THE (not so) LITTLE BOOK
of
ASTRONOMICAL CURIOSITIES

and Explanations of Celestial Phenomena

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PREFACE

This book is intended for amateur astronomers and more generally for anyone with an interest in astronomy. I hope it will further pique the reader's interest in the solar system and beyond. Fifty-nine eclectic topics fall into two general types, with some overlap. Many of the topics selected are ones that I think might contain a surprise and will intrigue you—"Wow" topics for short. Other topics provide explanations for various often-asked questions about celestial phenomena. Some of these latter topics involve mathematical arguments. A few of these arguments are included within the topics themselves, but most are in appendices at the end of the book and are intended for those of a more mathematical bent. Those who prefer to avoid mathematical intricacies can concentrate on the main text which I believe they will find quite interesting.

While reading the book one is struck by the number of scientific disciplines—including chemistry, optics, geology, and physics (even a little quantum mechanics)—that are involved in discussing astronomy. I do not assume the reader has a background in any of these areas. My goal is to carefully provide sufficient information to appreciate their application to astronomy.

Because there are 249 diagrams and images plus five tables accompanying the text, I have chosen to use higher-quality ink and paper. While these upgrades increase the cost of the book, they are essential for fully enjoying the subject matter.

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About the author: Since childhood Robert Douglas has been interested in astronomy and science fiction. He is an active night-sky observer using several telescopes he has acquired over the years.

He received his Ph.D. in mathematics in 1968 from the University of Washington, Seattle. After spending an International Combinatorial Year in the Department of Statistics at UNC Chapel Hill, he joined the mathematics faculty at San Francisco State University. Additionally, he has been a member of the computer science faculty since the department's inception in 1983. He remained at SFSU (with brief time off for sabbaticals at Harvard and the University of Washington and to study computer science at MIT on an NSF grant) until his retirement as Professor of Mathematics and Computer Science in 2000.

He is a member of the San Francisco Amateur Astronomers, the Rose City Astronomers (Portland, Oregon), the Tucson Amateur Astronomy Association, the Planetary Society, and the American Mathematical Society.

He has traveled to Australia nine times for its night skies, a journey he hopes all amateur observational astronomers and astrophotographers can make at least once in a lifetime.

Acknowledgments: My thanks to Alan Agrawal, M.D.; Steve Gottlieb, M.A. (Mathematics), a *Sky & Telescope* Contributing Editor; and Akarsh Simha, Ph.D. (Physics) for their many helpful suggestions, and to my wife, Fran Marsh, for her editorial and graphic assistance.

On the cover: The Homunculus of the star Eta Carinae
NASA/HST/J. Morse/K. Davidson http://chandra.harvard.edu/photo/1999/0099/

CONTENTS

...strange things may be generally accounted for
if their cause be fairly searched out.
—Jane Austen, Northanger Abbey c 1798

TOPIC 1. Miranda is perhaps the most bizarre moon in the solar system. It also has the highest known cliff in the solar system.

When the physicist Isidor Rabi learned of the discovery of the sub-atomic particle the muon he said, "Who ordered that?" The muon's existence had come as a complete surprise to physicists. Likewise, astronomers were stunned when the first images of Uranus' moon Miranda were returned from Voyager 2 in January 1986. The surface was a hodgepodge of dissimilar terrains. The regions seemed sewn together like Frankenstein.

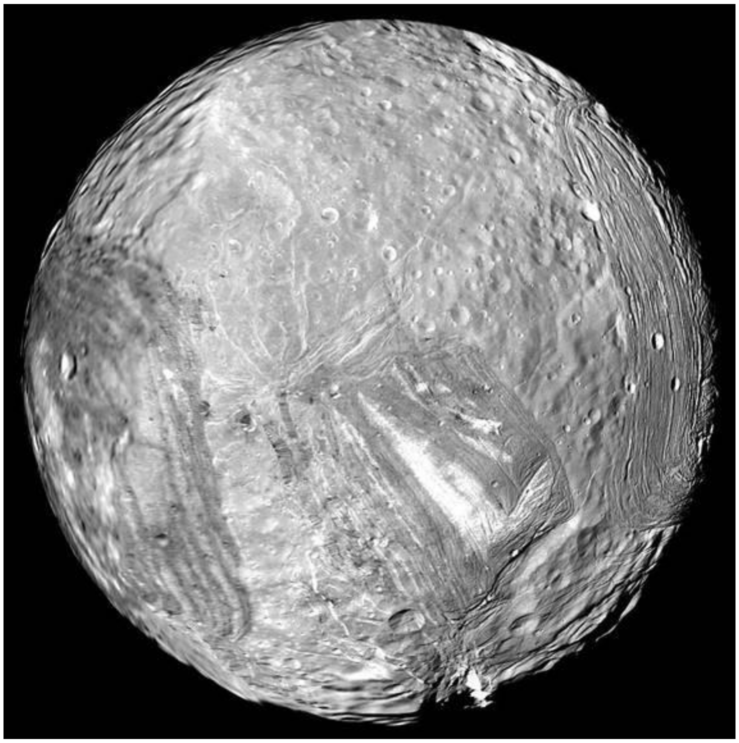

Figure 1. Miranda imaged by NASA's Voyager 2. January 24, 1986. Credit: NASA/JPL-Caltech

Of the five moons of Uranus known prior to the Voyager 2 mission, Miranda is the smallest and the closest to Uranus. Its mean diameter is 293 miles (472 kilometers), and it orbits Uranus in 34 hours at a mean distance of about 80,642 miles (129,780 kilometers).

Voyager 2 was a flyby mission and only imaged the southern hemisphere. Unusual terrain lying in the northern hemisphere will have to wait for another mission. If Miranda has a rival for its peculiarity, it would be Io, Jupiter's volcanic moon (see Topic 7).

From the surface of Miranda, Uranus would be a cyan (bluish-green) ball roughly 22.5 degrees in diameter, or about 45 times the angular diameter of our Moon as seen from Earth. That would indeed be an awesome sight. See *Appendix 1.1* for the calculation. Uranus' cyan color is caused by methane absorbing red light.

Two conspicuous regions in Figure 1 are the "Chevron," a bright, V-shaped feature in a darker, rectangular region, and the oblong, grooved terrain, called coronae, in the upper right, bringing to mind ancient Rome's Circus Maximus chariot racetrack. Regarding the rectangular region, it is unusual to see straight lines in natural terrain.

Several theories[2,3,4] have been put forward to explain the strange appearance of Miranda, one of which is that Miranda in the past had a more eccentric orbit which resulted in tidal heating due to Uranus' gravity (similar to that on Io due to Jupiter's gravity), causing upwelling of softer material.

Now for something that future ecotours in the solar system will advertise: The ultimate experience for those who love to climb cliffs is on Miranda, namely *Verona Rupes*—the highest cliff in the solar system. See Figures 2 and 3. The cliff is currently estimated to be an astonishing 12 miles (20 kilometers) high.[1,2] If you fell or jumped off of it, it would take about 12 minutes to reach the bottom. The long fall time is due to the very low acceleration of gravity on the moon, namely 0.079 meters/second^2 (compared to the Earth's 9.807 meters/second^2). See *Appendix 1.2* for the calculation. If you were climbing it and fell (perhaps not too near the top) you might even survive. But you might want to take an inflatable airbag with you. If you jumped off from the top of the cliff you would be hitting the bottom at about 125 mph (202 kilometers per hour). See *Appendix 1.2* for the calculation.

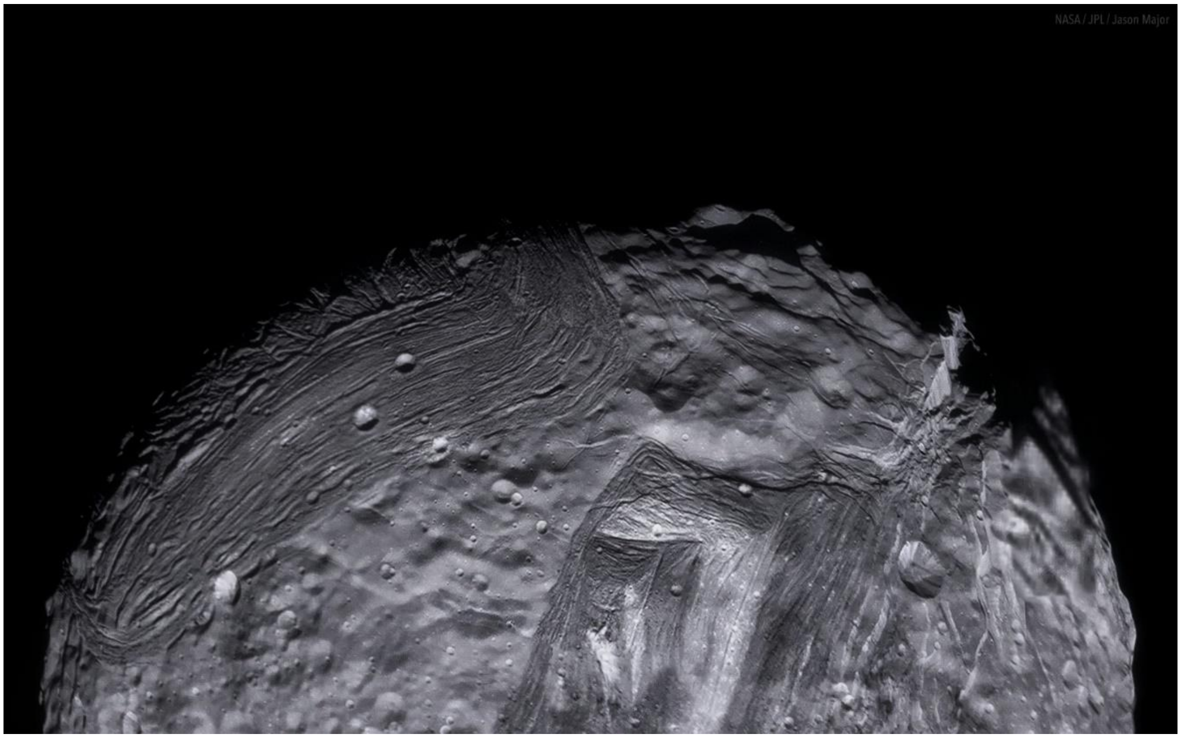

Figure 2. The Circus Maximus region (on the right in Figure 1) is prominent here in the upper left. Verona Rupes (cliff) is on display in the upper right edge and is pointed to by the Chevron. Credit: Voyager 2 (NASA)

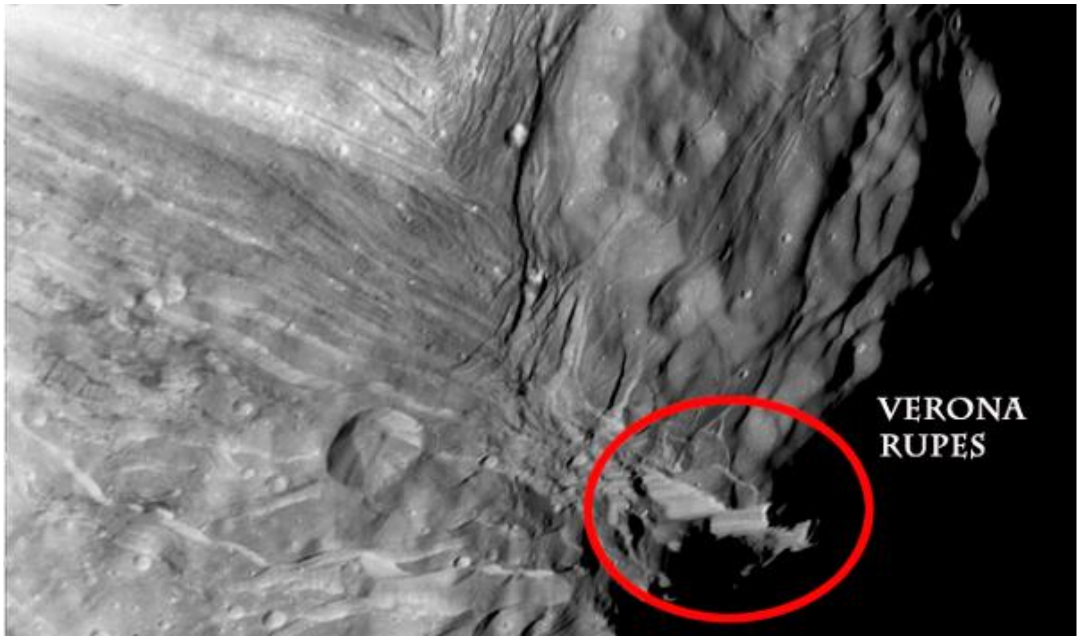

Figure 3. A closer view of Verona Rupes. Credit: Voyager 2 (NASA)

Figure 4. Base jumping off the tallest cliff in the Solar System. Credit: Erik Wernquist, www.erik wernquist.com/wanderers. Wernquist also produced visuals for a beautiful, short film Wanderers, *written and narrated by Carl Sagan—from his book "Pale Blue Dot," courtesy Ann Druyan.*

To give you some perspective on *Verona Rupes'* height, the highest cliff on Earth is on Mount Thor in northern Canada. The mountain itself is 5,495 feet (1,675 meters) high—a little over a mile. Its cliff drops 4,101 feet (1,250 meters) and overhangs at an angle of 105 degrees—steeper than vertical.

Figure 5. Mount Thor on Baffin Island in northern Canada.
Its cliff is the largest drop on Earth. Credit: ***bwallpaperhd.com***

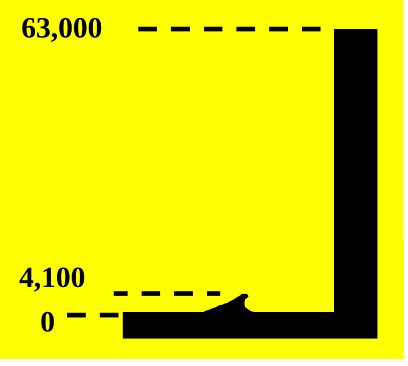

Figure 6. A height comparison. Mt. Thor's cliff on the left at 4,100 feet vs Verona Rupes on the right at 63,000 feet.

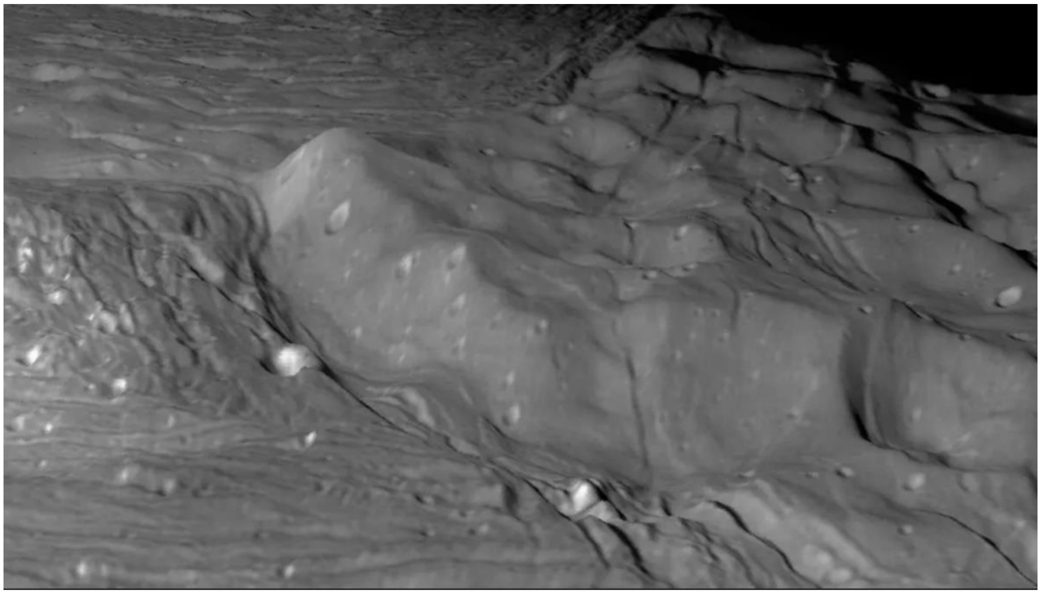

Figure 7. A closeup of the terrain just above the Chevron in Figure 2. It shows cliffs (not Verona Rupes). In the upper left is the edge of the Circus Maximus. Credit: Voyager 2 (NASA)

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It is like the two are staring at each other
never breaking their gaze,
as they waltz around the solar system…

—Maggie Aderin-Pocock
The Book of the Moon: A Guide to Our Closest Neighbor

TOPIC 2. Pluto's largest moon is Charon. How would Charon appear from Pluto's surface?

Everyone knows that our Moon is tidally locked (also called gravitationally locked) to the Earth, that is, the Moon rotates once on its axis for each revolution of the Moon about the Earth. So, on Earth we can see only one side of the Moon. Indeed, many moons in our solar system are tidally locked to the planet they revolve around.

In the case of the dwarf planet Pluto we have an unusual situation. Pluto's largest moon Charon (half the diameter of Pluto itself) is tidally locked to Pluto, but Pluto is also tidally locked to Charon. So if you were on the "far" side of Pluto, you would never see Charon. Getting in your Pluto car and driving to the other side of Pluto would result in quite a shock when in the sky there would appear this enormous moon. How large would Charon be to an observer on Pluto? The answer is 3.76 degrees, i.e., about seven times the diameter of our Moon. See *Appendix 2.1* for the mathematical details. And Pluto would be 7.18 degrees, i.e., about 14 (Earth) Moon diameters in size as seen from Charon.

Figure 1. Pluto and Charon as viewed by NewHorizons, July 11, 2015.

It is interesting to note that it is not the case that a moon revolves around its primary. Strictly speaking both the moon and its primary revolve about a point called the *barycenter* (or center of gravity) which is on a line between the centers of the two objects. Usually the primary (e.g., the Earth) is so much more massive than its moon that the barycenter lies inside the primary. In the case of Pluto and Charon the barycenter lies outside the surface of Pluto. Pluto and Charon have been called double planets.

Some statistics for Pluto and Charon: Pluto is 1,477 miles in diameter and Charon is 750 miles. The distance between their centers is 12,160 miles.

Change is inevitable. Change is constant.

—Benjamin Disraeli

TOPIC 3. The sky has changed dramatically over the time of human civilization. For most of human history Polaris was not special—it was not the pole star until relatively recently. During the Roman empire there was no pole star. The ancient Greeks could see the Southern Cross from the Mediterranean. Not now. And for the Egyptians at the time of the first Pharaohs the sky was different still.

When the pyramids were built around 2550 BCE, the star Thuban in the constellation Draco appeared very near true north. True north or the *north celestial pole* (NCP) refers to the northern point on the celestial sphere to which the Earth's axis points. At its closest approach in 2830 BCE Thuban was less than 10 arc minutes (one arc minute = 1/60th of a degree) from the NCP. At the present time Polaris is about 40 arc minutes from the NCP and will be closest just after 2100 when it will be about 27 arc minutes away—not as close as Thuban got. Keep in mind that the Moon and Sun are each 30 arc minutes (a half a degree) in diameter. At the time of the ancient Greeks (~350 BCE) the NCP lay halfway between Thuban and Polaris––about 10 degrees from each. During the entire history of the Roman empire there was no pole star. It wasn't until about the 12th century CE that Polaris might reasonably be considered the Pole Star.

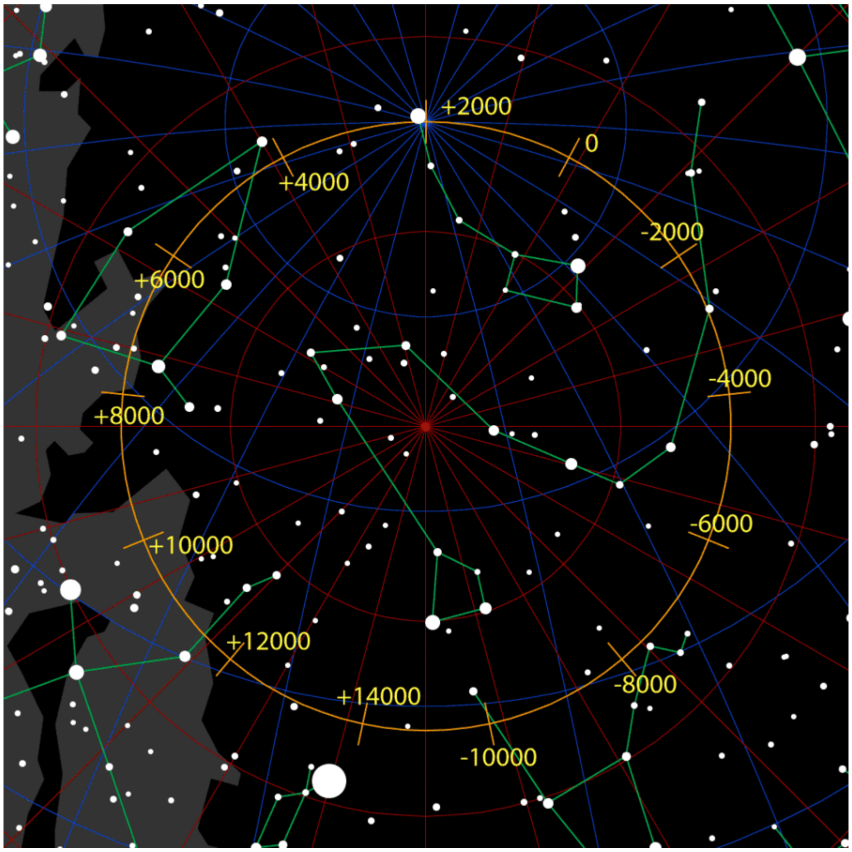

Figure 1. The circle traces the location of the NCP for one complete wobble of the Earth's axis. Credit: Tau'olunga

Figure 1 shows the circle that the NCP traces over about 26,000 years. Polaris is at 12 o'clock. Thuban is the star on the circle CW from Polaris that lies between the years -2000 and -4000. You can see that other stars near the circle and CCW from Polaris will become the pole star in the future. But other than the first-magnitude star Vega (at about 6:30 o'clock), Polaris is the brightest. In about 14000 CE, Vega will be within five degrees of the NCP, not anywhere near as close as Polaris comes. Interestingly, at the same time, Canopus (the second-brightest star in sky) will be within eight degrees of the south celestial pole (SCP). That is because Vega and Canopus are virtually antipodes of each other (opposite each other on the celestial sphere).[2] In about 2800 BCE, the first-magnitude star Achernar was about eight degrees from the SCP, at the same time that Thuban was within about 10 arc minutes of the NCP. Currently the SCP is in the constellation Octans and is without a pole star.

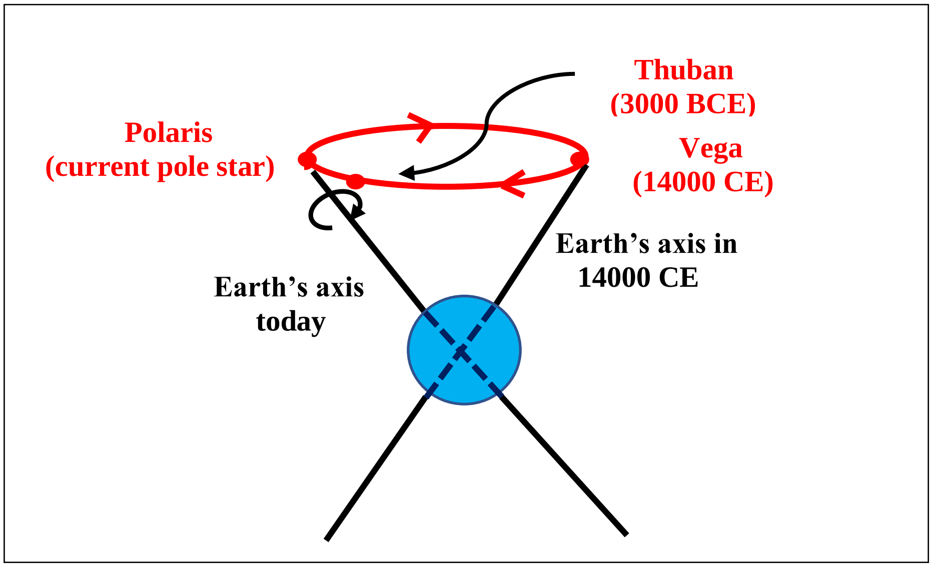

Figure 2. The Earth's axis spins like a top or a gyroscope completing one circuit in 26,000 years.

Why is the NCP (and the SCP) changing in a circular cycle? The reason is that the Earth is spinning like a top. So, in addition to the Earth rotating about its axis, its axis rotates as well, tracing a large circle on the celestial sphere. But unlike the rapid rotation of the axis of a top, the Earth's axis makes one circle against the background stars about every 26,000 years. The Earthly top precesses (wobbles) slowly (at least compared to a human life span). The cause of this wobble is the combined gravitational attraction of the Sun and Moon on the Earth's equatorial bulge. This bulge is from centrifugal force caused by the Earth rotating about its axis every 24 hours. See *Appendix 3.1* for more details. The wobble of the Earth's axis produces a related effect called the "*precession of the equinoxes*." By this we mean a shifting or rotation of the equinoxes against the background stars (the stars in the zodiac).

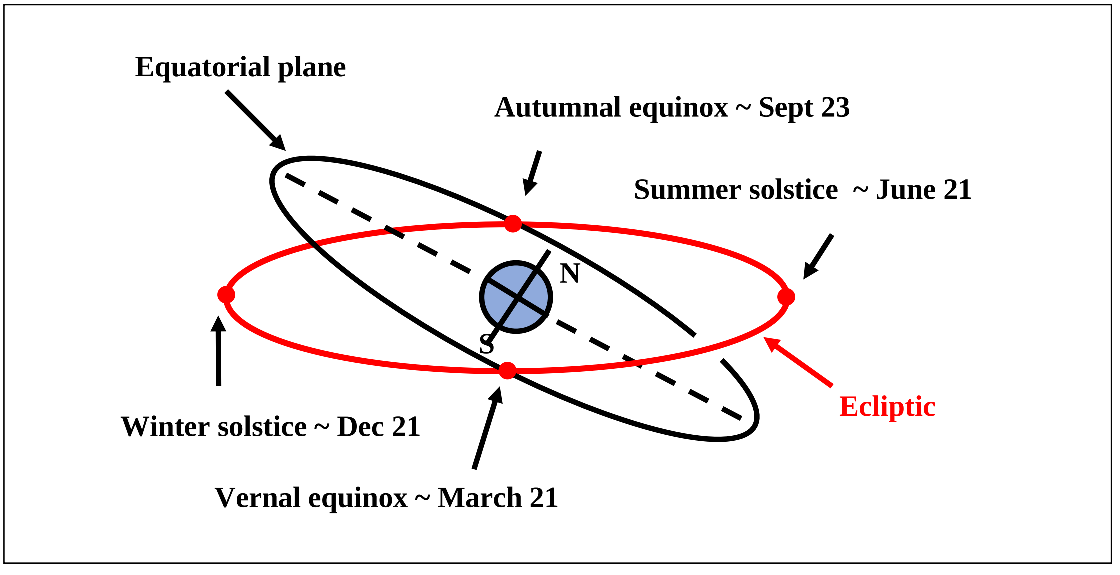

Figure 3. The ecliptic (red ellipse) defines the plane of the of the Earth's orbit around the Sun. It is the projection of the orbital plane of the Earth onto the celestial sphere (the background stars). The black ellipse is the projection of the Earth's equator onto the celestial sphere (and is currently inclined 23.5 degrees to the ecliptic plane). From the

point of view of an observer on Earth, the Sun travels in one year around the red ellipse.

First we need some terminology. The *celestial equator* is the projection of the Earth's equator onto the celestial sphere (an imaginary sphere centered on the Earth and containing the stars as seen from Earth). The Earth revolves about the Sun, and the plane defined by the Earth's path intersects the celestial sphere in a circle called the *ecliptic*. The ecliptic is the path that the Sun takes against the background stars over the course of one year as seen from Earth. The inclination of the plane determined by the ecliptic with the plane determined by the celestial equator is currently about 23.5 degrees. The two points where the ecliptic and celestial circles intersect are called *equinoxes,* and when the Sun is at either of these points the length of the day and night are (almost) the same everywhere on Earth. One of these points is called the *autumnal equinox* (~September 23) and the other is the *vernal equinox* (~March 21).

Now you might think that if the axis of the Earth wobbles 360 degrees in about 26,000 years, that the ecliptic (one large circle) would swivel around the celestial equator (a second large circle) with the two equinoxes rotating 360 degrees around the celestial equator in 26,000 years. And you would be correct. This is called the *precession of the equinoxes.* At the time of the ancient Greeks the point on the celestial sphere for the vernal equinox was in the constellation Aries. It was there from 1865 BCE to 68 BCE. It is now in Pisces until 2597, when it moves into Aquarius (the dawning of the age of Aquarius).

In addition to the equinoxes we also have two other important points: the solstices. As seen from Earth, when the Sun is at the farthest northern point on the ecliptic from the celestial equator, we are at the *summer solstice;* when the Sun is at the farthest southern point on the ecliptic from the celestial equator, we are at the *winter solstice.* (Of course, the words summer and winter are only applicable from the vantage point of someone in the northern hemisphere—the reverse holds in the southern hemisphere.) At the time of the ancient Greeks the point on the celestial sphere for the summer solstice was in the constellation Cancer and that for the winter solstice was in Capricorn. Hence the circles of latitude for the summer solstice and winter solstice are respectively called the Tropic of Cancer and the Tropic of Capricorn. At solstices it is at these circles of latitude where the Sun is found directly overhead. But the solstice points have moved due to precession of the equinoxes so that now these points are actually in the constellations Gemini and Aquarius. Should we thus change these names to the Tropic of Gemini and the Tropic of Aquarius? Well, the old names have stuck despite this change.

The above discussion sounds technical, but *the precession of the equinoxes actually has changed what parts of the night sky are visible at any given latitude*. For example, at the time of the ancient Greeks the Southern Cross was visible from the Mediterranean, but is not now. That should be clear as the NCP has shifted position in the night sky, so all other points on the celestial sphere must have also changed position in the night sky.

It is also easy to see this with another argument. Consider a person at a (northern) latitude looking at a star a little above his/her southern horizon. See Figure 4a. Then consider the extreme case of the orientation of Earth 13,000 years later (so the Earth's axis has rotated 180 degrees around the circle traced by the NCP). The same person (much older now) again tries to see the same star. It is clear from Figure 4b that now the star has sunk below the southern horizon.

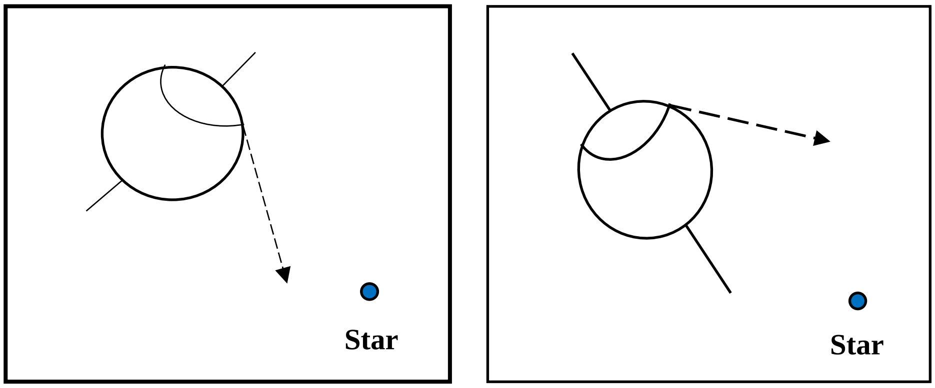

Figure 4a (left). The dashed line is tangent to the Earth's surface at the location of a person, defining the person's southern horizon. A southern star is visible. Figure 4b (right). Thirteen thousand years later the Earth's axis has rotated 180 degrees around the circle traced by the NCP. The same star is now below the southern horizon.

One might very well ask if the angle of about 23.5 degrees between the plane of the celestial equator and the ecliptic plane (the angle of obliquity) changes over time. Indeed it does. That will also affect where the NCP and the Tropic of Cancer (and Capricorn) are against the fixed stars. This effect is due to the combined gravitational attraction of the other planets on the Earth causing the orbital plane of the Earth to precess (relative to distant stars) in a period of approximately 71,000 years. So here it is *the ecliptic plane* that is changing. This is in contrast with the 26,000-year wobble in which the plane of the celestial equator changes. Both effects combine to cause the obliquity to oscillate in an approximately 41,000-year period. But the change is only about ±1.3 degrees, the average obliquity being 23.3 degrees.

If it were not for the Earth having a large moon, this change would be much greater and would lead to large climate fluctuations occurring over any given spot on the Earth. Such a scenario would have adversely affected the ability of life to arise and to sustain itself. Think of a tropical area having a sheet of ice over it in a relatively short (geologically speaking) time period. Living creatures would have to adapt quickly or perish.

While 1.3 degrees is a small angular deviation in the sky, there is a rather dramatic effect on land. Currently the Tropic of Cancer is close to its average position, but is changing at about its fastest rate, namely about 14 meters (approximately 45.5 feet) a year. In 10 years that is 1.5 football fields. In 1908 the Japanese colonial government in Taiwan erected a concrete landmark at the spot where the Tropic of Cancer crossed a newly completed railroad line. Since then the Taiwanese government has made the area a park. But now the Tropic of Cancer has moved entirely out of the park and the administration cannot acquire more land.[1]

I give another illustration to show the effect of the precession of the equinoxes. If someone is asked what a year is, the response might be that it is the time for the Earth to make one orbit around the Sun. But that year is the orbital period of the Earth around the Sun, called a *sidereal year*, which is the time it takes for the Sun to move from one location with respect to the background *"fixed" stars* back to the same location.

However, that is not what a year is with respect to our calendars. We use a calendar that is based on the *seasons*, not on the fixed stars. We use a *solar year*, also called the *synodic year or tropical year*, which is the time the Sun takes to return to the same position in the cycle of seasons, as seen from Earth. For example, it is the time from vernal equinox to vernal equinox, or from summer solstice to summer solstice. That is a more useful year for agricultural purposes—of interest to all peoples in the history of the world. One sidereal year is 365 days, 6 hours, 9 minutes, 10 seconds. One solar year is 365 days, 5 hours, 48 minutes, 45 seconds. So a sidereal year is about 20 minutes longer than one solar year.

Suppose the Mayans constructed a temple so that the Sun's rays on summer solstice at noon would pass through an opening in the temple and light up an inside passageway. Further suppose they presumed that in each succeeding year this event would repeat. If the year-long period is defined as a solar year, then the precession of the equinoxes is already taken into consideration. No problem. But if by a year one means a sidereal year, then after just one year the Sun would be seen in the passageway not at noon, but 20 minutes before noon. And after three years, the event would occur one hour too early. Using the sidereal year doesn't take into consideration the precession of the equinoxes, with disastrous consequences.

Finally, let us instead assume that the passageway was desired to be constructed so that the star Sirius could be seen from it when Sirius, year after year, reached its highest point in the sky (i.e., was on the meridian). From our earlier discussion we see that this is not possible as the positions of the stars in the whole sky are shifted due to precession of the equinoxes. From some latitudes Sirius would be visible for many years during the 26,000-year precession, and for many other years, from those same latitudes, it would never be visible.

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2. Berman, Bob (March 2021). Voyage to the antipodes. *Astronomy Magazine,* p 12. Here Berman points out that Vega and Canopus are antipodal to each other and the consequence that they will simultaneously be (almost) pole stars.