Under Lucky Stars Audit

Compiled by Thomas Barclay, Ph.D.

Summary of Under Lucky Stars Audit

Under Lucky Stars (hereafter, ULS) is a company that provides star maps to customers. The customer provides a location (anywhere on Earth) and time and the company provides a star map - a map of the sky as one would see it at the time and date provided. The primary aim of the maps is for sentimental and aesthetic purposes. ULS have requested this audit to ensure the accuracy of their maps. I performed this audit in March 2019 and this report was completed in April 2019. The audit was conducted independently from ULS and this report reflects my opinions. Details on my credentials as a professional astronomer and astrophysicist can be found at the end of the report.

The strategy I employed for this audit was to take delivery of images from ULS and to verify the accuracy of the position of the stars and other astronomical sources in the maps. As a secondary action I conducted a review of the ULS software code-base.

I used software that was entirely independent from that used by ULS. The result of this audit is that the locations of the astronomical objects in the ULS images are highly accurate, to the level that there are no noticeable differences between maps I create and the ULS products. I therefore deem that the ULS maps have passed this audit.

Products and Information Provided By ULS

ULS provided high resolution maps to me for times and locations I specified. I requested maps that were within the bounds of what a ULS customer can request on the website. On https://www.underluckystars.com/designer the user is restricted to dates between 1900 and 2100. This audit does not consider dates outside of these ranges.

The following information was provided by ULS at the start of the audit

- The stars come from the Yale Bright Star Catalog.

- ULS set the observation point (latitude/longitude) and time (a UNIX timestamp) based on the customer's input.
- The apparent position of all stars in the Yale Bright Star Catalog brighter than 6th magnitude are calculated.
- ULS maps use a stereographic projection but with east-west flipped from a traditional astronomical projection.
- The apparent magnitude of each star maps linearly to the size of the star point.

This audit assesses the accuracy of the following things:

1. The accuracy of the locations of the stars
2. The appropriate stars are included in the maps
3. Whether the stereographic projection is being applied correctly

ULS initially provided me with seven high-resolution maps with the following locations and dates:

- North pole on Jan 1, 2019 at 12am UTC
- South pole on Jan 1, 2019 at 12am UTC
- 65-1120 Mamalahoa Hwy, Waimea, HI 96743, USA on July 21, 1995 at 12pm local time
- 65-1120 Mamalahoa Hwy, Waimea, HI 96743, USA on July 21, 1900 at 12pm local time
- Sesme, Ecuador on June 1, 2000, at 12pm local time
- Mompiche, Ecuador on June 1, 2000, at 12pm local time
- Silver City, NM 88061, USA on June 6, 1973, at 3am local time

The North and South pole maps were chosen to check the accuracy of the ULS maps at the poles. Two maps at the location of Waimea, Hawaii, were chosen to test the same location in two different time stamps. The two maps at the location of Ecuador were chosen to test the accuracy of the maps close to Earth's equator. The two Ecuador locations are approximately 0.5 degrees south (Sesme) and north (Mompiche) of the equator.

Validation of the Accuracy of the Star Positions

To provide an independent verification of the star maps produced by ULS, I reproduced the sample maps by adapting the astronomy package K2Fov[1]. This is the tool used to select target stars for NASA's Kepler/K2 mission (Howell et al., 2014).

Because the star maps under study are limited to dates in the range 1900 to 2100, the maps can be verified with a somewhat simple model of the Earth's motion through space. Assuming that the Earth rotates with a period of 23 hours and 56" (the sidereal day[2]), and that the axis of rotation is fixed in space, I can therefore ignore the effects of precession and nutation. Precession changes the position of stars by no more than 1.4° per century. Nutation is a much smaller effect, with a peak amplitude of no more than 25 arcseconds on times scales of 18 years (there are 3600 arcseconds in one degree).

I also neglect changes in the stars' positions due to parallax and precession. Alpha Centauri, the visible star with the largest parallax changes in position by no more than 0.004° over the course of a year, too small a change do be noticed by the human eye (one of the greatest naked eye observers in history, Tycho Brahe, is noted for being able to perceive the sky with an accuracy of 0.02°). The star with the largest proper motion, Barnard's Star, moves by no more than 0.3 degrees per century. Smaller effects such as velocity aberration were also ignored.

The model I used to validate the accuracy of the ULS maps consists of the following steps;

I map the requested location on the Earth in longitude and latitude to a vector in a three-dimensional cartesian coordinate system with the formula

[1] http://adsabs.harvard.edu/abs/2016ascl.soft01009M
[2] See, for example https://en.wikipedia.org/wiki/Sidereal_time

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos\lambda\cos\phi \\ \sin\lambda\cos\phi \\ \sin\phi \end{bmatrix}$$

where λ is the longitude west of Greenwich, and Φ is the latitude.

I then rotate this vector around the North celestial pole by an angle corresponding to the fraction of a full turn that the Earth has rotated through for that time of day. The Earth's angle of rotation, θ, is given by the formula

$$\begin{aligned} t_{\mathrm{u}} &= \mathrm{jd} - \mathrm{jd}_0 \\ \theta &= 2\pi \times (0.7790572732640 + 1.00273781191135448 t_{\mathrm{u}}) \end{aligned}$$

where $\mathrm{jd}\text{-}\mathrm{jd}_0$ is the number of days that have elapsed since midnight on 2000-01-01 (see equation 5.14 of IERS conventions (2010)[3])

This rotated vector represents the location of the zenith at the time of observation. Note that I do not account for the time of year in this calculation so I do not check whether the requested time is consistent with day or night time. Such a calculation is possible, but not required for the sample star maps provided.

I take a list of stars bright enough to be seen from the Yale Bright Star catalog[4], and convert their sky coordinates (right ascension and declination) to position vectors, then compute their apparent positions on the sky relative to the zenith vector with the stereographic projection.

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[3] https://www.iers.org/SharedDocs/Publikationen/EN/IERS/Publications/tn/TechnNote36/tn36_043.pdf?__blob=publicationFile&v=1

[4] http://adsabs.harvard.edu/abs/1991bsc..book.....H

The stereographic projection is computed by projecting a sphere onto a plane. By the nature of projecting a three-dimensional object onto a two-dimensional surface, there is some distortion. However, a stereographic projection is a very common map projection to use for showing whole hemispheres at once. In the maps provided by ULS the East points to the right and West to the left. This is the opposite than would be seen in astronomical images created for scientific purposes. This aesthetic choice does not affect the accuracy of the projection.

The next step is to compare our projected locations for stars with those in the sample maps and I find good agreement.

Figure 1 shows the star map provided by ULS for Waimea, HI, USA on July 21, 1995 at 12pm in the left-hand panel, and the independent reconstruction of the map in the right-hand panel.

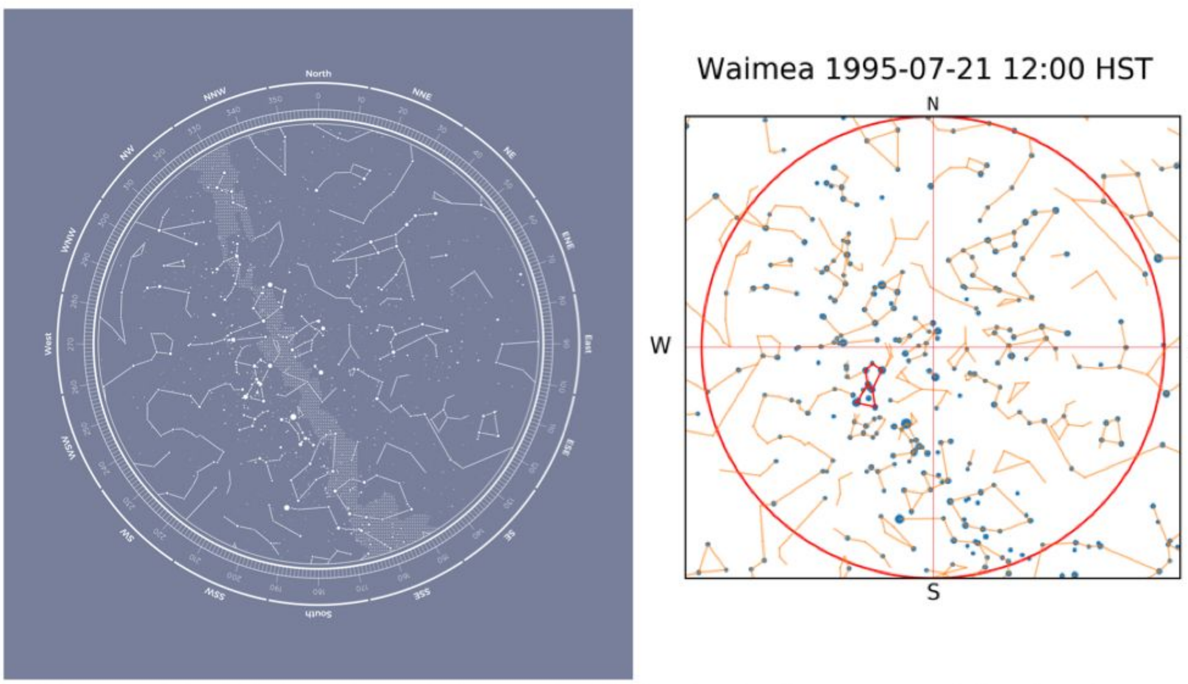

Figure 1: The left-hand panel shows the Under Lucky Stars map of the sky above Waimea, Hawaii on July 21, 1995 at noon local time. The right-hand panel shows the data created for this audit for comparison purposes.

In the images that were created for the audit, North is at the top, and west is to the left in this projection, consistent with ULS images. Stars are indicated by blue circles, with larger circles indicating brighter stars. Constellations are indicated by yellow lines connecting the stars. Note that there is no universally agreed set of constellation lines, and the set we use differs from the more artistic choice of Under Lucky Stars. Careful examination of these two figures shows that the star locations are nearly identical, validating the map created by ULS. The constellation of Orion the hunter is indicated by red lines, to help guide the eye.

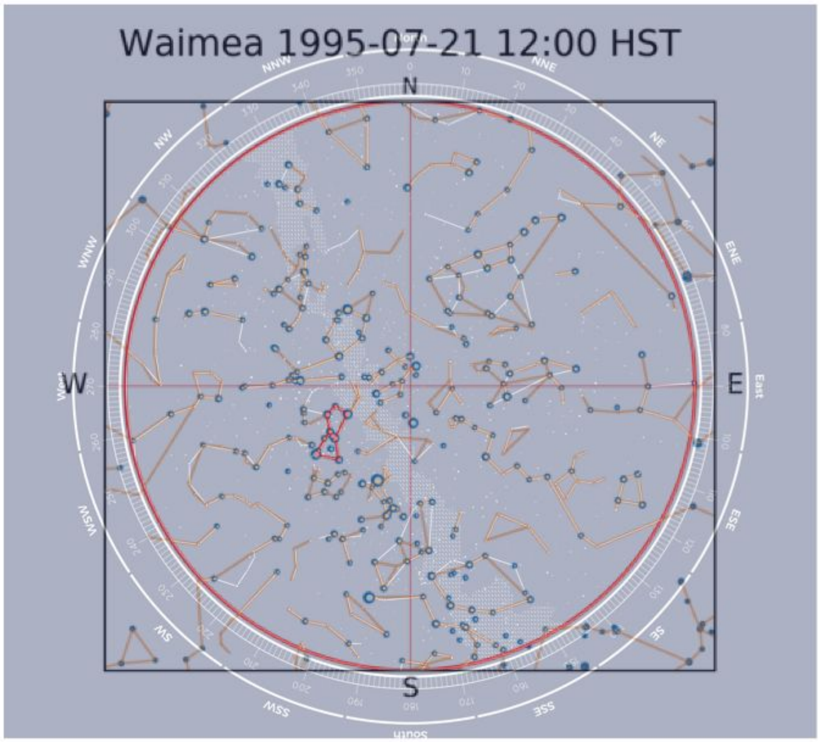

Figure 2: The image created by Under Lucky Stars of the sky above Waimea, Hawaii on July 21, 1995 at noon local time and the data created for this audit are overlaid.

To more carefully compare the two images, I overlaid the sky image that I created on top of the ULS image. This is shown in Figure 2. As can be clearly seen, the stars in the two images overlap perfectly. This exercise was repeated for the two images of the north and south pole, and for the two images of the sky above Ecuador. Figure 3 shows the overlap of the South Pole image from ULS and the one created for the audit, and Figure 4 shows the overlaps out the Sesme image created and the one created by ULS. In the latter two images only stars are marked in the images I created. The stars in my images are colored blue and completely overlap those of the ULS images. These two images demonstrate that here are no problems in the projections near the poles or near the equator. All images were examined and all passed this inspection.

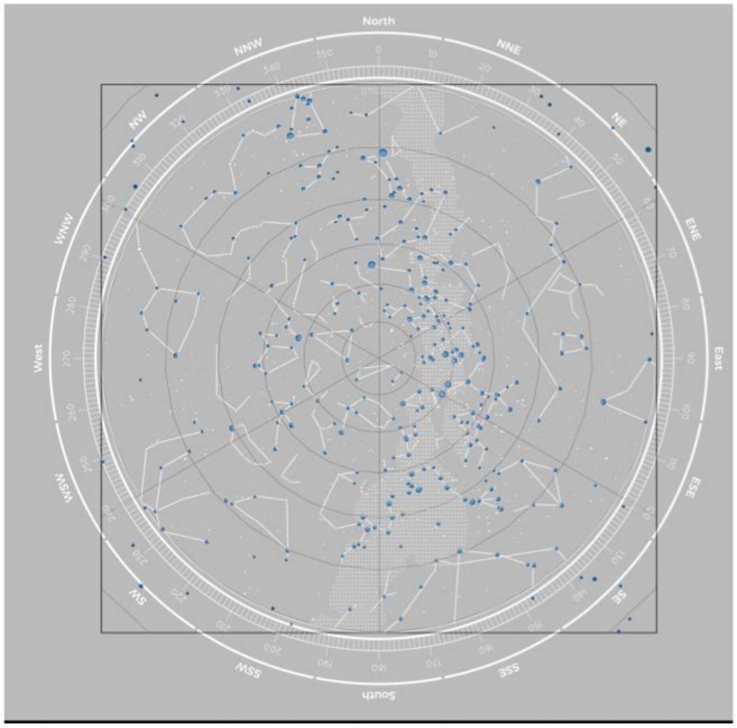

Figure 3: The image created by Under Lucky Stars of the sky above the North Pole on January 1, 2019 at midnight UTC and the data created for this audit are overlaid.

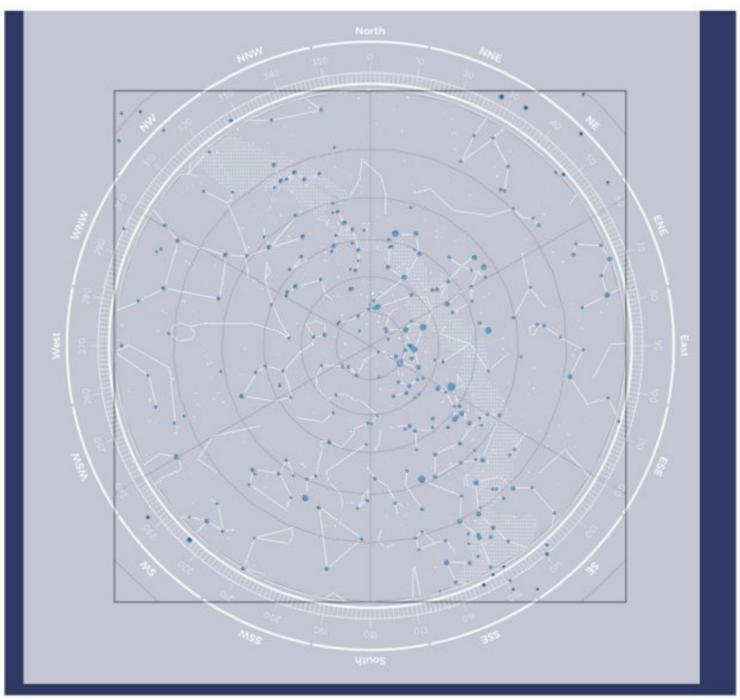

Figure 4: The image created by Under Lucky Stars of the sky above the Sesme, Ecuador on June 1, 2000 at noon local time and the data created for this audit are overlaid.

One additional check I made is to the location of the Milky Way in the ULS images. The shape and width of the Milky Way has no firm definition and the Milky Way is very unevenly distributed with stars. However, it should approximately follow the line of zero latitude in galactic coordinates -- the galactic equator. Figure 5 shows the galactic equator in red and it does indeed approximately follow the Milky Way seen in ULS images. Offsets of the marked Milky Way from this galactic equator are not errors in the ULS images but reflect true offsets that are caused by large dust lines within our galaxy that absorb star light and appear dark to us. The ULS maps accurately show the location of the Milky Way.

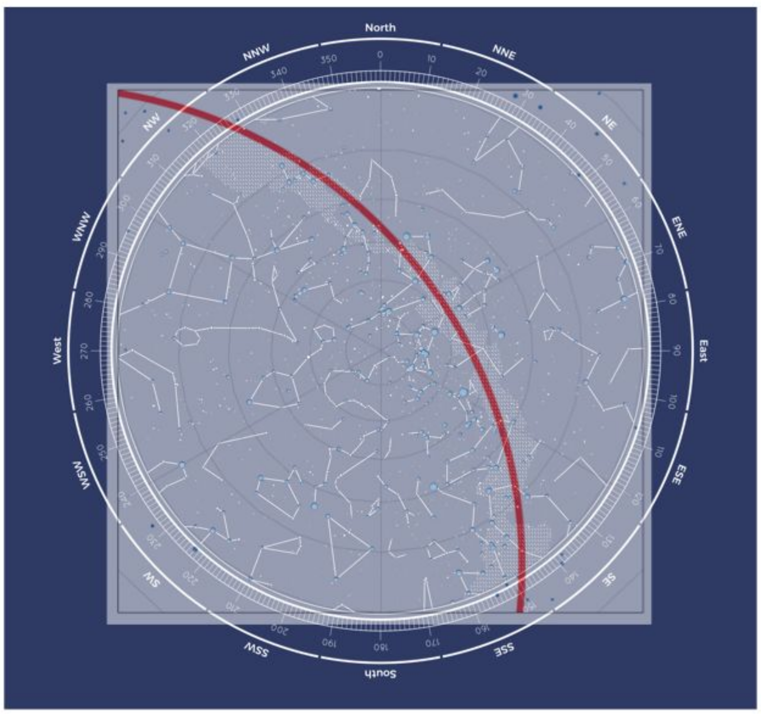

Figure 5: The image created by Under Lucky Stars of the sky above the Sesme, Ecuador on June 1, 2000 at noon local time and the data created for this audit are overlaid. In this image the location of the galactic equator is marked in red. The galactic equator should approximately match the location of the Milky Way.

Review of the ULS code-base

On March 29, 2019 I was able to complete a thorough review of the ULS code. This was done via screen-sharing, during a video call with a member of the ULS team. During this review I was walked through the software used to create the star maps. The software was primarily written in the Python language; I have extensive experience with Python and could fully follow the explanation.

The code takes the input of the customer, converts the location to geographic coordinates and the time to a common time frame. The code then takes the Yale Bright Star Catalog and transforms the coordinates in that catalog from Right Ascension and Declination to Altitude and Azimuth for the location and time provided. Finally, the software plots the stars at the correct locations and then adds constellation lines and the Galaxy. The software and methods used are appropriate and the design choices are well reasoned.

The Yale Bright Star Catalog is an ideal choice of catalog. There are alternatives like the Hipparcos catalog but I find no compelling reason to recommend a change of catalog. The Yale catalog is in use by professional astronomers. For example, NASA's Transiting Exoplanet Survey Satellite is using this catalog for their bright star target list.

Recommendations

The star maps have passed the audit. However, I have a small number of recommendations.

1. The maps would be improved by showing the locations of the bright solar system planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn).
2. The location of the moon could be shown.
3. If ULS ever wishes to broaden their offering to include dates earlier than 1900 (for example, biblical times), they should ensure that their charts correctly account for precession.

About the author

This report was compiled by Dr. Thomas Barclay. Dr. Barclay obtained his Ph.D. in Astrophysics from University College London. He has worked on several NASA missions, most notably the Kepler mission which operated from 2010-2018. Dr. Barclay was based at the Kepler headquarters at NASA Ames Research Center, in California. Dr. Barclay now works as a Research Scientist at NASA's Goddard Space Flight Center in Maryland where is he is Associate Project Scientist for NASA's Transiting Exoplanet Survey Satellite. Dr. Barclay has published numerous scientific publications in prestigious journals such as Nature and Science. He is noted as the discoverer of the smallest known exoplanet. In 2017 Dr. Barclay was awarded the NASA Exceptional Public Service Medal.

Dr. Barclay's expertise lie in astronomical data analysis, software development and statistical methods.