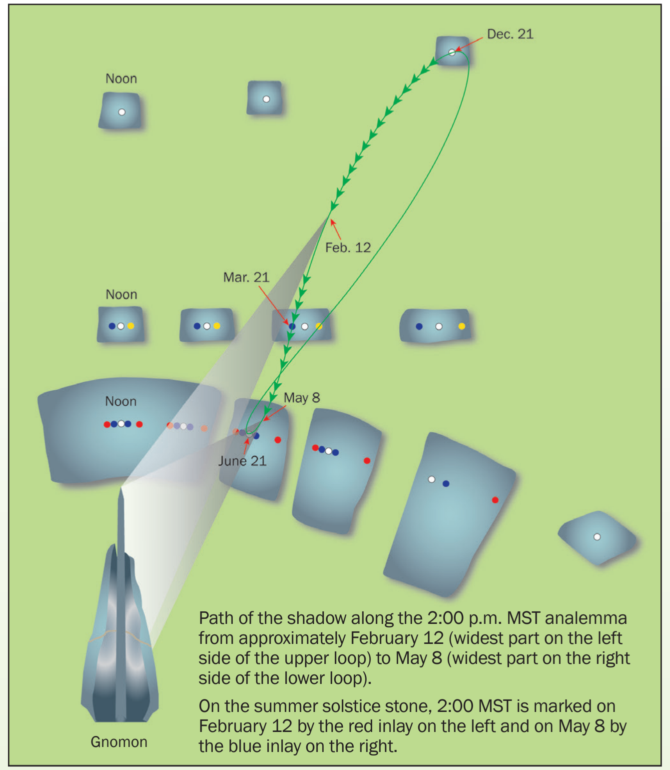


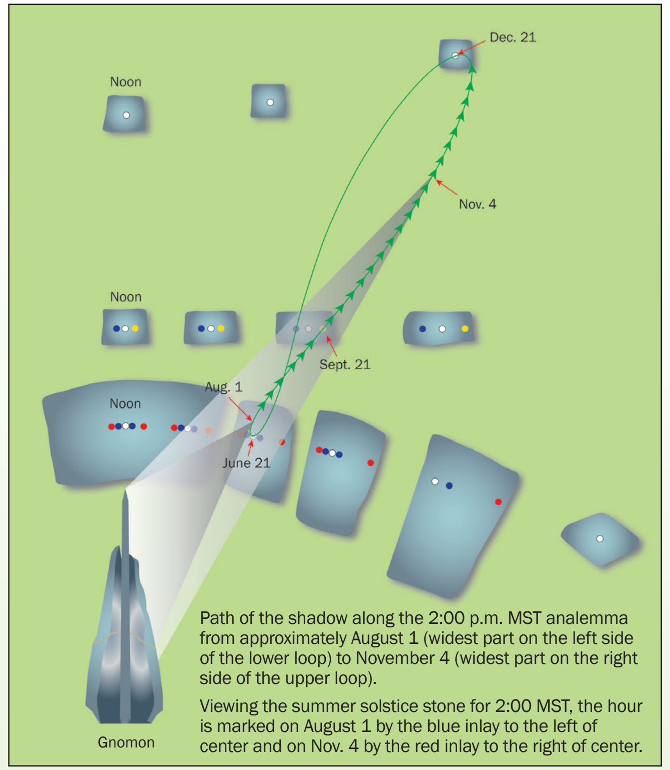
Path of the shadow along the 2:00 p.m. MST analemma from approximately February 12 (widest part on the left side of the upper loop) to May 8 (widest part on the right side of the lower loop).

On the summer solstice stone, 2:00 MST is marked on February 12 by the red inlay on the left and on May 8 by the blue inlay on the right.

will find that there are exact marks for the hours on four days of the year, June 21 (solid white inlays on the inner row), September 21 (yellow-brown inlays on the middle row), December 21 (the single inlays on the outer row), and March 21 (blue inlays on the middle row). On other dates, the white inlays on any row of stones that is crossed by the shadow will mark the hours with some error. However, from the first week of April to the first week of September the error is less than 5 minutes, and at no time is it greater than 16 minutes.

Understanding the Equation of Time

What causes this error? Why doesn't the style's shadow cross the white inlays at the exact hour on every day of the year? The cause arises from the earth's elliptical (rather than circular) orbit and, in part, the earth's axial tilt. As a result of its elliptical orbit, the earth is sometimes traveling slightly toward the sun and sometimes slightly away. When its orbit is curving toward the sun, slightly less than 24 hours is needed to bring the sun around to the same position in the sky, and of course vice versa when the orbit is curving away. The daily errors are small, but they accumulate to as



Path of the shadow along the 2:00 p.m. MST analemma from approximately August 1 (widest part on the left side of the lower loop) to November 4 (widest part on the right side of the upper loop).

Viewing the summer solstice stone for 2:00 MST, the hour is marked on August 1 by the blue inlay to the left of center and on Nov. 4 by the red inlay to the right of center.

much as 14 to 16 minutes in early February and November, respectively.

These errors are expressed formally by the "equation of time." Tables for the errors were used in the 19th century to set clocks for local time. After marking apparent solar noon as the moment when shadows pointed directly north, one would have determined 12:00 noon MST by applying the equation-of-time correction for that date. That would have been true local time. After 1883, when time zones were first used, Eastern Standard Time would have required a further adjustment by adding 11 minutes, 28 seconds (for our longitude).

The Analemma

The equation of time could be graphed on the plane of the sundial's hour markers as the path of the tip of the shadow at exactly the MST hour over the course of the entire year. Such a graph would look like a lopsided "figure 8," and the term for that figure in a sundial is analemma. The analemma for 2:00 p.m. MST at our location is shown in the figures, which depict the location of the tip of the style's shadow on eight dates and the direction of the path it takes over the course of the year. If the Myers Sundial could show the analemmas for all the hours, and if days of the year were ticked along the graphs, then one could precisely mark each hour on any date. The result, after adjustments for longitude and Daylight Savings Time as described above, would agree with your cell phone to within a few seconds.

Instead, our sundial represents the analemmas with colored inlays on the inner row of stones. For each hour, the red inlays to the left and right of center are intersected by the lines of the shadow when the analemma is widest, in the cold months of the year (about February 12 and November 4, respectively). For example, on February 12, 2:00 p.m. MST is marked when the line of the shadow passes through the center of the red inlay on the left side of the cluster of five inlays on this stone. Similarly, the blue inlays to the left and right of center mark the lines of the shadow when the analemma is widest in the warm months of the year (about August 1 and May 8, respectively).

To summarize, small inlays in the stones of the sundial can be used to mark the hours precisely and accurately on eight days during the year (exact dates vary slightly from year to year):

February 12	(left-hand red inlay, inner row)
March 21	(blue inlay, middle row)
May 8	(right-hand blue inlay, inner row)
June 21	(solid white inlay, inner row)
August 1	(left-hand blue inlay, inner row)
September 21	(yellow-brown inlay, middle row)
November 4	(right-hand red inlay, inner row)
December 21	(single inlay, outer row)

Also, as stated previously, from the first week of April to the first week of September, the hour can be marked to within about 5 minutes of correct time (MST) by observing when the shadow bisects any white inlay. Using information provided here, a ruler, and perhaps a calculator, one could interpolate the expected position of the shadow any day of the year and mark the hour accurately to within a couple of minutes (a linear interpolation is only approximate).

A Third Scale of Time

Our sculpture appears to consist of 26 stones, the gnomon plus 25 stones for the hours. However, there is a 27th piece to the sculpture, a stone across the walk and under the Hosler Oak. This stone marks the direction of the gnomon's shadow at noon on the solstices as it would have been 65 million years ago, based on current understanding of the positions of continents and poles in ancient times. The complete sculpture, then, illustrates the passage of time on three scales: over the course of a day (the hours from left to right), a year (the three rows for the solstices and equinoxes and the colored inlays on the inner row marking the limits of the analemma), and a geologic era (the Cenozoic) (the direction of true north from the 27th stone to the current noon stones).

One could, therefore, choose to interpret the sundial from any of these perspectives when visiting the gardens. Of course, one could also choose to enjoy the sundial as a sculpture and get the absolutely correct time from a cell phone.

Visit The Arboretum at Penn State website for more information: www.arboretum.psu.edu/SUNDIAL/

THE ARBORETUM AT PENN STATE

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THE ARBORETUM AT PENN STATE

Joel N. Myers Sundial

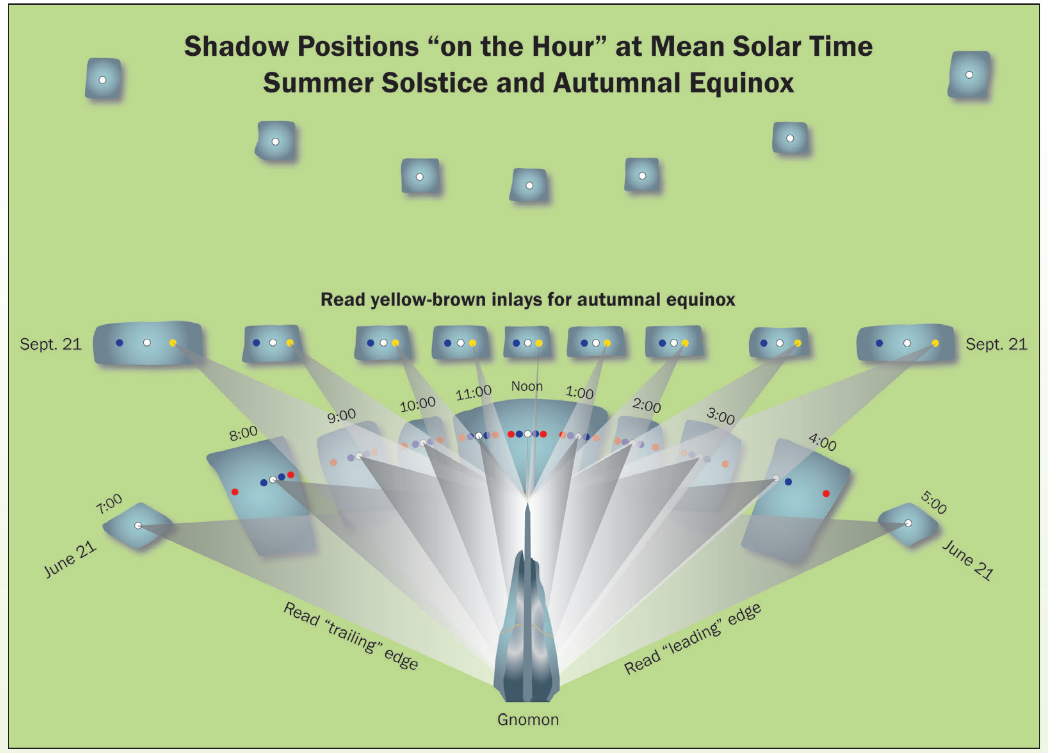
The Myers Sundial in The Arboretum at Penn State was created by sculptor Mark Mennin in 2011 and was made possible by a gift from 1961 Penn State alumnus, Dr. Joel N. Myers, founder of AccuWeather. The Sundial is a granite sculpture that serves as a functionally accurate timepiece and artistic attraction.

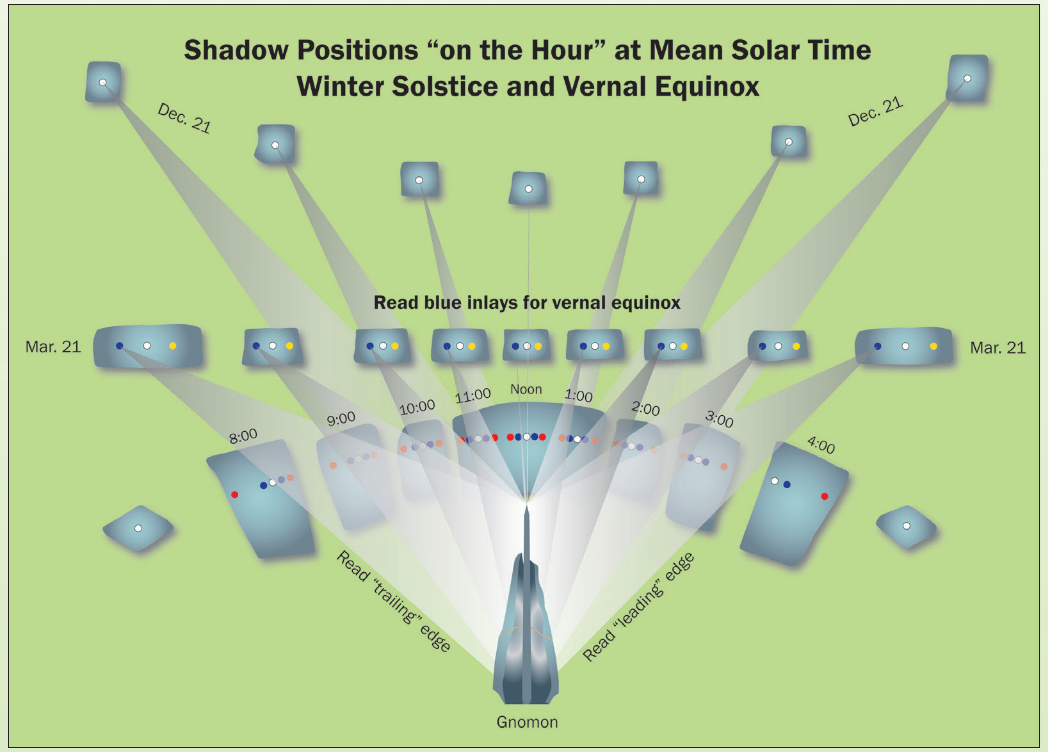
Accurate sundials have existed since ancient times. However, the sundials seen most often are decorative pieces that are valued for their beauty or novelty rather than accuracy and function. Highly accurate sundials as large as the Myers Sundial must be custom-made and installed for their exact locations, and this requires sophisticated technical knowledge and surveying skill. As a piece of sculptural art, the Myers Sundial incorporates features of a functional and highly accurate timepiece.

While everyone can enjoy the artistry of the Myers Sundial, the functionality of the timepiece introduces a complexity that requires explanation, which we provide in this brochure. We hope this information will educate you about our sundial and enrich your understanding of solar time. The following YouTube video "*Explaining the science behind, 'What time is it?'*" (**www.youtube.com/watch?v=Io5kOEYA3Vo**) is also a nice introduction. It features Dr. Chris Palma, who helped with the technical aspects of the Myers Sundial.

What is Mean Solar Time (MST)?

The first thing to understand about the sundial is that it is surprisingly accurate,[1] but it will not usually give you the exact time. As explained below, the various stone inlays mark only the hours with high accuracy. The sundial does not mark minutes, and even the hours are precisely marked on only a few days during the year. Nevertheless, by learning the features of the sundial, you will learn a great deal about the way sundials work and about the relationship between the sun and the earth as told by shadows.





The second thing to understand is that time on the sundial cannot be read directly as Eastern Standard Time or Eastern Daylight Time. Instead, the sundial marks the hours at **Mean Solar Time (MST)** for our exact position on the earth. To convert MST to **Eastern Standard Time (EST)** on your watch, **add 11½ minutes to MST**. The reason for the correction is that our time zone is 5 hours behind Greenwich Mean Time, but our longitude (77° 52′ 08″) is 5 hours, 11 minutes, and 28 seconds "behind" the Greenwich Meridian (0° longitude). Stated another way, the sun is directly overhead State College 5 hours, 11 minutes, and 28 seconds after it is directly overhead Greenwich, England.

So, for example, when the sundial reads 12:00 noon MST, your watch should read 12:11:28 EST or 1:11:28 EDT (Eastern Daylight Time).

The Gnomon

Now let's look at the parts of the sundial. The tall structure that is represented near the bottom of the diagrams is the gnomon (NO mon), and its upper edge is called the style. Gnomon styles must point directly north, and ours is set at an angle to the horizontal of 40° 48′ 18″. That is the latitude of the sundial's location, and angled in this fashion the style is exactly parallel to the earth's axis of rotation.

Time is marked by the style's shadow as it crosses the three rows of low stones to the north of the gnomon. Viewed from the gnomon, the shadow moves left to right over the course of the day as the sun transits from east to west. The full length of the style – not just the tip – defines the edge of the shadow for telling time. In the morning, the style's shadow is the trailing edge or the edge being "pulled" by the rest of the gnomon's shadow. In the afternoon, the style's shadow is the leading edge or the edge being "pushed" by the rest of the gnomon's shadow. Place your hand anywhere along the style's edge. The shadow of your hand can help you to identity the edge of the style's shadow.

For quick reference, you can read the sundial by looking at the placement of the style's shadow on the arched row of stones closest to the gnomon. The central, solid white, inlays on these stones mark the approximate average position of the style's shadow on the hour (MST) from 7:00 a.m. (stone on far left) to 5:00 p.m. (stone on far right). This inlay will mark the hour to within 16 minutes of accuracy on any day of the year (provided there is sunlight!).

What do the inlays tell us?

For a more precise reading of the sundial, the hours are indicated by variously colored inlays within the stones. The hours are not labelled, but 12:00 noon is directly north of the gnomon. Counting on either side of "noon" in the middle stone closest to the gnomon, there are inlays representing the hours of 7:00 a.m. to 11:00 a.m. on the left and 1:00 p.m. to 5:00 p.m. on the right. In this arc of stones, 11:00 a.m., noon, and 1:00 p.m. are all on the same stone.

The middle row of stones (in a straight line) has the hours from 8:00 a.m. to 4:00 p.m., and the distant arc has the hours 9:00 a.m. to 3:00 p.m. Remember, these are Mean Solar Time hours.

As shown in the diagrams, the inlays on the three rows of stones mark the path of the *tip* of the style's shadow on four dates: the summer solstice (usually June 21), the autumn and spring equinoxes (September 21 and March 21), and the winter solstice (December 21). Note that the shadow touches or crosses the inlays on the inner (summer solstice) row of stones on every day of the year. It touches or crosses the middle (equinox) row of inlays on half of the days of the year. And it touches the outer (winter solstice) row on only a single day (December 21).

Because the inner row is *always* touched by the style's shadow, this row is more useful than the others for telling time. The design of the sundial provides more detail in this row in the form of five inlays for most of the hours (7:00 a.m. and 5:00 p.m. have only a single inlay, and 4:00 p.m. has only three).[2] On the inner row of stones, the central (solid white) inlay marks the approximate average position of the shadow at that hour for every day of the year. Also, as shown in the top diagram on the previous page, the white inlay marks exactly that hour on June 21 (for example, 8:00 a.m. MST). If you study the two figures carefully, you

[1] Positions and angles for the pieces were surveyed with the highest accuracy. The slightly rounded edge of the gnomon's style and other sculptural elements introduce some small errors.

[2] Some stones appear to have extra inlays of the same granite as the stone itself. These are plugs for bolts used to secure cantilevered stones to their footers.