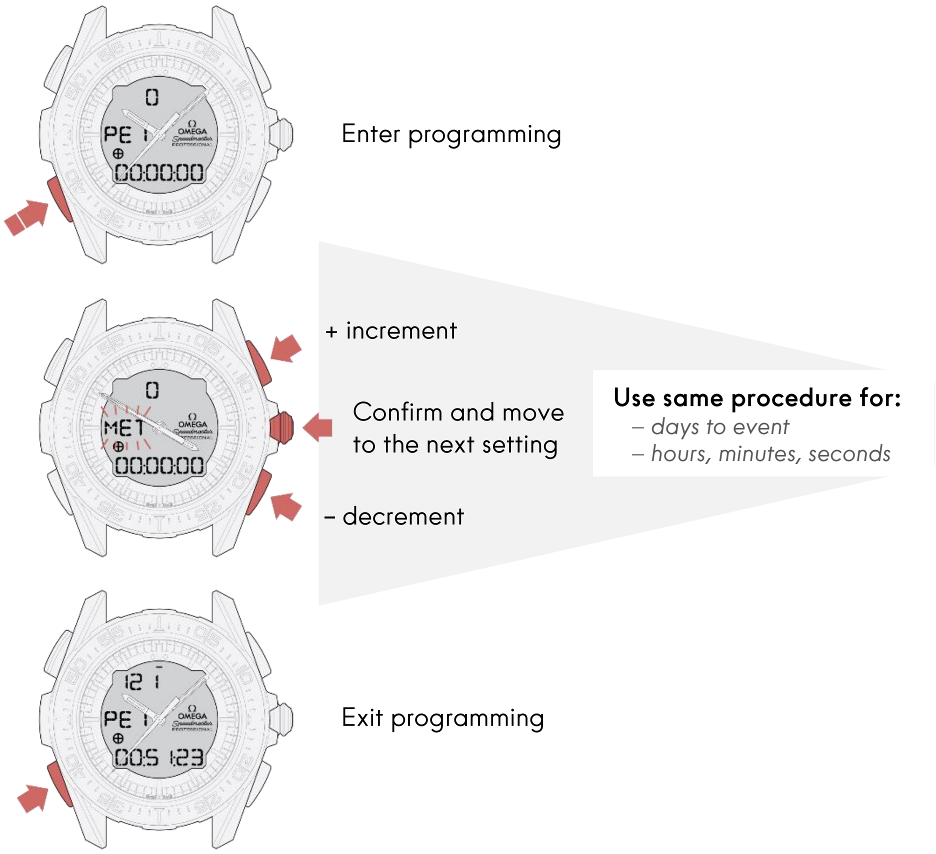
Topography of Aeonia Terra
ESA/DLR, Mars Express, HRSC

# PET PROGRAMMING RELATIVE TO MET

Here, the PE1 countdown has been programmed for an event 1 day plus 2 hours after start of mission (MET).

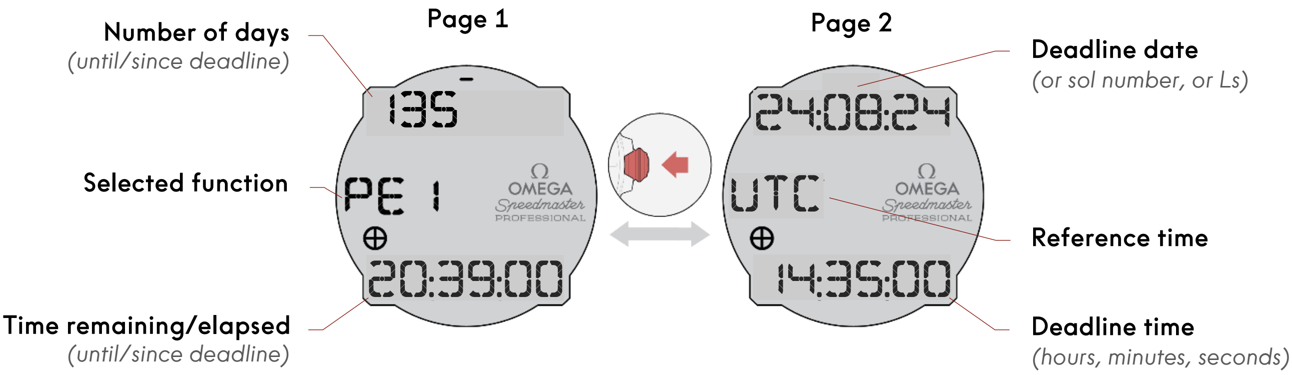



Please navigate to the **PE1**, **PE2**, or **PE3** functions.

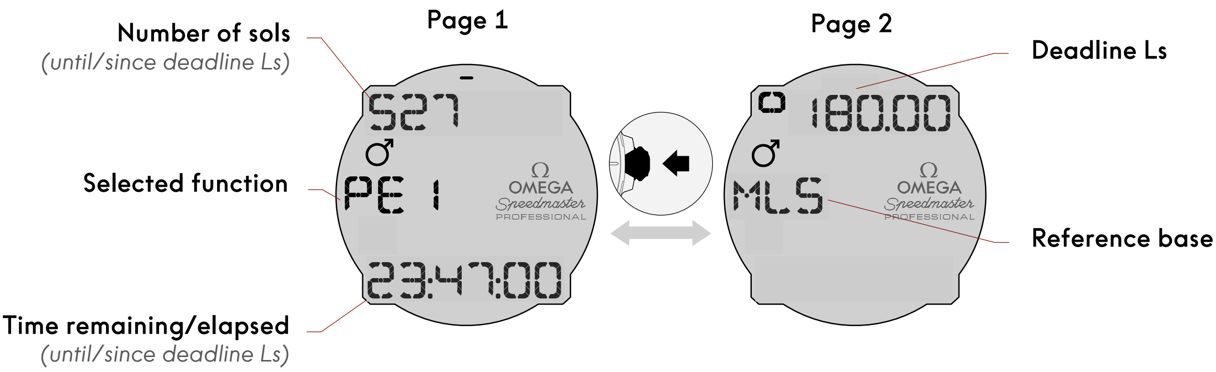


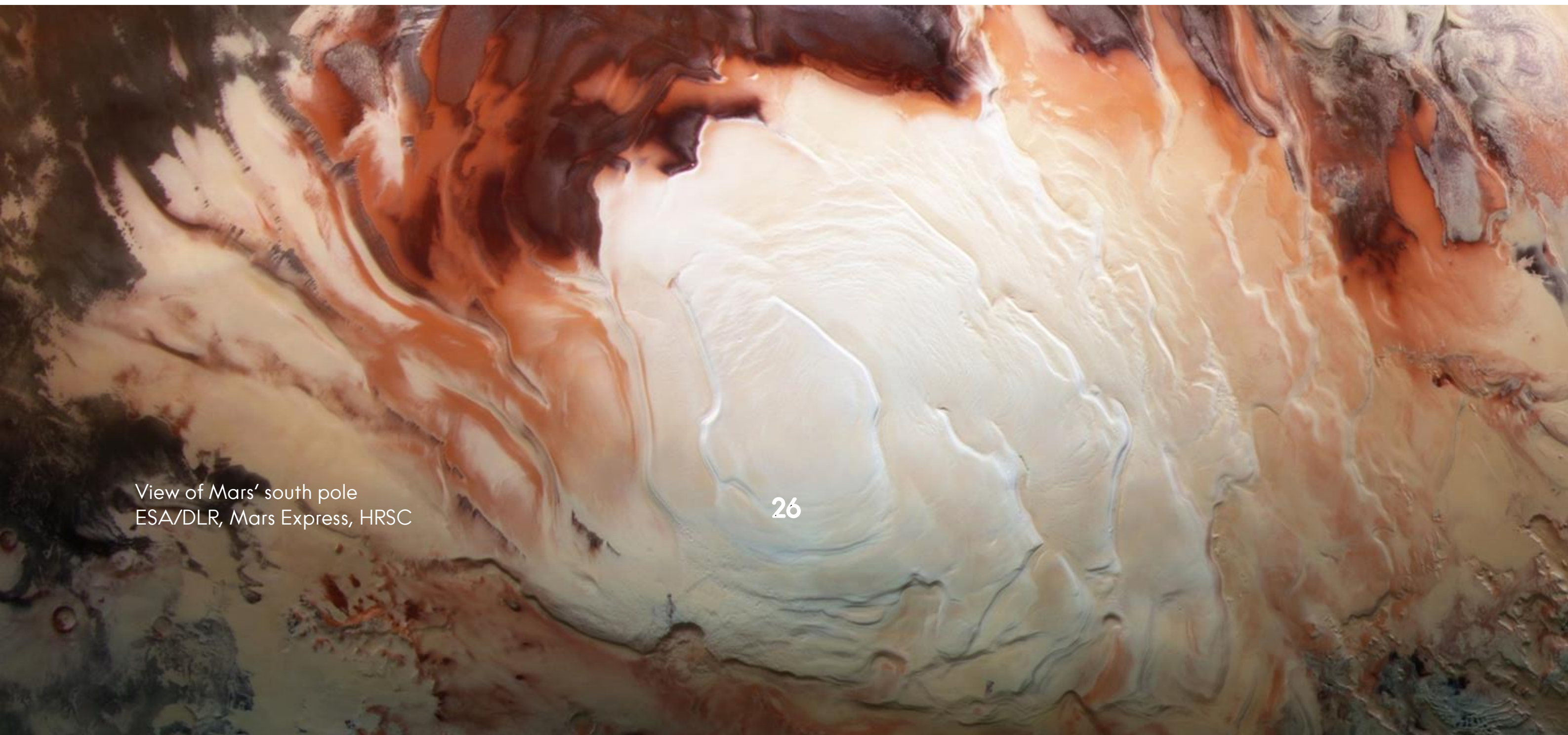
# PET ABSOLUTE

In this example we have programmed PE1 to countdown to a user-defined UTC date and time.




Here we show PE1 configured to ring when Mars has reached solar longitude Ls = 180°.



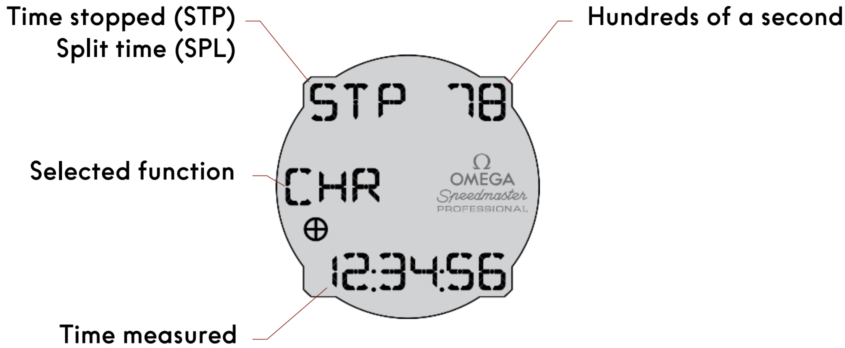


View of Mars' south pole
ESA/DLR, Mars Express, HRSC

EARTH

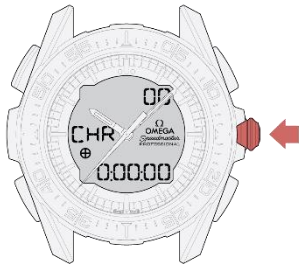
# CHRONOGRAPH (CHR)

The chronograph function works on Earth time, counting hours, minutes, seconds, and hundredths of a second up to a maximum of 99 h, 59 m, 59 s, 99 hths.

## CHR DISPLAY




## USING CHR



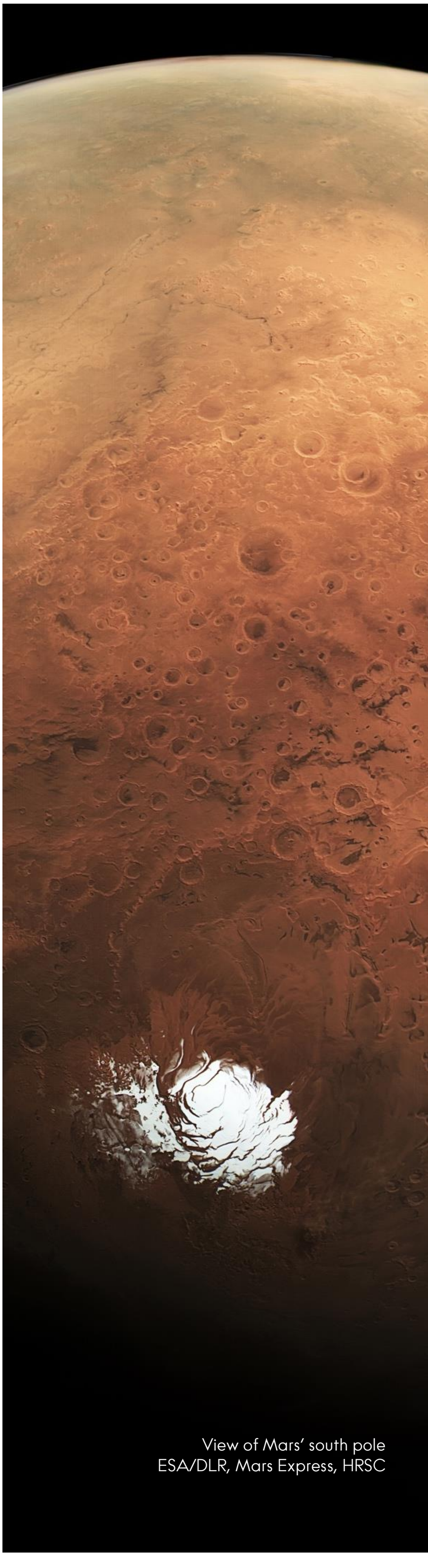
Enter/exit CHR

Start/stop (STP) measuring time

Stop (STP)/restart measuring time

Display split time (SPL)
*Press again to continue measuring time*

Reset to zero
*After the chronograph has been stopped (STP)*

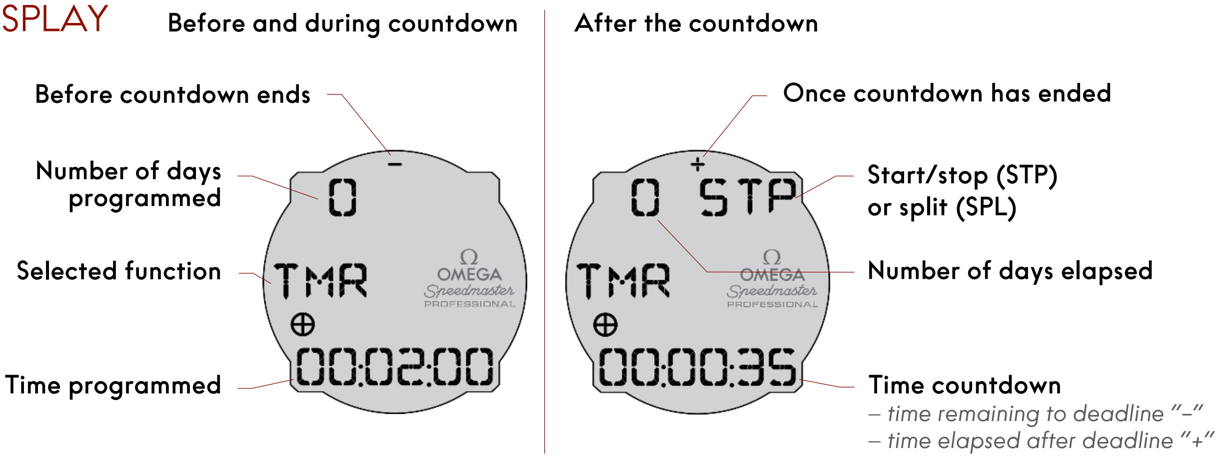


View of Mars' south pole
ESA/DLR, Mars Express, HRSC

# TIMER (TMR)

**TMR** allows you to **count down**, on Earth time, a pre-defined period (up to 99 d, 99 h, 59 m, 59 s). A chime sounds once "zero" has been reached. Thereafter, TMR reports the time elapsed beyond "zero".

## TMR DISPLAY

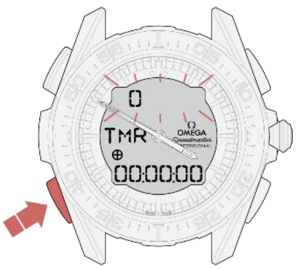



## TMR PROGRAMMING AND UTILISATION

Enter/exit TMR

Press to start

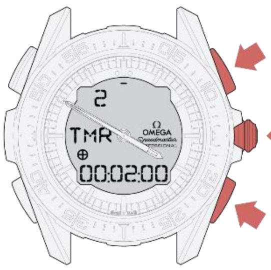
*Press again to stop*



Enter programming

Display split time (SPL)

*Press again to continue*



+ increment

Confirm and move to the next setting

– decrement

Reset to zero

*After the timer has been stopped (STP)*

Exit programming

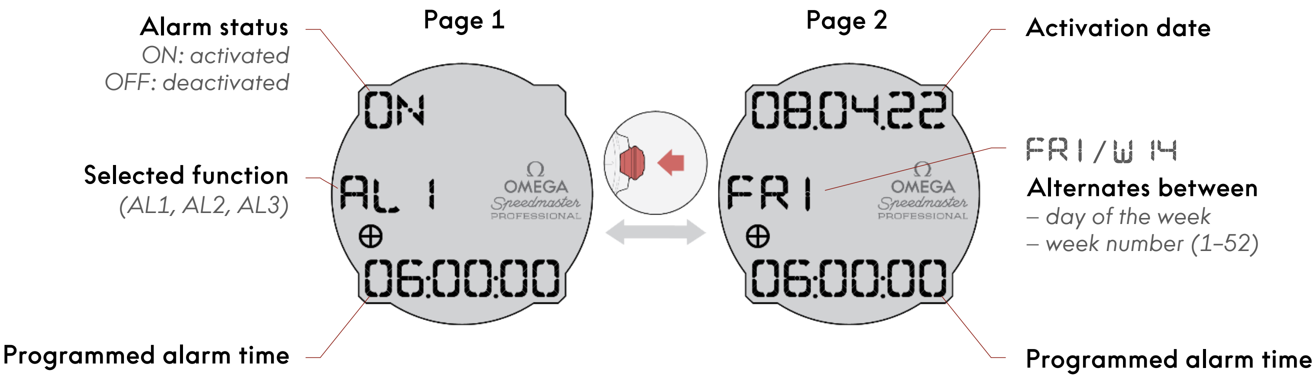
Stop the chime by pressing any button

UNIVERSAL

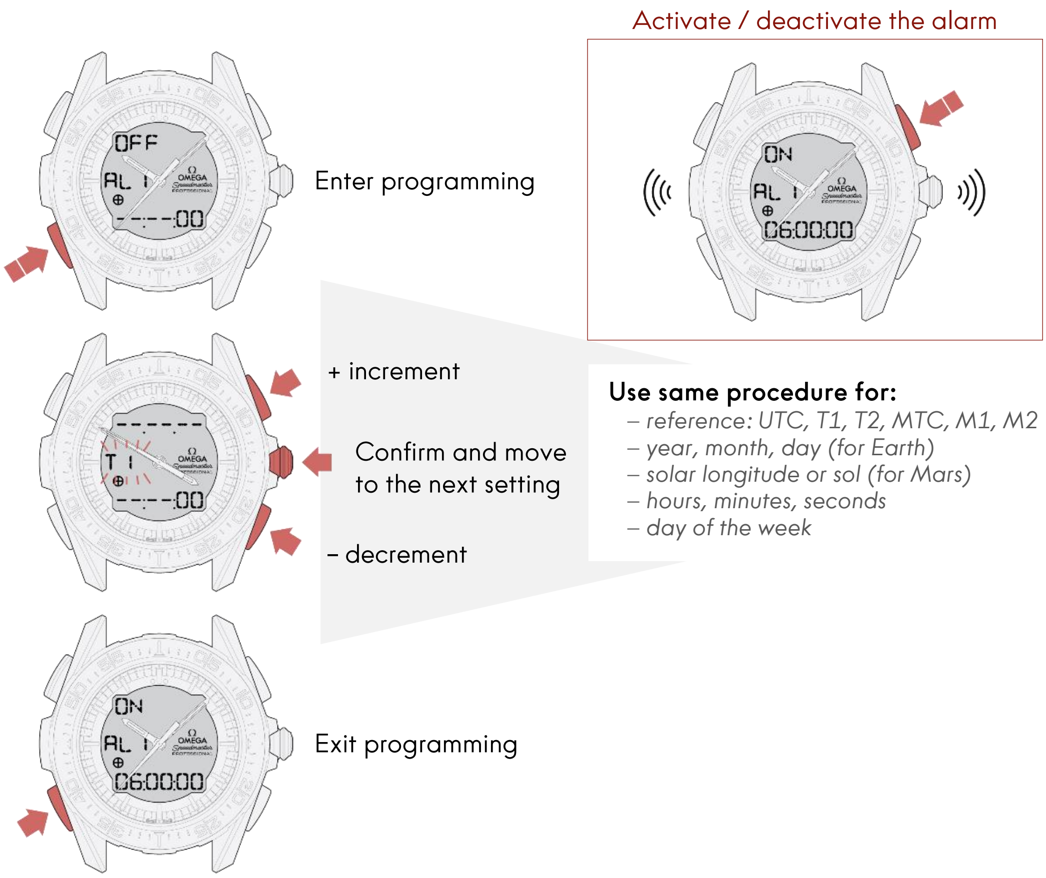
# ALARMS (AL1, AL2, AL3)

Three alarm functions are available, each with its distinct ring. Their reference time may be UTC, T1, T2, MTC, M1, or M2. Once programmed, an alarm will sound at every allowed occurrence. For example, if you set the alarm time without specifying a date or a day of the week, the alarm will be triggered daily at the same time.

## AL DISPLAY

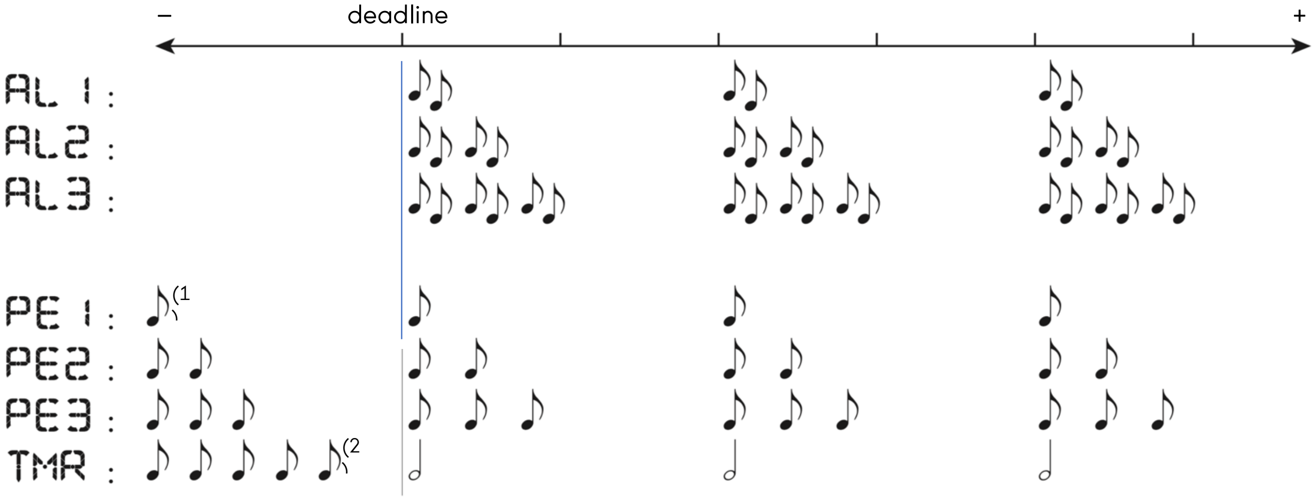



## AL PROGRAMMING AND UTILISATION



# CHIMES

## CHIME SEQUENCES



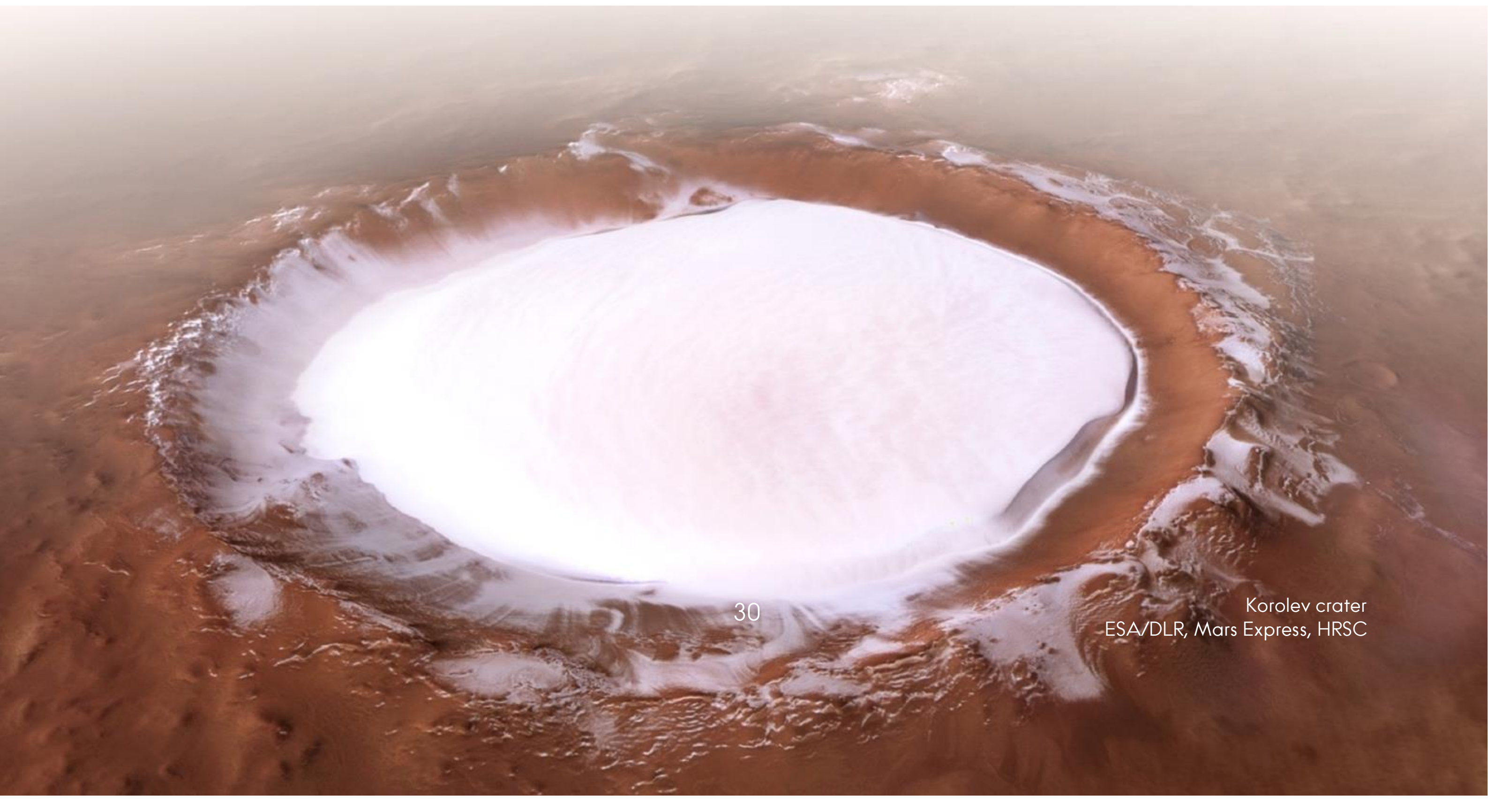

(1) For the PET function, three chimes sound one minute prior to the deadline.
(2) For the TIMER function, the last five seconds sound before the deadline chime is heard.

## CHIME PRIORITIES

In case two alarms (*e.g.*, AL1 and AL2) are set for the same time, only the lowest number alarm will sound (AL1). A Likewise, if two PET functions are due simultaneously (*e.g.*, PE2 and PE3), PE2 will chime.

In case of conflict, an ALARM always takes precedence over PET and/or TIMER.

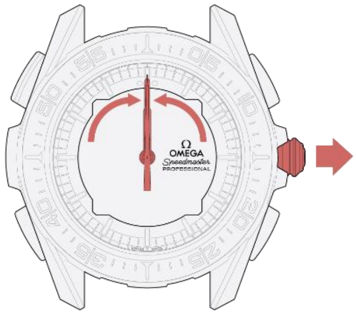
If necessary, the TIMER interrupts PET.



Korolev crater
ESA/DLR, Mars Express, HRSC

# SPECIAL MODES AND FUNCTIONS

## ENERGY SAVING MODE



**Energy Saving Mode** is activated by **pulling out the crown**:

- the digital display disappears,
- the hands move to 12 o'clock,
- chimes are deactivated,
- all measurements in progress continue.

## SYNCHRONISATION OF WATCH HANDS

With the watch in Energy Saving Mode, it is possible to synchronise the position of the hands. In case the hands do not display exactly 12:00:00, please follow the procedure hereunder:

- Press **P4** to move the hour and minute hands forward in half-minute intervals.
- Press **P3** to move the hour and minute hands forward in one-hour intervals.
- Press **P1** to move the seconds hand forward in one-second intervals.

## DISPLAY BACKLIGHT

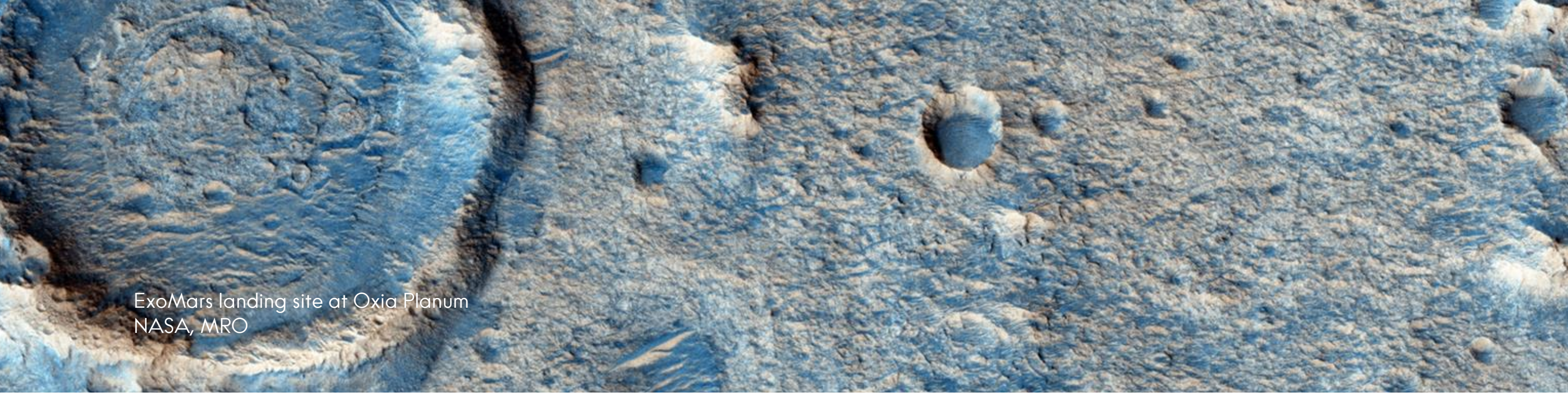
In low-light conditions, press **P3** to activate the **electroluminescent backlight** function and read the display.


Activate digital display backlighting
*(after 5 seconds the display returns to nor-*


Momentarily park hands to read digital display
*(after 5 seconds the hands return to their normal po-*

## SWITCH T1 & T2

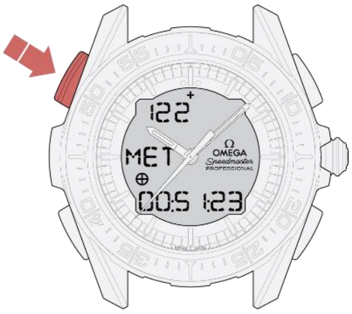
**Press P4 twice to exchange time zones T1 and T2**. Because alarms, MET, and PET remain assigned to their time references, this is very useful during journeys across multiple time zones. Please see the Examples section.




# FAVOURITE FUNCTION

It is possible to assign a **favourite function** to become accessible when pressing once pusher **P4**.

**PROGRAMMING**




Assign the favourite function

**USE**


Toggle between favourite function and the last function displayed

# ANALOGUE ONLY MODE

Your watch enters **Analogue Only Mode** (requiring minimal energy) after five days without any activity (no crown or pushers engaged).

- The digital display disappears.
- The hands continue to indicate T1.
- All measurements in progress continue.
- The ALARMS, the TIMER, and PET can still sound (if the chime is not stopped by the user, the watch returns to standby after 20 s).

In case you would like to turn off the digital display and operate in Analogue Only Mode, please do the following: Activate Energy Saving Mode, then press the crown once to go into Analogue Only Mode.

Press the crown or one of the pushers to exit Analogue Only Mode and turn on the digital displays.

# LOW BATTERY INDICATION

The seconds hand starts making 5-second jumps to indicate that the battery has reached the end of its service life.

To ensure that your watch remains fit for space, please ensure that the new battery is installed by an OMEGA dealer.

Concordia Antarctic station
ESA/IPEV/PNRA-M. Buttu

# SOLAR COMPASS

Being able to quickly check our bearings is fundamental when traversing remote landscapes. For centuries, until the recent advent of GPS, the orientation tool of choice employed by explorers has been the magnetic compass. However, a traditional compass can be deceiving in regions where the angular divergence between the geographic and magnetic pole (the magnetic declination) is substantial. Moreover, magnetic compasses are downright useless on worlds with no natural magnetic field dipole—like Mars. But there is another way.

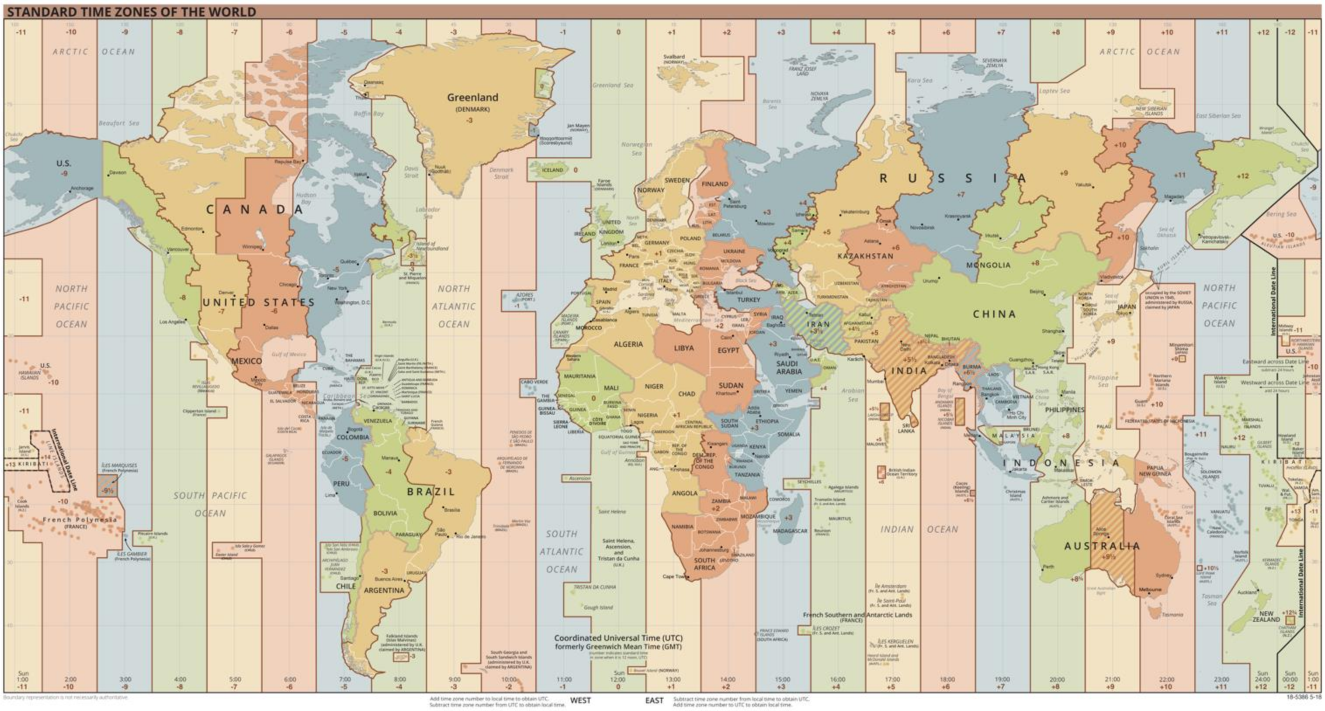
The bezel of your OMEGA Speedmaster X-33 Marstimer contains a special symbol for each cardinal direction (top, bottom, left, and right). The angle between two contiguous bezel tick marks is 6°. Let us discuss how we can use watch and bezel as a solar compass.

During daylight, the evolution of the Sun across the sky describes an arc whose apex corresponds to solar south (or north, if you are on the southern hemisphere)—not magnetic south, but true south. Therefore, a relationship exists between the Sun's position on that arc and time of day that we can utilise to estimate the north-south direction.

But there is a complication. No typical watch reports a location's true solar time (also called apparent time or sundial time). We must address this at some length.

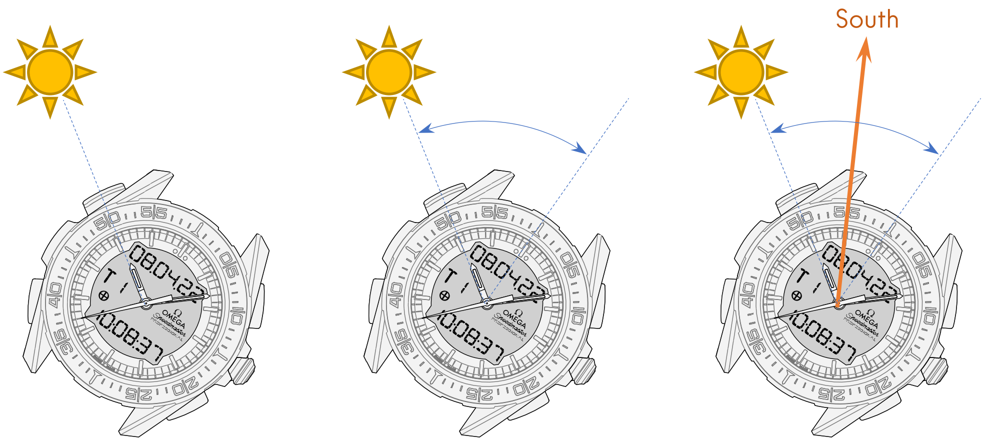
Clocks display mean solar time. Earth's prime meridian (0° longitude) passes through the Royal Observatory, in Greenwich, London (UK). UTC coincides with the mean solar time there. Ideally, Earth time zones would be exactly 15° wide, centred on successive 15°-multiples of longitude, at 0°, 15°, 30°, etc. This is not the case. As we can see on the map below, Earth time zones can have bizarre shapes, responding more to commercial and political needs rather than to astronomical common sense. For example, Spain, France, Belgium, the Netherlands, and Algeria should be on the same time zone as the UK. Also, given its meridional position, Bolivia is in the correct time zone, but Argentina and Uruguay are not; etc., etc.

Since the time zone assigned to a given position on Earth may differ significantly from its true solar time, we can only achieve a rough determination of the north-south direction using a traditional watch as a solar compass.




# ROUGH ESTIMATE: BASED ON TIME ZONE

1. In the northern hemisphere, position your watch horizontally so that the hours hand points to the Sun.
2. Note the angle formed between the hours hand and your watch's 12 o'clock direction (1 o'clock when in daylight saving time).
3. Rotate the bezel until the top symbol bisects the previous angle (lies in the middle between the hours hand and the 12 o'clock mark).
4. The top symbol now points (more or less) due south.




1: Point hours hand to Sun 2: Note angle to 12:00 3: Approximate N-S direction can be found at half angle.

5. For the southern hemisphere, the method is slightly different. Place your watch so the 12 o'clock direction aims at the Sun. Note the angle to the hours hand. Rotate the bezel until the top symbol bisects this angle. The top symbol now points (more or less) due north.

In theory, at 12:00 the Sun should be at its highest point in the sky (13:00 during daylight saving time), but if you care to check, you will see that this is seldom the case.

Let us examine the following example. The city of Leiden (NL) is situated at 4.50°E, in time zone UTC+1. All locations in UTC+1 are assigned the mean solar time corresponding to longitude 15°E. Thus, from a solar point of view, the time shown by a clock in Leiden is off; we will now calculate, on average, by how much.

We have seen already that:

(1) LMST for a given planetographic longitude, $\Lambda_{pg}$, in degrees west, is: LMST = UTC – $\Lambda_{pg}$ (24 h / 360°).

(2) LMST for a given planetographic longitude, $\Lambda_{pg}$, in degrees east, is: LMST = UTC + $\Lambda_{pg}$ (24 h / 360°).

Using Equation 2, we obtain that a watch in Leiden should read:

$LMST_{Leiden}$ = UTC + 4.50° x 24 h / 360° = UTC + 0.3 h, or UTC + 20 m.

Instead, it displays UTC + 60 m. We therefore conclude that, to properly track LMST, watches in Leiden must be set back 60 m – 20 m = 40 m.

If we want to use a watch as a more accurate solar compass, we need to understand the effect that this 40 m offset would have on the hours hand—something that most people fail to account for. We can figure out this easily.

The hours hand moves a full circle (360°) in 12 h. In one hour it sweeps an angle of 360° / 12 = 30°. Hence, 40 m correspond to 40 m x 30° / 60 m = 20° of hour hand movement.

So, if we apply in Leiden the method described before—dividing by two the angle formed between the hours hand (pointing to the Sun) and the 12 o'clock direction—we will be 10° off from true South.

Let us reflect on this outcome. Considering that time zones are (or should be) 15° wide, we should never be off by more than 7.5°. We selected the Leiden example to illustrate how time zone conventions can lead to inconsistencies larger than 7.5°.

Perhaps you would like to know where on our planet the difference between clock time and mean solar time is greatest. In China all clocks are set to Beijing time; hence, in the westernmost regions, solar noon can take place as late as 15:00.

# BETTER DETERMINATION: BASED ON TRUE SOLAR TIME

The duration of a solar day is not constant. When mechanical clocks started to take over timekeeping from sundials, which had served humanity for centuries, the difference between clock time and sundial time became an issue for everyday life. *True solar time* (also called *apparent solar time*) is the time indicated by the Sun on a sundial (or measured by its noon transit over the local meridian), while *mean solar time* is the average displayed by well-regulated clocks.

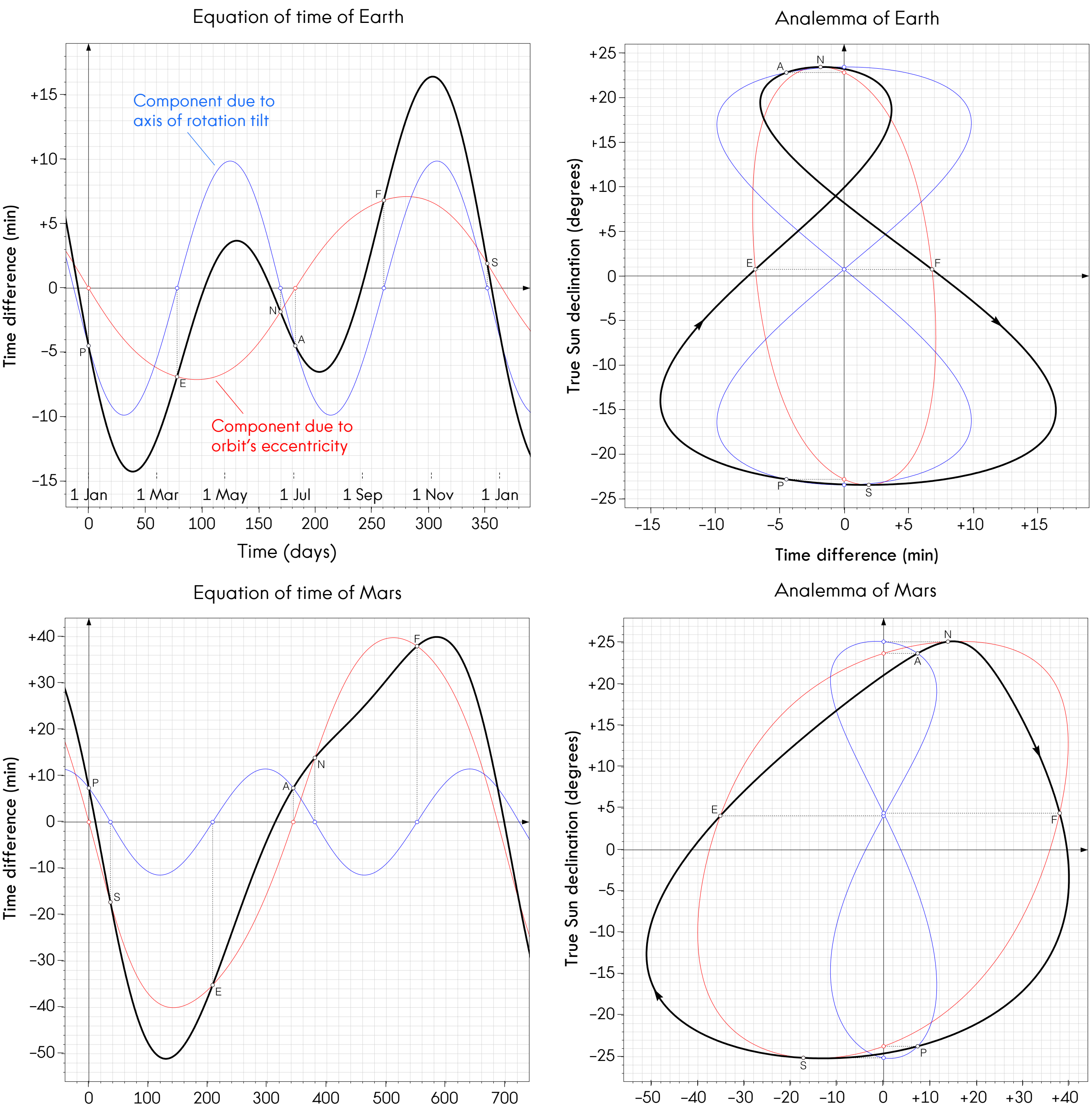
The *equation of time* describes the difference between true solar time and mean solar time throughout the year. Its shape can be understood as the sum of two sine curves, the first having a period of one year (its amplitude is a function of the planet's orbital eccentricity) and another with a period of half a year (whose amplitude depends on rotational axis inclination). The equation of time would be constant only for a planet with a perfectly circular orbit and zero axial tilt.

Another interesting way to look at this effect is to consider a planet's *analemma*. This plot describes the annual evolution of the Sun's position in the sky as you would see it if you were to set up a stationary camera to take multiple exposures every day at the same mean solar time.

We next examine the equation of time and analemma for Earth and Mars.

As we can see from Earth's equation of time, true solar time can lag mean solar time by as much as 14 m 6 s (around 12 Feb) or be ahead by 16 m 33 s (around 3 Nov). The equation of time has zeroes (dates when true solar time and mean solar time coincide) near 15 Apr, 13 Jun, 1 Sep, and 25 Dec. On Mars, whose orbit has much higher eccentricity than Earth's, the difference between true solar time and mean solar time can reach 50 m.

In these diagrams we can also recognise several special orbital positions that we have studied in previous sections: (P) perihelion, when the planet is closest to the Sun; (A) aphelion, the point most distant from the Sun; and (E), (F), (N), (S), which correspond, respectively, to the equinoxes and solstices.



Adapted from *The Equation of Time*, Pierre Barbier, 2012

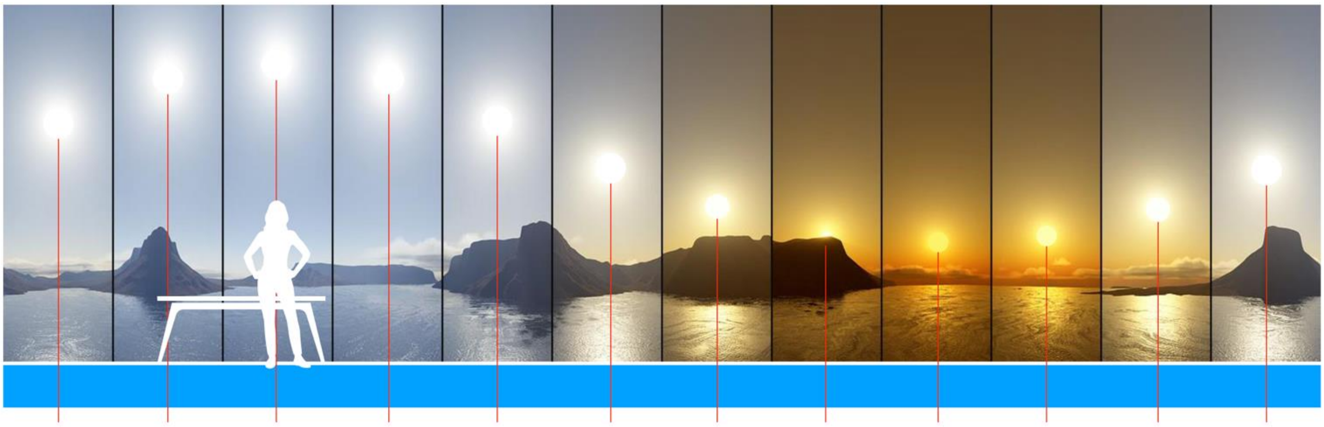
We now understand that we can implement a more precise solar compass if the hands of our watch are able to display true solar time every single day of the year. However, as we will see next, even this is not enough.

# EXACT DETERMINATION: BASED ON APPARENT SUN MOTION

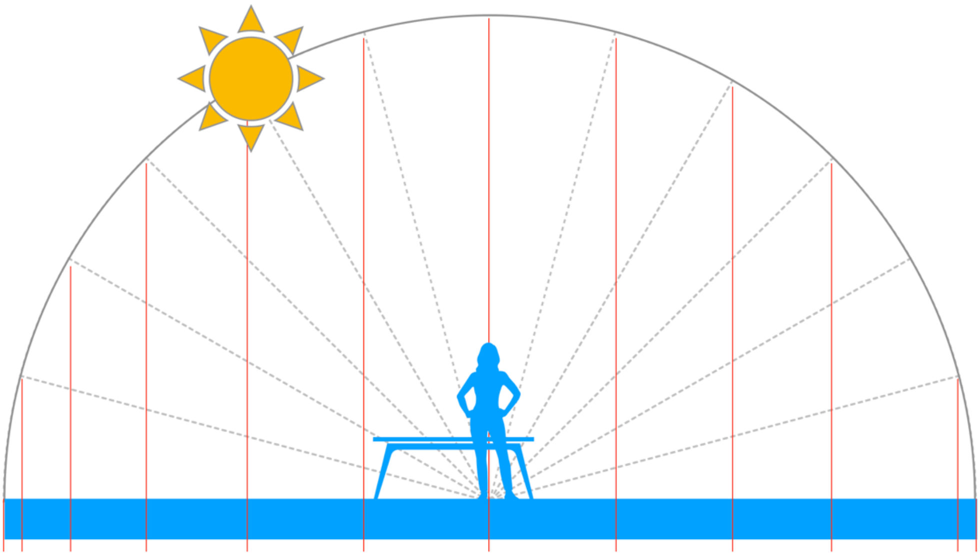
A Sun compass based on an equation of time watch reporting local true solar time (LTST) has the potential to be extremely accurate, but only if used well. The traditional method outlined previously is simple but includes an additional source of error that we have not yet accounted for.

To illustrate this, let us think of an explorer standing somewhere close to the North pole during the summer with our watch in true Solar Time Earth (STE) mode. At exactly 12:00, when the Sun is at its apex, she sets the watch on a horizontal table with the hours hand pointed in the Sun direction.

She then observes that the Sun travels across the sky at a rate of 15° per hour, while the hours hand on her watch moves 30° per hour (the angle corresponding to a 5-min tick increment). She knows that this is because the hours hand on the watch makes a full revolution every 12 hours, whereas the Sun takes 24 hours to circle around her. She also notes that, as long as the Sun is low in the sky, its apparent motion sweeps equal angles on equal periods when projected onto the horizon plane, which was our assumption for the Sun compass method described previously.



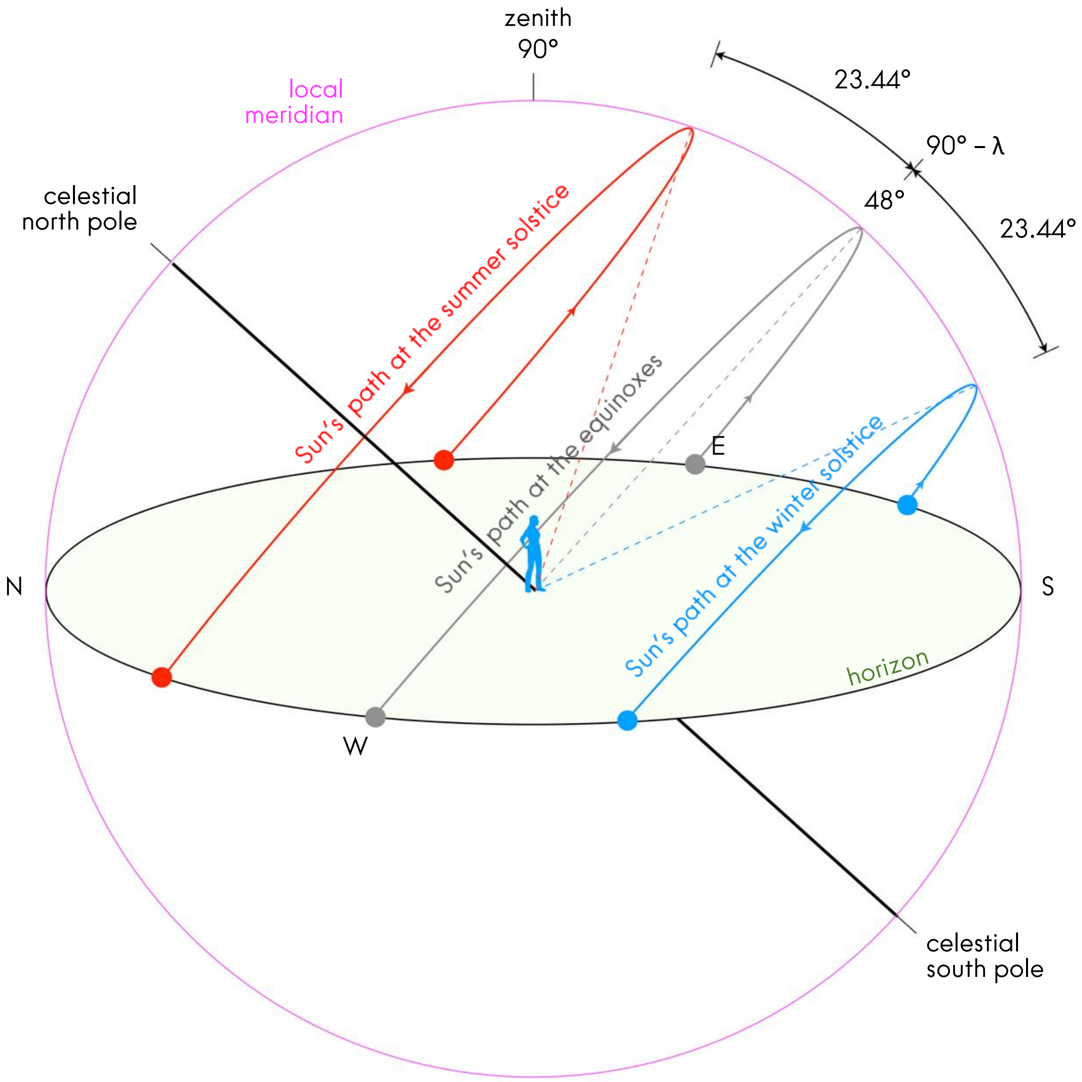
S N



E W

Let us now see what happens when our explorer travels to a location at the equator during an equinox. Using her watch in STE mode, she sees the Sun rise on the east and gradually travel across the sky to arrive overhead precisely at 12:00. If, as before, she sets the watch on a horizontal table, she cannot point in the Sun direction at all. She needs to tilt her watch at 90° relative to the table since the noon Sun is directly above. After she does this, she realises that, also in this case, the Sun sweeps equal angles on equal periods, but on a plane perpendicular to the table. As she projects the Sun's position for every daylight hour onto the horizon plane, she sees that all the points lie on a line. Clearly, the approximation on which the traditional Sun compass method is based, that on the horizon plane the Sun direction sweeps equal angles on equal periods, is not true for this case. She concludes that the traditional method will have large errors for places and seasons having a high solar apex (furthest away from the horizon plane), notably in the tropics and during the summer months.

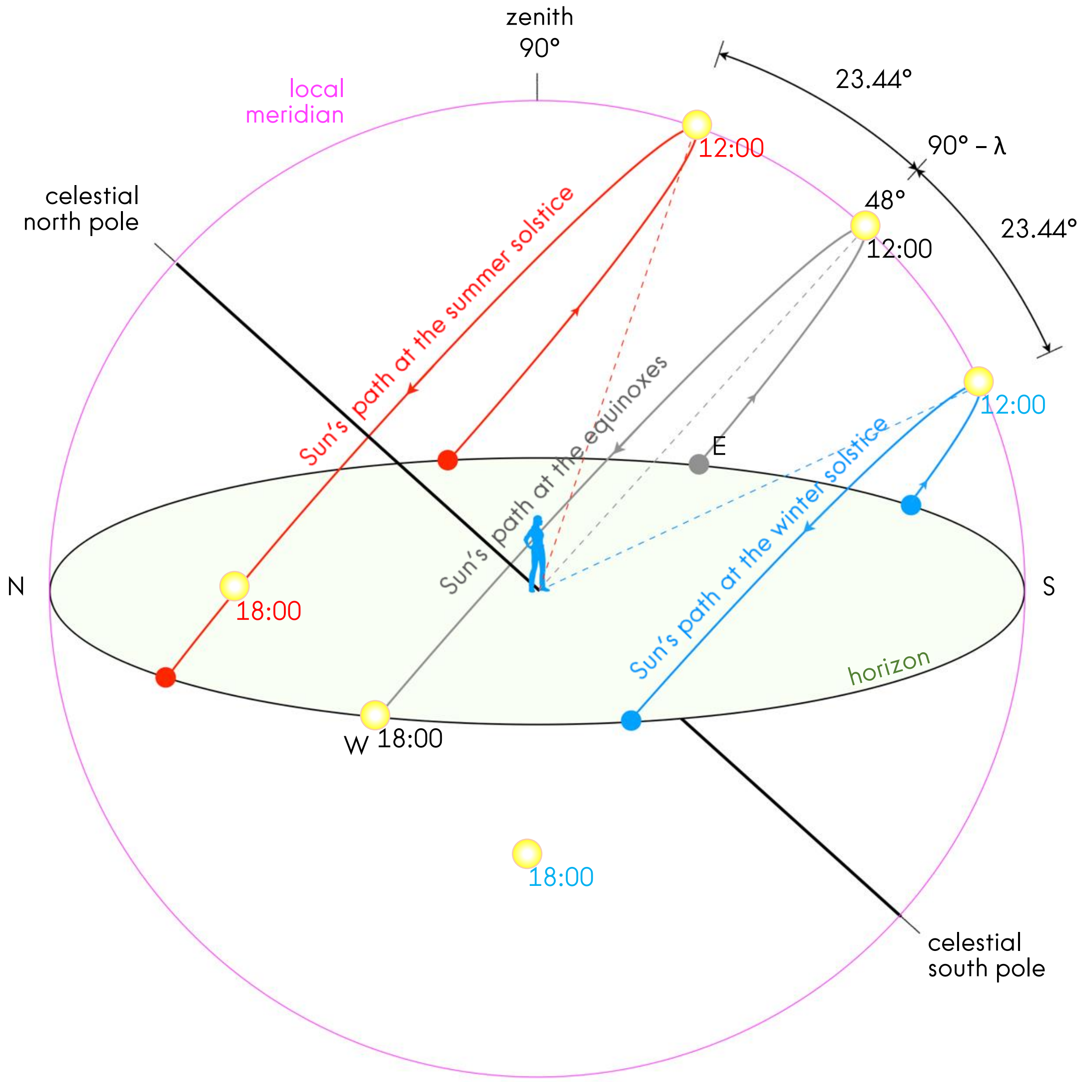
Next, our explorer travels to Rome (42°N) to study the laws of apparent Sun motion throughout the year. She expects to devise some form of compensation that can allow her equation of time watch to achieve an exact north-south determination for all seasons and latitudes.




She observes that the plane defined by the Sun's diurnal evolution across the sky is always inclined relative to the horizontal plane with an angle equal to 90° minus the local latitude (λ). Additionally, for every day of the year, the Sun's angle at its highest point is $\alpha_z = 90° - \lambda + \delta$, where δ is the Sun's declination, which changes with the seasons between zero at the equinoxes and ±23.43662° (the Earth's axial tilt) at the solstices.

She now has all the additional information she requires. With knowledge of the user's longitude and latitude, it is possible to calculate the Sun's apparent motion and project it onto the horizontal plane.

To further illustrates why this correction is needed, let us consider the following figure:




For the traditional Solar compass method to work flawlessly, the Sun would have to be on the east at 06:00 LTST, on the south (or north) at 12:00 LTST, and on the west at 18:00 LTST. This is seldom the case.

Every day of the year, the Sun's apparent motion describes a tilted circle with centre on the celestial polar axis; that is, on the line connecting the celestial north and south poles. The circles' apex lies always at 12:00 LTST at which moment the Sun is due south (or north). We now examine what happens at 18:00 LTST after the Sun has travelled 90° from its 12:00 LTST datum. During the spring equinox, at 18:00 LTST the Sun crosses the horizon exactly on the west. Thereafter, the Sun's 18:00 position shifts progressively further north from west, to achieve its maximum northward deviation on the summer solstice. The Sun's circle then reverts its motion, crossing the horizon once more on the west at 18:00 LTST on the fall equinox. For the next six months, the Sun will be below the horizon at 18:00 LTST, reaching a minimum during the winter solstice.

There exist two interesting extreme situations. When at the north pole ($\lambda = 90°$), the Sun's apparent motion circles are horizontal, with the red circle 23.44° above the horizon and the blue one 23.44° below. At the equinoxes the Sun travels exactly along the horizon. We see that the traditional Sun compass method works well because the Sun is low in the sky, but we cannot use it during the six winter months when the Sun remains below the horizon.

For the case at the equator ($\lambda = 0°$), the Sun's apparent motion circles are vertical, with the red circle 23.44° due north of the east-west line and the blue one 23.44° due south. We can now understand why at tropical latitudes it is difficult to use the traditional Sun compass method. Firstly, for most of the day the Sun is high in the sky. Secondly the north (or south) deviation relative to the east-west line becomes the biggest source of error in the determination of the south (or north) pointing, and it is largest close to the solstices.

West Antarctic ice sheet
ESA/Copernicus Sentinel-2

COMPASS

# TRUE SOLAR TIME EARTH (STE)

Your watch is able to calculate Earth's equation of time to provide local true solar time (LTST) for a specific site.

Select **T1**. Then press **P1 twice**. The function field now reads **STE** (true solar time Earth).

A **long P3** is required to enter a **new position**, otherwise the previously specified coordinates are used.

Programme the **planetographic longitude** (0°–180°, with the – & + signs denoting W & E, respectively).

Thereafter, please provide the **latitude** (0°–90°, the – & + signs designate S & N, respectively).

Exit programming with a short P3. The watch hands and display now show Earth's true solar time at your location.

Follow this procedure to achieve an accurate north-south line determination on Earth.

1. Position your watch horizontally with the 12 o'clock direction aiming at the Sun.

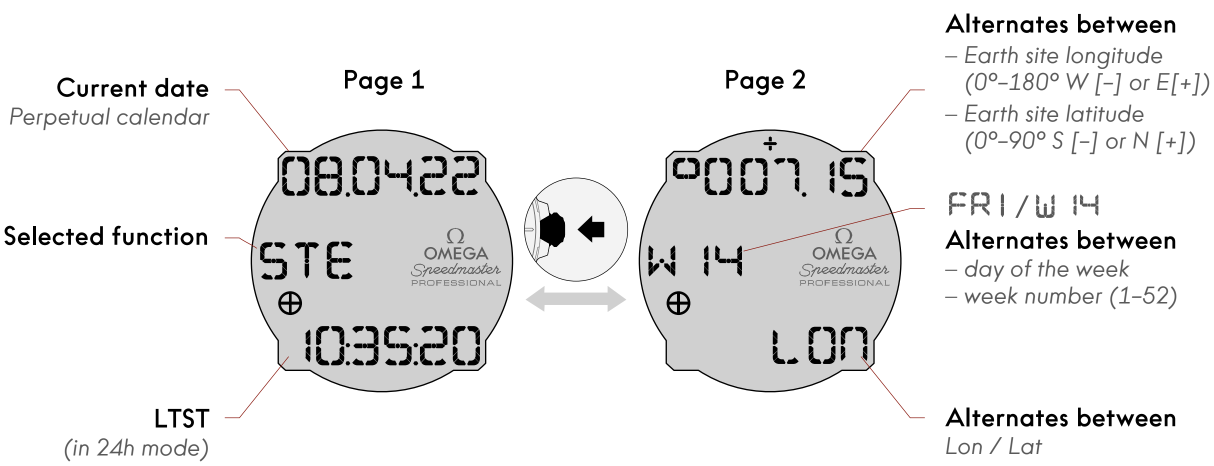
   To determine the Sun direction on a cloudy day, hold a stick or a pencil over a light patch of ground or a piece of paper. You may see a shadow indicating the Sun's position.

2. Press **P1**. The seconds hand will move to **point due north**.
   Please note: The watch computer calculates the north pointing exactly. However, the seconds hand moves in 1 s increments. Each tic of the seconds hand traces an angle of 360°/60 = 6°. For this reason, the seconds hand points to the north with an accuracy of ±3°.

Press **P1** to have the seconds hand working normally again.

Press **P2** to **exit STE** and go back to **T1**.

It is possible to assign STE to pusher P4 as your favourite function. You must programme the correct longitude and latitude when you travel to a new Earth location.



Bonneville crater
NASA, Spirit rover

COMPASS

# TRUE SOLAR TIME MARS (STM)

Your watch can also calculate Mars' equation of time to report local true solar time (LTST) at a specific Mars site.

Select **M1**. Then press **P1 twice**. The function field now reads **STM** (true solar time Mars).

A **long P3** is required to enter a **new position**, otherwise the previously specified coordinates are used.

Programme the **planetocentric longitude** (0°–360°E).

Thereafter, please provide the **latitude** (0°–90°, the – & + signs designate S & N, respectively).

Exit programming with a short P3. The watch hands and display now show Mars' true solar time at your location.

Follow this procedure to achieve an accurate north-south line determination on the surface of Mars:

1. Position your watch horizontally with the 12 o'clock direction aiming at the Sun.

   To determine the Sun direction on a high atmospheric opacity sol, hold a thin, vertical element over a light horizontal surface or patch of ground.

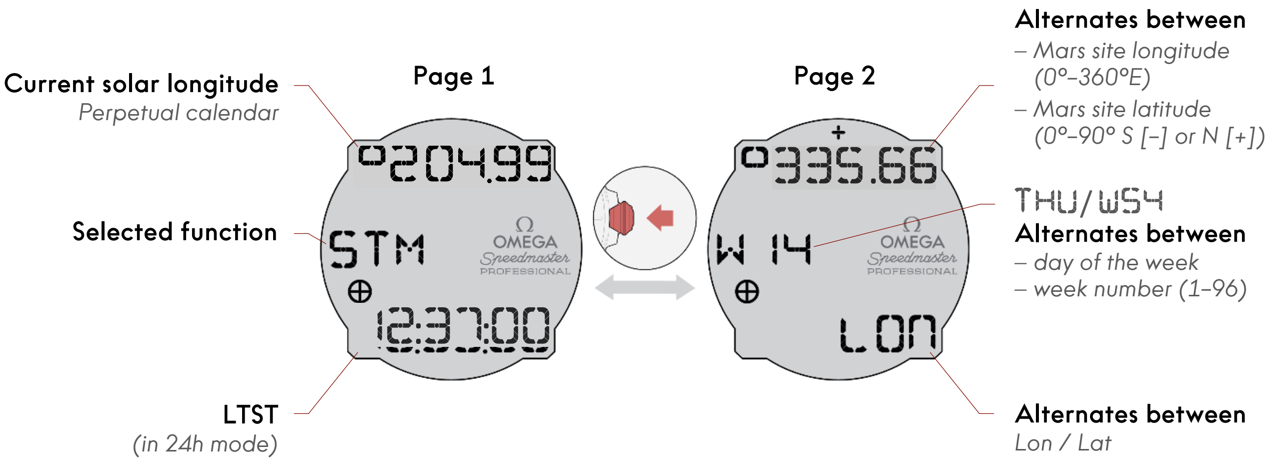
2. Press **P1**. The seconds hand will move to **point due north.**

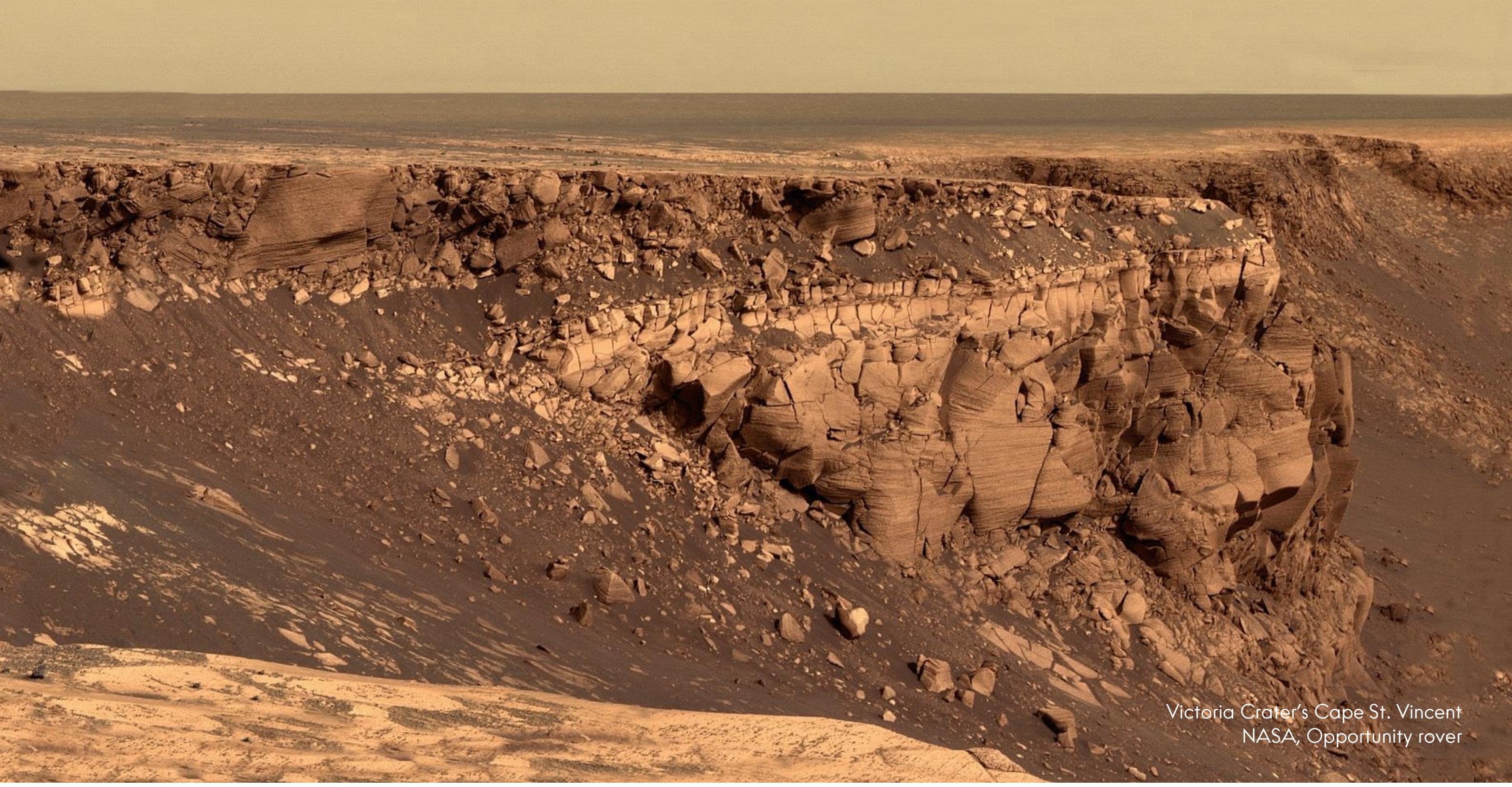
Press **P1** to have the seconds hand working normally again.

Press **P2 twice** to **exit STM** and go back to **M1** with the watch hands reporting **M1 time**.

Press **P2 once** to **exit STM** and go back to **M1** with the watch hands displaying **T1 time**.

It is possible to assign STM to pusher P4 as your favourite function. You must programme the correct longitude and latitude every time you travel to a new Mars location.





Victoria Crater's Cape St. Vincent
NASA, Opportunity rover

# ACKNOWLEDGEMENTS

Your Speedmaster X-33 Marstimer is the result of a fruitful partnership between OMEGA and the European Space Agency. We would like to express our gratitude to the ESA colleagues who have helped with this project.

Most of the Mars algorithms implemented in this timepiece are based, directly or indirectly, on work published by Michael D. Allison and colleagues from NASA's Goddard Spaceflight Centre[1,2].

1. Allison, M. D., Accurate analytic representations of solar time and seasons on Mars with applications to the Pathfinder / Surveyor missions. *Geophys. Res. Lett.* **24**, 1967–1970 (1997).

2. Allison, M. D. and McEwen, M. A post-Pathfinder evaluation of areocentric solar coordinates with improved timing recipes for Mars seasonal/diurnal climate studies. *Planet. Space Sci.* **48**, 215–235 (2000).

# MORE INFORMATION

Mars24 is a powerful computer application based on the algorithms by Michael D. Allison that is produced and maintained by Robert B. Schmunk (NASA Goddard Institute for Space Studies). It provides a graphical representation of Mars' day/night illumination and can report time at various mission and landmark locations. Mars24 is freely available at: https://www.giss.nasa.gov/tools/mars24/.

Another interesting site, at the Laboratoire de Météorologie Dynamique (LMD), hosts the Mars Climate Database and includes useful information on Earth-Mars calendars. Please visit: http://www-mars.lmd.jussieu.fr.

If you want to learn more about the Equation of Time for the various planets, we recommend Pierre Barbier's excellent description, available at: http://pbarbier.com/eqtime/eqtime.html.

# EXAMPLES

EARTH

## AIRPLANE JOURNEY

Your OMEGA Speedmaster X-33 Marstimer can prove useful in a host of occasions. Here, we consider a trip from Paris to Los Angeles with take-off scheduled at 10:20 and landing at 14:05 on 17 Dec 2022.

*The situation:*

You work for the European Space Agency (ESA) in Noordwijk, the Netherlands, on a robotic planetary mission that is being developed in collaboration with the Jet Propulsion Laboratory (JPL) in Pasadena, United States. Your team has regular, weekly teleconferences with their west coast colleagues. You are travelling there from Paris for a face-to-face project meeting.

*For teleconferences when at home:*

**T1** = Amsterdam time, UTC+1 (your local time displayed by the watch hands).
**T2** = Los Angeles time, UTC−8 (the time at JPL).
**AL1**, with reference T1, set to wake you up at 06:45.
**AL2**, with reference UTC, set to chime 15 min ahead of your weekly project teleconference.

*Before your trip departure:*

**MET**, with reference T1, at 10:20 on 17 Dec 2022 (take-off time and day).
**PET**, with reference MET, set at −3 h (when you need to leave to make it to the airport on time).

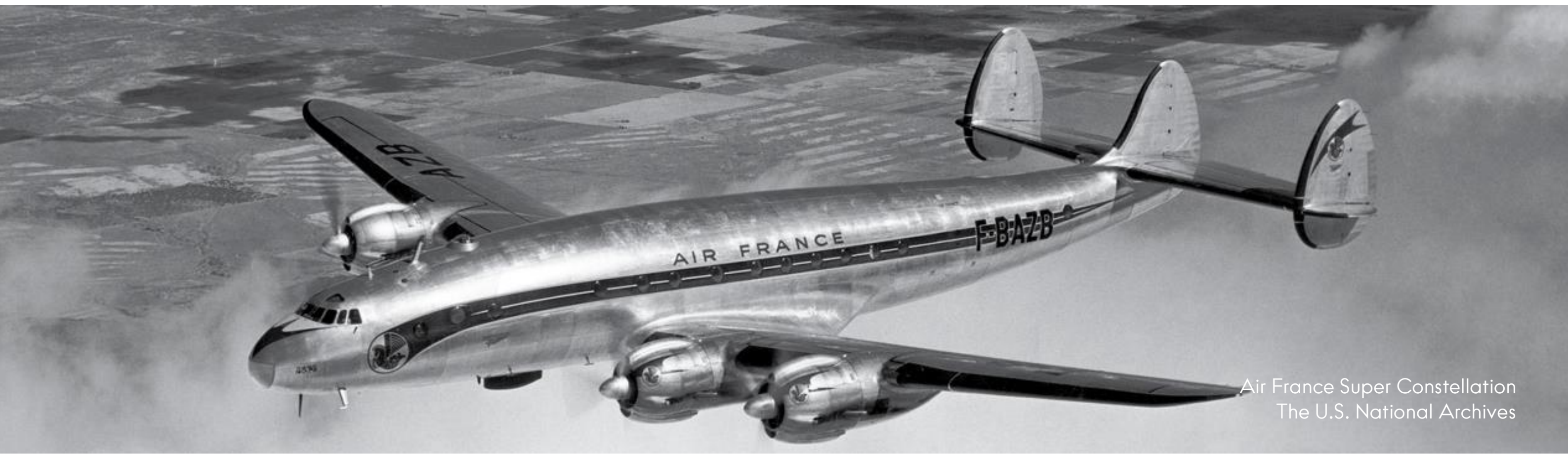
*During flight:*

**Switch T1 & T2**
The west coast time zone becomes your local time T1 and time back at home is displayed as T2.
AL1 will now wake you up at 06:45 west coast time.
Since AL2 was set using UTC (which is a universal time reference), it will continue to remind you 15 min ahead of the weekly project teleconference, which you will now join from Pasadena.

*After landing:*

**T1** = Los Angeles time, UTC−8 (your new local time).
**T2** = The Netherlands time, UTC+1 (time at home).

You can *exchange* T1 & T2 once more on your way back.

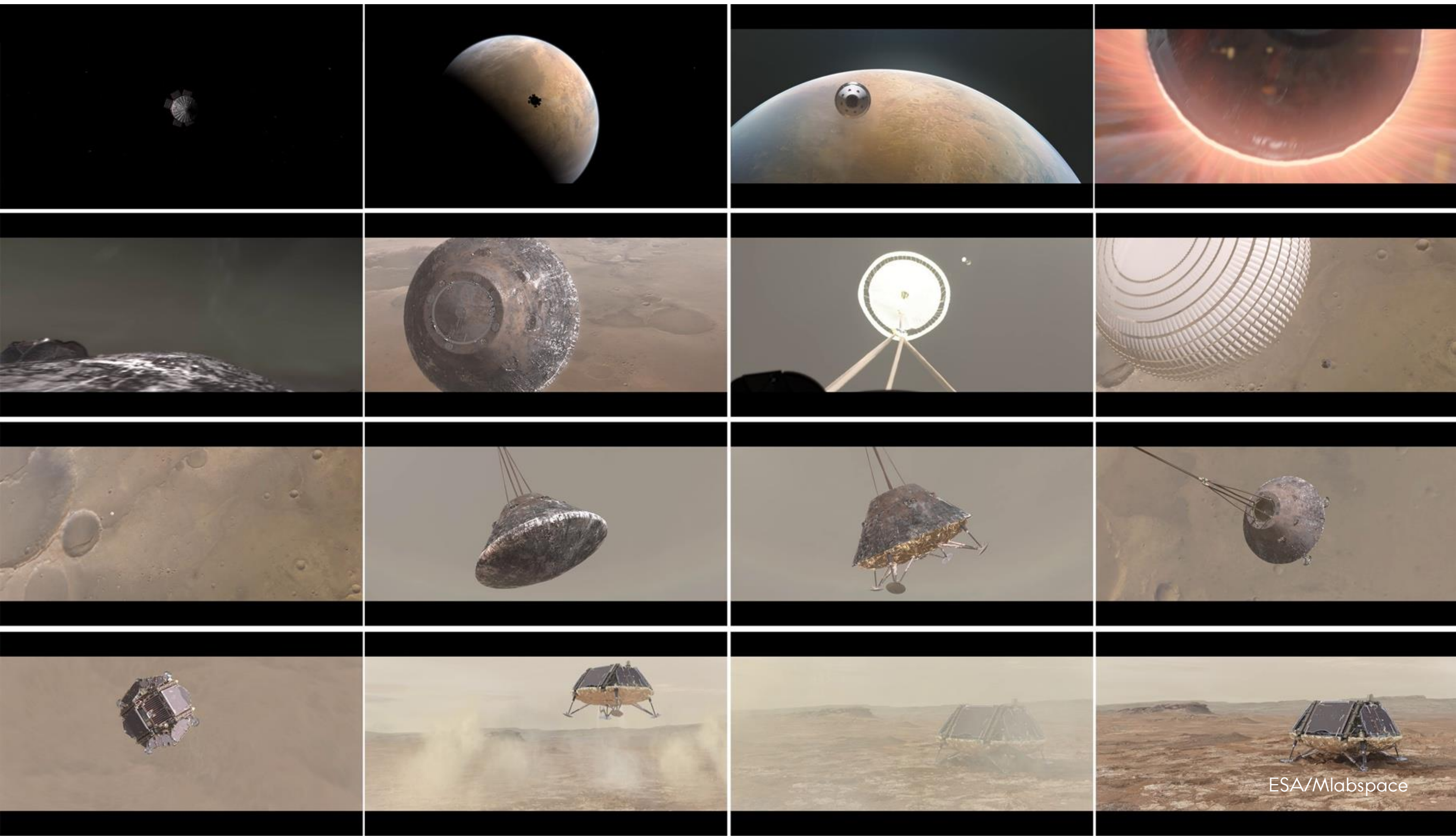



Air France Super Constellation
The U.S. National Archives

MARS

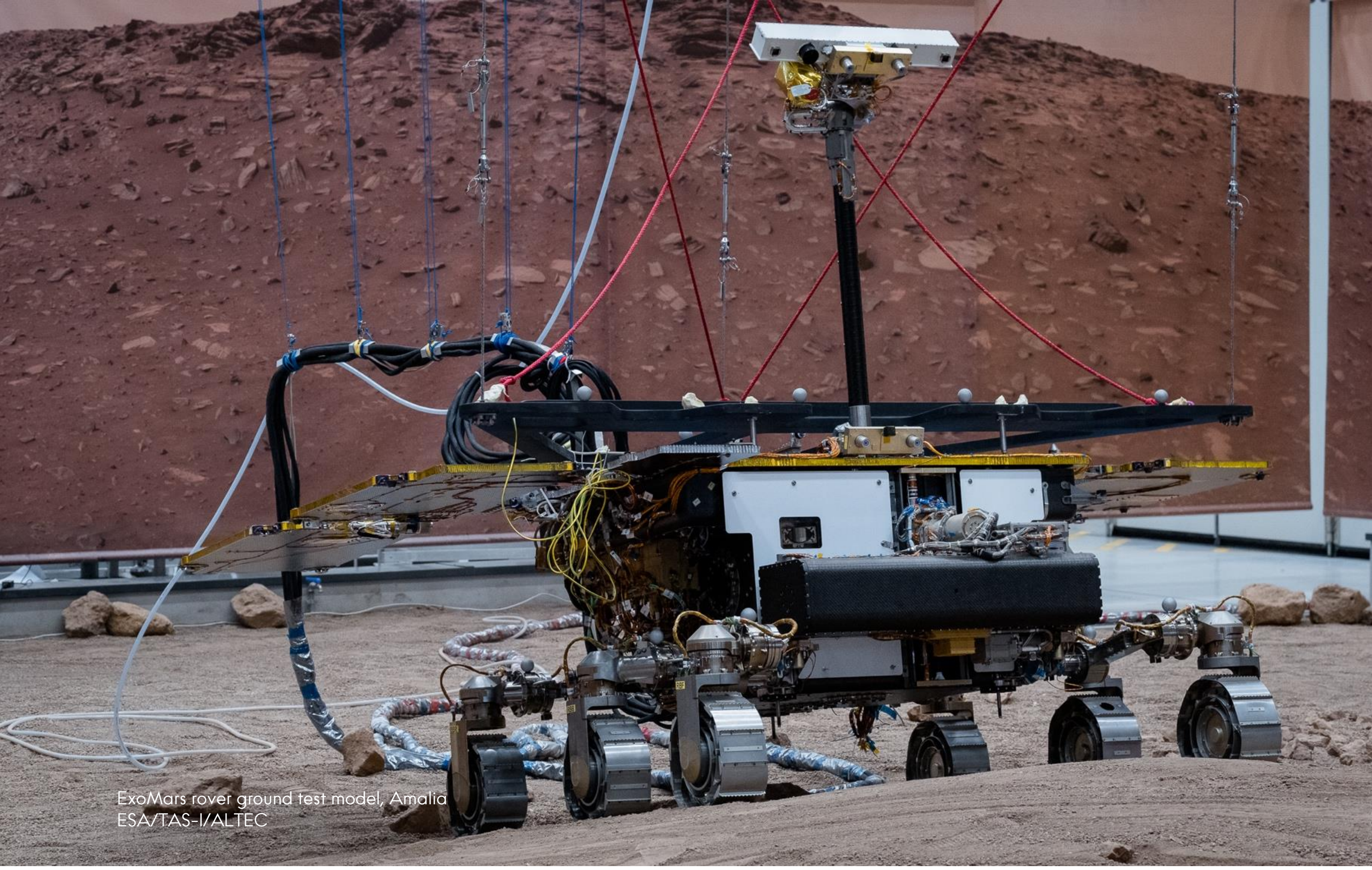
# FOLLOW EXOMARS

## LAUNCH, CRUISE, ENTRY, DESCENT, AND LANDING




A typical ExoMars launch window lasts in the order of 12 days. Rocket launch programmes have been assigned to only 6 days in this period. Each one of these possible launch dates has a slightly different trajectory. For this example, we provide times assuming a launch at the first possible opportunity.

| | | | | |
|---|---|---|---|---|
| <u>Flight to Mars</u> | | | | |
| Lift off | 20 Sep 2022 | 15:10:57 | UTC | **MET** |
| Upper stage separation | 21 Sep 2022 | 01:55:57 | UTC | **AL1** |
| Launcher insertion correction | 28 Sep 2022 | 01:55:57 | UTC | **AL2** |
| <u>Landing</u> | | | | |
| CM-DM Separation | 10 Jun 2023 | 14:56:38 | UTC | **AL1** |
| Atmosphere entry interface point (EIP) | 10 Jun 2023 | 15:25:51 | UTC | **MET** |
| Gravity altimeter trigger | 10 Jun 2023 | 193.84 s | after EIP | |
| Supersonic parachute trigger | 10 Jun 2023 | 197.84 s | after EIP | **PE1** 197.84 s after MET |
| Supersonic parachute release | 10 Jun 2023 | 217.84 s | after EIP | |
| Subsonic parachute trigger | 10 Jun 2023 | 218.14 s | after EIP | **PE2** 218.14 s after MET |
| Front shield jettison | 10 Jun 2023 | 227.84 s | after EIP | |
| Lander separation | 10 Jun 2023 | 300.45 s | after EIP | **PE3** 300.45 s after MET |
| Nominal touchdown | 10 Jun 2023 | 15:31:39 | UTC | **AL3** |
| Programme mission time | 10 Jun 2023 | 15:22:00 | LMST | **M1** |

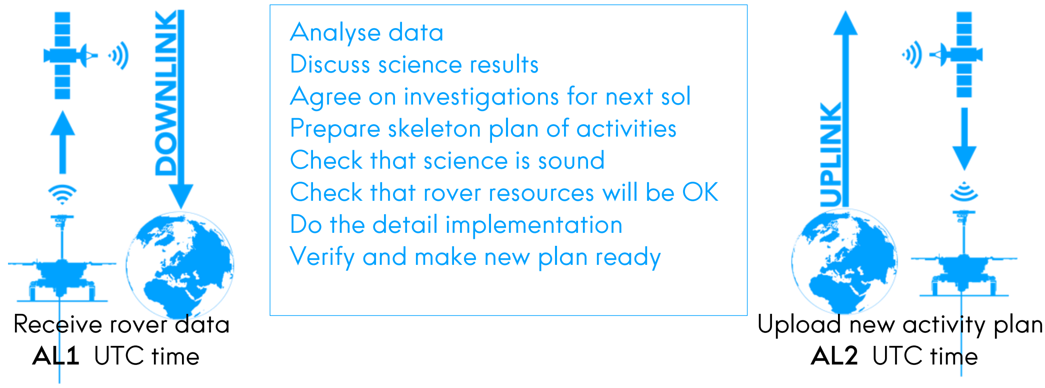


ExoMars rover ground test model, Amalia
ESA/TAS-I/ALTEC

## SURFACE EXPLORATION

As is the case for most landed missions, the ExoMars rover must use an orbiter bridge for transmitting and receiving large blocks of information. This is only possible during an overflight, when the distance rover-satellite is short, affording a good data rate. Rosalind Franklin will benefit from two (occasionally three) such communication opportunities per sol, each lasting between 5 and 8 minutes. Ground control will tell the rover what to do during a morning pass. Rosalind Franklin will work through the Mars day and inform us of what it has accomplished using the next evening pass. The Mars local time of communications passes is not always the same... and sometimes different satellites provide them. This means that we must orchestrate our work at the Rover Operations Control Centre (ROCC) very precisely so that, every day, a new activity plan can be produced, checked, and made ready for upload at the next morning communications pass.

The following example shows how we can set up our watch to help us with this work:




**MET** UTC time for new activity plan ready
**PE1** Science discussion ready: 3 hr before MEP
**PE2** Skeleton plan ready: 2 hr before MEP
**PE3** Engineering check ready: 1 hr before MEP

**M1** ExoMars mission time
**M2** Perseverance mission time

# MISSION CLOCK REFERENCE DATA

Here we discuss how to programme M1 and M2 for tracking active and upcoming Mars missions.

Your watch can report mission time for landers with touchdown dates in the year range 2000 to 2255.

## Mars Science Laboratory 2011 "Curiosity"

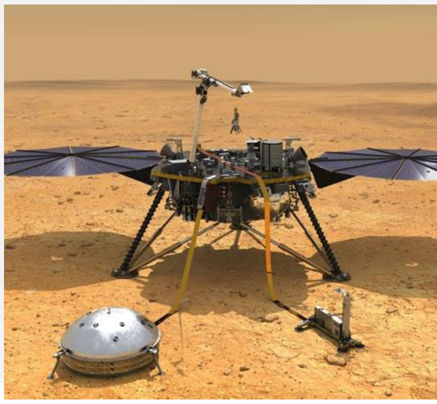
Prior to launch, the MSL project team defined Sol 0 as the solar day on which the rover would touch down on Gale Crater at 137.42°E, the nominal landing site's longitude. However, as a result of course corrections during cruise, Curiosity landed at 137.442°E, slightly "long" of the intended target. As is often the case, the team did not redefine the MSL mission clock to match the actual landing coordinates. Hence, please use 137.42°E. The landing took place on 6 Aug 2012, 05:17:00 (UTC), but we need to programme the watch for 7 Aug 2012 to match the mission sol count, which started at Sol 0.

| | |
|---|---|
| Lon | 137.42°E |
| Date | 2012 Aug 7 |
| Time | 05:17:57 UTC |
| Leap | 34 s |

## InSight 2018

InSight specified its mission clock for a nominal landing at 135.97°E on 26 Nov 2018. The spacecraft touched down at 19:52:59 (UTC) on a location at 135.62°E. The mission clock was not adjusted for the new position. Since landing day was counted as Sol 0, please programme 27 Nov 2018 for the landing date.

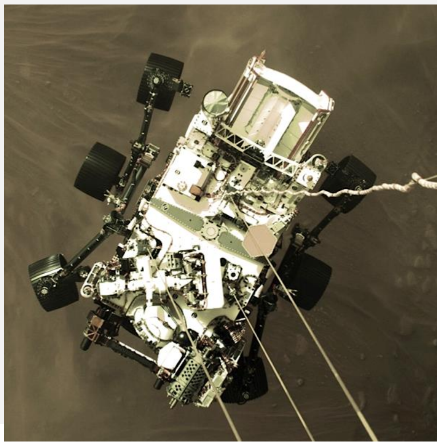
| | |
|---|---|
| Lon | 135.97°E |
| Date | 2018 Nov 27 |
| Time | 19:52:59 UTC |
| Leap | 37 s |



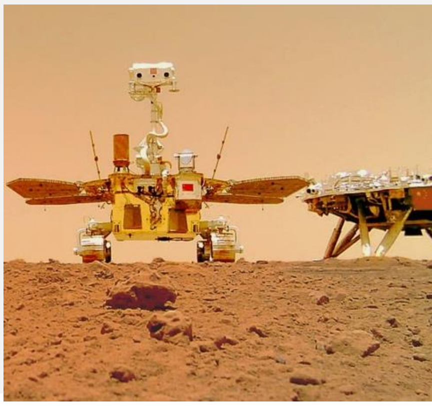
## Mars 2020 "Perseverance"

The Mars2020 project team defined its mission clock considering a landing on Jezero Crater at 77.43°E. Touchdown took place at 11:50:00 (UTC) on 18 Feb 2021. The landing date is counted as Sol 0, so we must programme 19 Feb 2021.

| | |
|---|---|
| Lon | 77.43°E |
| Date | 2021 Feb 19 |
| Time | 11:50:00 UTC |
| Leap | 37 s |



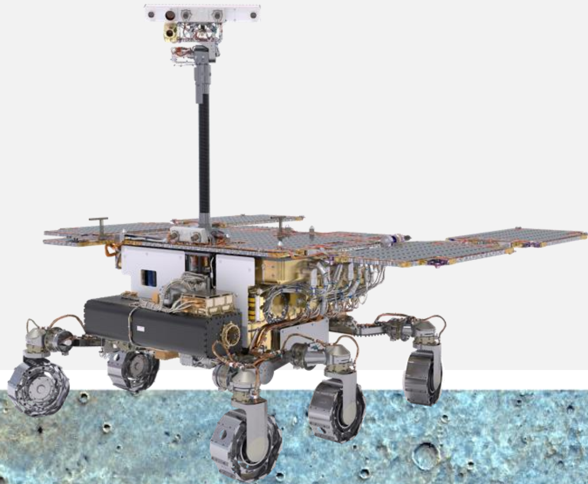
## Tianwen-1 2020 "Zhurong"



It is not known how the Tianwen-1 project team has defined its mission clock time. Touchdown took place at 23:18:00 (UTC) on 15 May 2021.

| | |
|---|---|
| Lon | 109.93°E |
| Date | 2021 May 15 |
| Time | 23:18:00 UTC |
| Leap | 37 s |

## ExoMars 2028 "Rosalind Franklin"



The ExoMars project has designated the landing date to be Sol 1. The nominal touchdown point in Oxia Planum lies at 335.666°E.

The launch trajectory has not been decided, so the landing date and time are not yet known.

| | |
|---|---|
| Lon | 335.67°E |
| Date | 2028 YY ZZ |
| Time | XX:YY:ZZ UTC |
| Leap | XX s |

ExoMars landing site at Oxia Planum
ESA/Roscosmos, TGO, CaSSIS

# MARS SOL AND WEEK NUMBERS

As is the case for our planet, the duration of Mars' orbit around the Sun is not an integer number of sols. A martian year is 668.599 sols long. This means that we must sometimes add an extra sol in our calendar to ensure that, on average, sol 1 coincides as much as possible with $L_S = 0°$. Following this convention, a short (S) Mars year has 668 sols and a long (L) one 669.

The martian leap year sequence is much more complex than Earth's. It repeats every 76 years according to the pattern below:

| | |
|---|---|
| S L S L S L L S L S L L S L S L L S L S L L | 22 years |
| S L S L S L L S L S L L S L S L L S L S L L S L S L L | 27 years |
| S L S L S L L S L S L L S L S L L S L S L L S L S L L | 27 years |

The Mars Coordinated time (MTC) display in your watch correctly reports the year sol number: 1–668 (on short years) and 1–669 (on long ones).

Earlier, when discussing MTC, we explained that the equivalent of the Earth's Julian Date (JD) is the Mars Sol Date (MSD), which provides a running count of sols since noon MTC on 29 Dec 1873. The watch assumes that MSD=0 occurred on a martian Monday and propagates the sols of the week to the present taking into account short and long years.

We next address how week numbers are assigned. For MTC we employ the same ISO 8601 norm that is used for UTC: Week 1 is the week that has the first Thursday of the year. Its Monday is nearest to the year's first day—sol 1

Rear wheel on Rosalind Franklin
ESA/TAS-I/Airbus/MDA

# SPACE QUALIFICATION

In addition to the exacting tests that OMEGA performs for new developments, the Speedmaster X-33 Marstimer platform has undergone additional space environment verification campaigns.

ESA's Large Diameter Centrifuge at ESTEC (NL)

# RADIATION

On 13 October 2021, the French aerospace laboratory, ONERA, performed gamma radiation tests on two watches using a Cobalt 60 source in their Toulouse MEGA bunker facility. They were exposed to 3 Gy to simulate ISS, Moon, and Mars mission doses.

For reference, 3 Gy corresponds to about ten years on board the ISS (~0.26 Gy/yr). The Apollo 11 astronauts experienced about 2 mGy on their Moon voyage. They were lucky. During a solar eruption, doses can reach several Gy on a short time. The estimated dose for a round trip to Mars on a Hohmann transfer orbit is approximately 1.5 Gy, while on the surface is about 0.2 mGy/sol. Some of these values exceed the radiation limits for astronauts (0.6 Gy over their entire career), but your watch can withstand them. For prolonged human missions in deep space to be safe, we must develop effective—and light—spacecraft radiation shielding.


1. Bloshenko et al., Health check from cosmic radiation during manned missions to Mars, *Proc. of Sci.* (2021).
2. A. Märki, Radiation analysis for Moon and Mars missions. *International Journal of Astrophysics and Space Science* **8**(3), 16–26 (2020)
3. Hassler et al., Mars' surface radiation environment measured with the Mars Science laboratory's Curiosity rover, *Science* **343** (2014).


# SPACE ENVIRONMENT

Between December 2021 and February 2022, ESA conducted four different types of tests at its European Space Research and Technology Centre (ESTEC), in the Netherlands. Their objective was to simulate an envelope of conditions that a watch might endure during a round trip mission to Mars.

The tests performed were:

- X, Y, Z, 2-min, 7 g hyper gravity runs on the Large Diameter Centrifuge facility, 10 watches.
- X, Y, Z, 2-min, 20–2000 Hz random vibrations on the Mechanical Systems Laboratory's 22 kN table, 10 watches.
- 10 ambient-vacuum pressure cycles (5 min down, 5-min dwell, 3 min up) at ambient temperature, 10 watches.
- Two 40-hr long, thermal vacuum (TVAC) tests at $10^{-4}$ mb:
    - Procedure 1: 4 hr 0°C, 4 hr –10°C, 4 hr –20°C, 4 hr –30°C, 4 hr –35°C, 4 hr –40°C, 5 watches.
    - Procedure 2: 8 cycles from +75 to –40°C, with 45 min dwell at each temperature plateau, 5 watches.

ExoMars Rosalind Franklin rover
ESA/Mlabspace