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University Lowbrow Astronomers

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Latitude and Longitude from the Stars

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There was a time in the not too distant past when the Sun and stars were used extensively for navigation and geodetic surveying. Celestial navigation was, at one time, the primary method of determining one's position at sea. The stars were also routinely used in determining latitude and longitude of control points to establish absolute positions of geodetic triangulation networks. With the advent of GPS though, navigation and surveying have experienced dramatic changes. Still, there are applications where the Sun and stars are used. In surveying, the Sun and Polaris are used to determine absolute azimuth. Stars are also used to determine attitude of spacecraft. The use of the stars to determine latitude and longitude, however, has been mostly supplanted by GPS. In spite of this, there are people who practice celestial navigation just for the fun of it, or as a back-up in case other navigation systems fail.

I became interested in the use of stars to determine latitude and longitude by reading accounts of geodetic surveys of India and France, and books on surveying and celestial navigation. It seemed like an interesting thing to do, so I decided to try it myself. To do this, however, I would need a sextant or theodolite. These instruments are rather expensive to buy just to play with, so I decided to make my own theodolite. The measurements that I would need to make were elevation angles or their complement zenith angles. Theodolites usually measure both vertical and horizontal angles. I only needed to measure vertical angles, so my theodolite does not measure horizontal angles. It is not really a theodolite with full measurement capabilities. My theodolite was built mostly from materials lying around in my basement that had been collected over the years. I purchased a 360 degree protractor that had markings every half degree to measure the angles. With a full 360 degree measurement capability, redundant measurements of star zenith angles can be made that cancel certain errors. The other item I purchased was a surveyors tripod to support the instrument in the field.

Figure 1 Zenith Angle Measuring Theodolite

A photo of the theodolite is shown in Figure 1. It consists of a small telescope mounted on a common ½ inch shaft with the protractor. I had a supply of fiber gears from old teletype machines that a friend had given me years ago. These

Figure 2 Close-Up Showing Vernier Dial and Spirit Level

gears were used as both bearings and bushings on the shaft. In addition to the protractor, an adjustable vernier arm was fabricated that held the vernier dial and a spirit level for measuring zenith angle with respect to the local gravity gradient. Tangent arms for fine adjustment of both the telescope and the spirit level were incorporated in the instrument. A close-up photo of the vernier dial and spirit level is shown in Figure 2. Since the instrument did not have an illuminated reticle, I mounted a small LED directly in front of the objective lens of the telescope. The light from the LED produces an out-of-focus blob of red light which back-lights the cross wire reticle. The LED current is adjusted so that a faint background light illuminates the cross wire reticle but does not overpower the light from the star. The LED attachment is shown in Figure 3.

The procedure for measuring star zenith angles with my theodolite is to first set up and level the tripod. This is done with a small circular spirit level. The instrument is then placed on the tripod and secured with a hand nut. The telescope is centered on a star using first coarse motion and then fine adjustment with the tangent screw. When the star is centered on the horizontal cross wire, the time is immediately recorded. It is important that time be recorded to within a second or two because the point on the Earth for which latitude and longitude are to be determined is moving rapidly. On the Equator, points are moving at a speed of about 460 meters per second in an easterly direction. At my latitude (about 42.5 degrees north), this motion is only about 340 meters per second, but this is still rather fast. This motion can be sensed easily by observing stars that are rising or setting. Within a few seconds, they can be seen to move away from the horizontal cross wire of the telescope a significant distance. When the time is recorded, the vernier tangent arm is adjusted so as to center the bubble of the spirit level. This establishes the angular orientation of the vernier with respect to the local gravity gradient or plumb line. The zenith angle is then read on the protractor using the vernier to estimate the angle to the nearest 0.1 degrees. A second measurement of the same star is then made by reversing the direction of the telescope and rotating the instrument horizontally 180 degrees. The zenith angle measured using the telescope reversed is 360 degrees minus the value indicated on the protractor. For example, if the zenith angle read in the forward direction is 30 degrees, the angle read in the reverse direction would be 330 degrees (plus errors). The reason for making these two measurements is that any error in the alignment of the telescope with respect to the protractor (collimation error) will be canceled when the two zenith angles are averaged.

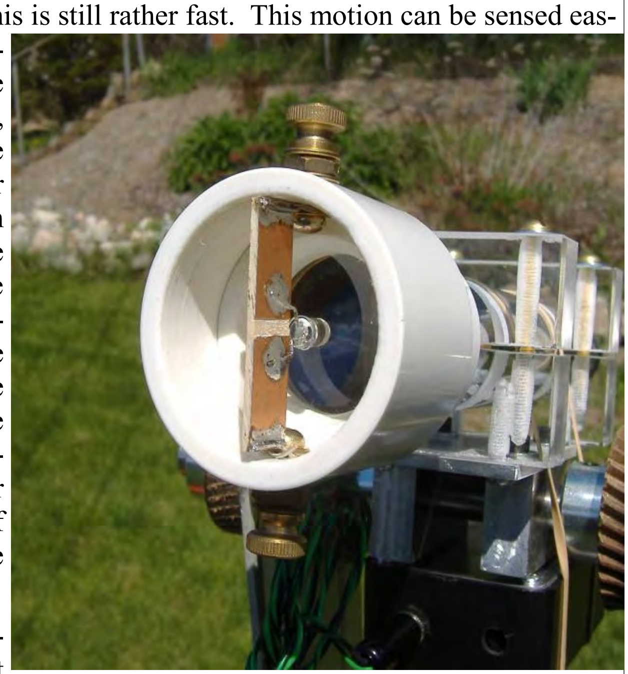


Figure 3 LED Background Illumination Attachment

To determine both latitude and longitude, at least two star measurements are required. To improve accuracy, I usually measure about 10 stars and use the weighted least squares technique to solve for latitude and longitude. The solution for latitude and longitude is based on the following relationship between zenith angle, latitude, longitude, star right ascension and declination, and time.

$$\cos(ZA) = \sin(lat)\sin(dec) + \cos(lat)\cos(dec)\cos(GHA + lon)$$

where:

ZA = Zenith Angle; lat = Latitude; dec = Star Declination; GHA = Greenwich Hour Angle of the Star; lon = Longitude

Greenwich Hour Angle is determined from Greenwich Mean Sidereal Time (GMST) and right ascension of the star. GMST is determined from the date and UTC or Greenwich Mean Time. Algorithms are available for finding GMST from UTC. To ensure that my watch is correct within a second, I listen to the National Institute of Standards and Technology (NIST) broadcasts from station WWV on one of the standard frequencies of 5, 10, 15, or 20 MHz. Right ascension and declination of the stars are obtained from the Bright Star Catalog published yearly by the US Naval Observatory.

The weighted least squares observation equations used to determine latitude and longitude are of the form:

$$F = \text{arc-cos}(\ \sin(lat)\sin(dec) + \cos(lat)\cos(dec)\cos(GHA + lon)\ ) - ZA$$

These equations are used to relate measured zenith angles ZA to latitude, longitude and other parameters. There will be one such equation for each star measurement. Multiple star measurements provide a system of equations that is overdetermined when the number of measurements is greater than two. In other words, if the number of measurements is greater than two, there are more equations than are needed to uniquely determine latitude and longitude. The weighted least squares process determines values for latitude and longitude that best fit the system of equations in a least squares sense. Since the observation equations are non linear, linearized forms of the equations are generated by Taylor series expansion of the observation equations, and the solution is obtained by iterative application of linear least squares. A detailed explanation of this process is beyond the scope of this article.

I have used my home-made theodolite and the least squares analysis technique to determine latitude and longitude of my house to an accuracy of about 1 nautical mile. The theodolite accuracy of 0.1 degree implies an accuracy of roughly 6 nautical miles for a single pair of star measurements. By including 10 measurements, the error is substantially improved. This accuracy is, of course, nowhere near what can be achieved with a low cost GPS receiver. I have, in fact, used the coordinates of my house measured with a GPS receiver to determine the accuracy of my star-based positions. I find the measurement of stars an interesting hobby. Some people like to just look at stars in the night sky. I like to measure star positions and use the measurements to do other interesting things. In addition to determining latitude and longitude from the stars, I have used the Sun and Polaris to determine azimuth for laying out the baseline of a radio telescope interferometrer and used star field images to calibrate the radial lens distortion of a 35 mm camera. Measuring bright stars does not require really dark skies. The stars traditionally used for navigation can usually be seen from within cities. It is a good hobby for someone like me who lives in a city with large shopping malls.

LOWBROWS ON TOUR, PART 3

By Charlie Nielsen, May 11, 2011

Last Winter I promised (or threatened) to write part 3 of “Lowbrows on Tour” this Spring. It is definitely Spring at last, and here is the article.

For this edition, we open up with our presentation at the University of Michigan Exhibit Museum of Natural History. We have made several appearances here and we have enjoyed them all. This time we were talking about water in the solar system, and beyond. On Saturday, March 26 the crew of Dave Snyder, Jack Brisbin, Sandy Dugan, and Jim Forrester convened on the Museum at 8 AM to begin setup. Dave, Jim, Jack and I went to the demo lab to pick up the equipment we needed for 2 demos that we would be continuously running. Sandy went directly to the Museum to set up a large poster that Sandy and Betsy Dugan produced, which showed where and in what form we may (or have) found water in our solar system. There was a section of the poster that did a very nice job of showing how a star’s habitable zone varies with the size and temperature of the star. We found that the poster drew even more attention than we expected and caused visitors to ask questions, which of course is exactly what we hoped for. We also had a variety of other graphics available, including one that showed how we think Mars looked when it had liquid water on its surface and how it disappeared over millions of years. Alongside that picture was one of our demos. We had a small sealed container in which we could place a small amount of water. Attached to the container was a vacuum pump which would suck the air out of the container rapidly. We had visitors touch the water to verify it was room temperature, if not a little cooler. Then we put the lid on the container and started the pump. Within seconds the water began to boil. While they were fascinated by this we explained how water cannot stay in a liquid state without sufficient atmospheric pressure, despite the temperature. What I really enjoyed is when I had the younger people touch the water right after they saw it boil, and it was not hot. The expressions on their faces were priceless. If that was not enough to blow their minds, then I explained that Mars is also very cold, so that same water placed on the surface of Mars would try to freeze and boil at the same time! How weird! For our other demo we had my Astro Tech 66 mm APO refractor set up, but without an eyepiece. In place of the eyepiece was a plastic plug with a small hole in its center. In the hole was the end of a fiber optic cable that went to a spectroscope “black box” that connected to a laptop computer via USB. The laptop was running software that took the signal from the spectroscope and displayed the emission lines of whatever we were focused on in graphical form. The scope was focused on one of several light sources, an incandescent light bulb, a bulb with water vapor, and a bulb with deuterium. This way we could show our guests how we can detect hydrogen and oxygen just by analyzing the light from a star, or a planet. With the right conditions, this detection would most likely indicate the presence of water. We ran our presentation from 9 AM till 5 PM and we were visited by hundreds of guests, at least half of which were children. In the early afternoon we were visited b Warren Smith, manager of the Physics Demo Lab. He wanted to stop by to see how we were doing and what the setup looked like. His visit was most fortuitous and timely since our water vapor bulb had burned out. Warren and I went back to the demo lab to grab a new one, and we rolled on.

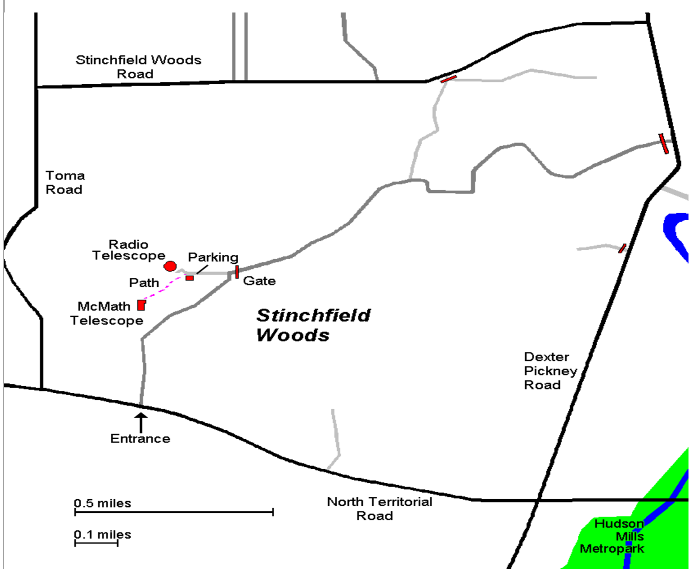
Now we continue on with our Ann Arbor Public Schools tour. Our first event this year was on March 3 at Bach Elementary. That was followed by Haisley on March 14, Wines on March 29, and Eberwhite on May 5. The students were a mixture of 3rd, 4th, and 5th grades, and ranged in size from 50 to70+ students. We did our usual presentation which consists of breaking the group into 2 sections. One of them watches a slide show about telescopes and then gets their chance to handle, aim, and focus them. The other section makes planispheres and they are showed how they work, while getting instruction about how to find North, distance and size scales, and sky movement. After about 45 minutes the 2 groups reverse and we start over again. Just like last year the students and the teachers really liked our program and we received many compliments and thanks. The presenters really enjoyed it too, as we always do. Crew members for at least one or more of these events were Amy Cantu, Raya Cooper, Betsy Dugan, Sandy Dugan, Belinda Lee, Dave Snyder, Jim Forrester, Jack Brisbin, Yumi Inugi, Yasu Inugi, David Jorgensen, and of course the author of this article. But, as of this writing we are not done! Upcoming is Lakewood School on May 19, and on an undetermined date just me and our main contact for the schools are doing a small follow up at Wines. At our Eberwhite event we started a slightly different format, that being that the students assembled their planisphere in advance, which means all the time for that section can be spent with our astronomy program running on our laptop and using it to describe more constellations, types of starts, etc. Next year all our presentations will be this new format, and we will be instruction 5th grade exclusively. We all agreed that 5th grade is a better target for what we are doing. Having stated that, I was very impressed with the 3rd grade at Eberwhite. They were the most engaged and well behaved of any of the 3rd grades, in my opinion.

Being that I could file a brief report on the last 2 schools for this year (but they have not happened yet), and that we have 2 events that are observing, education, and possibly demos for Hazel Park Schools (at Camp Hazelwood) on May 17 and 24…well, it looks like a “Lowbrows on Tour, Part 4” may be coming. That would cover the end of the AA Schools season, the Hazelwood events, and if I wait until the end of July, the two upcoming events at Leslie Park Science and Nature Center. So please stay tuned.

Places & Times

Dennison Hall, also known as The University of Michigan's Physics & Astronomy building, is the site of the monthly meeting of the University Lowbrow Astronomers. Dennison Hall can be found on Church Street about one block north of South University Avenue in Ann Arbor, MI. The meetings are usually held in room 130, and on the 3rd Friday of each month at 7:30 pm. During the summer months and when weather permits, a club observing session at the Peach Mountain Observatory will follow the meeting.

Peach Mountain Observatory is the home of the University of Michigan's 25 meter radio telescope as well as the University's McMath 24" telescope which is maintained and operated by the Lowbrows. The observatory is located northwest of Dexter, MI; the entrance is on North Territorial Rd. 1.1 miles west of Dexter-Pinckney Rd. A small maize & blue sign on the north side of the road marks the gate. Follow the gravel road to the top of the hill and a parking area near the radio telescopes, then walk along the path between the two fenced in areas (about 300 feet) to reach the McMath telescope building.



Public Open House / Star Parties

Public Open Houses / Star Parties are generally held on the Saturdays before and after the New Moon at the Peach Mountain observatory, but are usually cancelled if the sky is cloudy at sunset or the temperature is below 10 degrees F. For the most up to date info on the Open House / Star Party status call: (734)332-9132. Many members bring their telescope to share with the public and visitors are welcome to do the same. Peach Mountain is home to millions of hungry mosquitoes, so apply bug repellent, and it can get rather cold at night, please dress accordingly.

Membership

Membership dues in the University Lowbrow Astronomers are $20 per year for individuals or families, $12 per year for students and seniors (age 55+) and $5 if you live outside of the Lower Peninsula of Michigan.

This entitles you to the access to our monthly Newsletters on-line at our website and use of the 24" McMath telescope (after some training).

A hard copy of the Newsletter can be obtained with an additional $12 annual fee to cover printing and postage.
(See the website
http://www.umich.edu/~lowbrows/theclub/
for more information on joining the club).

Membership in the Lowbrows can also get you a discount on these magazine subscriptions:

Sky & Telescope - $32.95 / year

Astronomy - $34.00 / year or $60.00 for 2 years

For more information contact the club Treasurer. Members renewing their subscriptions are reminded to provide the renewal notice along with your check to the club Treasurer. Please make your check out to: "University Lowbrow Astronomers"

Newsletter Contributions

Members and (non-members) are encouraged to write about any astronomy related topic of interest.

Lowbrow's Home Page

http://www.umich.edu/~lowbrows/

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Website

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Check your membership expiration date on the mailing label