SETTING CIRCLES:

How to Make Patterns for Right Ascension (RA) and Declination (DEC) Setting Circles and More

by

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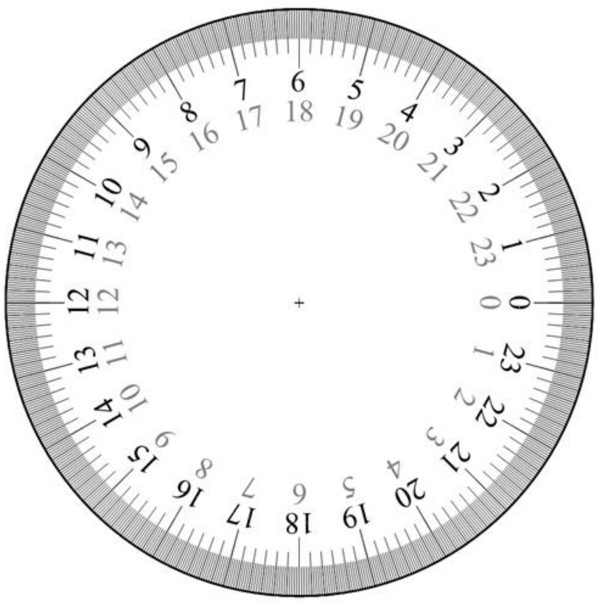

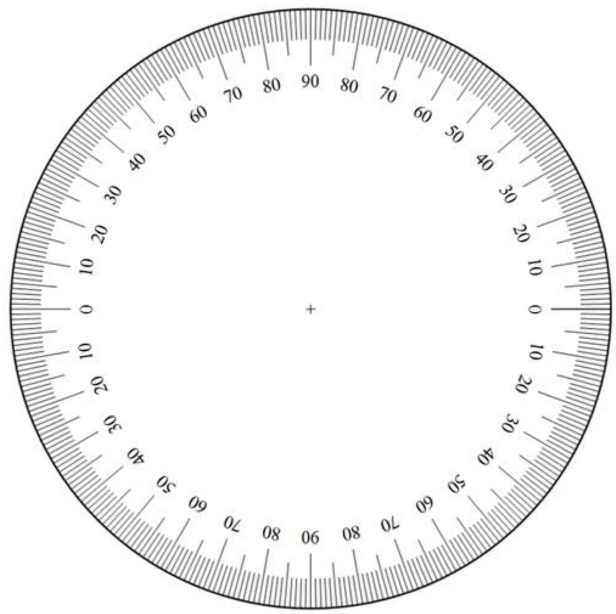

Introduction: Once upon a time, before the now ubiquitous Go-To Mounts, the “brains” and the “slewing” skills for finding Deep Sky Objects and faint solar system objects such as comets, asteroids, Uranus, Neptune and Pluto, or daytime views of Mercury and Venus, resided in the observer. The key to successful telescopic viewing of such objects relied on an Equatorial Mount, properly aligned, and *quality setting circles* with the RA circle, usually with the ability to be locked in step with a clock drive. (A clock drive was not essential for successfully finding objects, but was always very helpful. An Azimuth Mount with good azimuth and elevation indicators can be used successfully to find the objects mentioned through calculations that convert RA and DEC coordinates into equivalent azimuth and elevation coordinates.) Without a doubt the amazing ease and accuracy of today’s Go-To Mounts to find difficult objects is well beyond the capability of what was once only found in skilled observers with experience, and very knowledgeable, in the use of setting circles.

For example, to find the Crab Nebula, M1, in my 12 ½ inch, f/8, Newtonian, I would center an easily recognizable nearby star such as 3rd magnitude Zeta Tauri in a “wide field” eyepiece and then adjust the mount’s setting circles to Zeta’s coordinates of RA 5^{h} 37.6^{m} and DEC +21.14^{o} (i.e., DEC +21^{o} 08.6^{m}), where the superscript h and m represent hour and minute, respectively.

Next, the scope would be reoriented by hand to a point at which the mount's setting circles read the coordinates of M1 as RA $5^h\ 34.5^m$ and DEC 22.015^o (i.e., DEC $22^o\ 00.9^m$) to have the scope hopefully pointing at M1. With the development of modest skills for this process, M1 would be in the eyepiece, and often nearly centered in the eyepiece. (The above RA and DEC coordinates are at a resolution that roughly exceeds the capability of setting circles e.g., roughly 8 inches in diameter. With a reasonable vernier scale on 8 inch setting circles, the resolution would be roughly $\pm 1^m$ in RA and $\pm 0.25^o$ in DEC.)

Sure you can read the RA and DEC with many Go-To Mounts, or install encoders of high accuracy, to provide RA and DEC readouts digitally on older mounts. Compared to traditional setting circles of mechanical design, the superior digital settings circles' accuracy is breathtaking. Traditional setting circles are scorned by many of my fellow telescope users and that is understandable in the light of more "modern" aids for finding difficult objects. But their disdain is usually associated with almost useless "tiny setting circles", a poor alignment of their mounts polar axis, or RA axis, or the non-perfect orthogonality of the RA and DEC axes, scope alignment with mount, etc., or selecting objects too far from an easily recognizable reference star. Advantages of traditional setting circles include their mechanical, or "analog-like-nature", and their simple, and natural, connection to the sky and coordinates of RA and DEC. Besides, for me, they are fun to use if setups are correct and limitations recognized. In addition, finding those difficult objects in my 12 ½ inch, f/8, Newtonian is very rewarding. (As an alternative method in those days of "antiquity", star hoping techniques were also applied but the scattering of city lights has made that process utilizing a finder scope more and more difficult with the light pollution getting worse with each passing year.) Setting circle users do have to face the problem of reading the RA and DEC coordinates of the target object on a sheet of paper, and reading the setting circles too, and that process requires a light and thus night vision can be momentarily ruined.

Trying to find quality setting circles in today's Go-To environment is a frustrating challenge. I know because I have tried but failed and that motivated me to develop my own. An example of inexpensive setting circles, once available from Edmund Scientific, is shown in Figure 1. Fortunately, a number of simple techniques can allow interested telescope users to make their own quality setting circles far better than those in Figure 1.

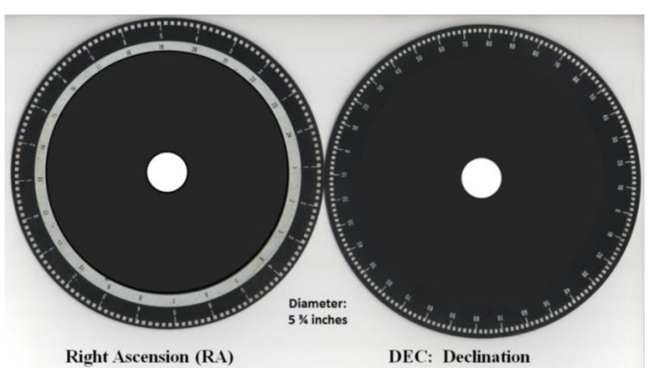

Figure 1: Edmund Style Setting Circles

For those interested in traditional setting circles, the following procedures for accurately making setting circle patterns are provided for what are now likely considered by many telescope users to be “curious antiques” but I find those “curious antiques” as fascinating and as useful today as I did 60 years ago. They make you think and make finding Venus or Mercury during the day “a sure thing” and rather pleasing. In the minds of some, setting circles are perhaps as extinct as the dinosaurs. But who wouldn’t like to see a dinosaur?

How to Make Setting Circle Patterns:

Two techniques for making setting circles follow. The first is based on PowerPoint and the other is based on *Mathematica* (suggest you Google Mathematica for its description).

PowerPoint Declination Setting Circle: As shown in Figure 2, begin with a circle with lines along the vertical diameter and select “Arrange”, as shown in the figure and then select “Rotate” to get to “More Rotation Options …”.

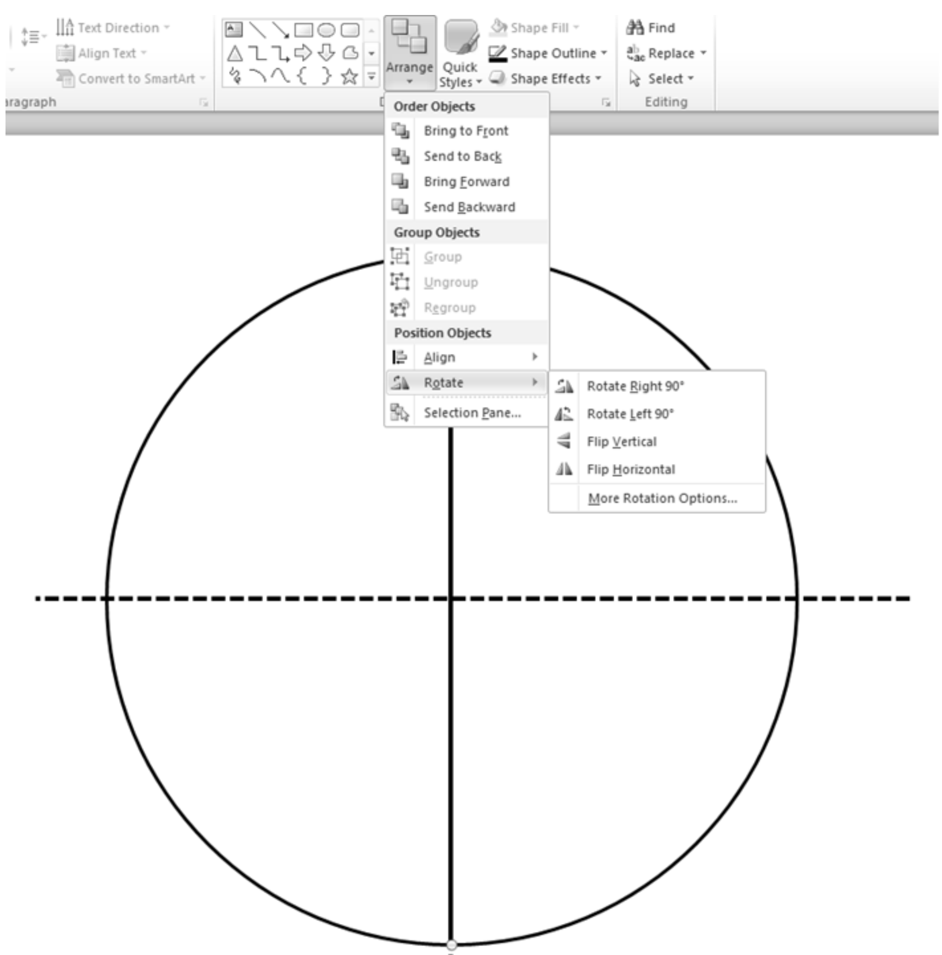

Figure 2: PowerPoint Approach

Next, with "More Rotation Options …" selected, in the "Rotation" block shown in Figure 3, enter the degrees to be rotated. As an example, 5^o is shown in Figure 3.

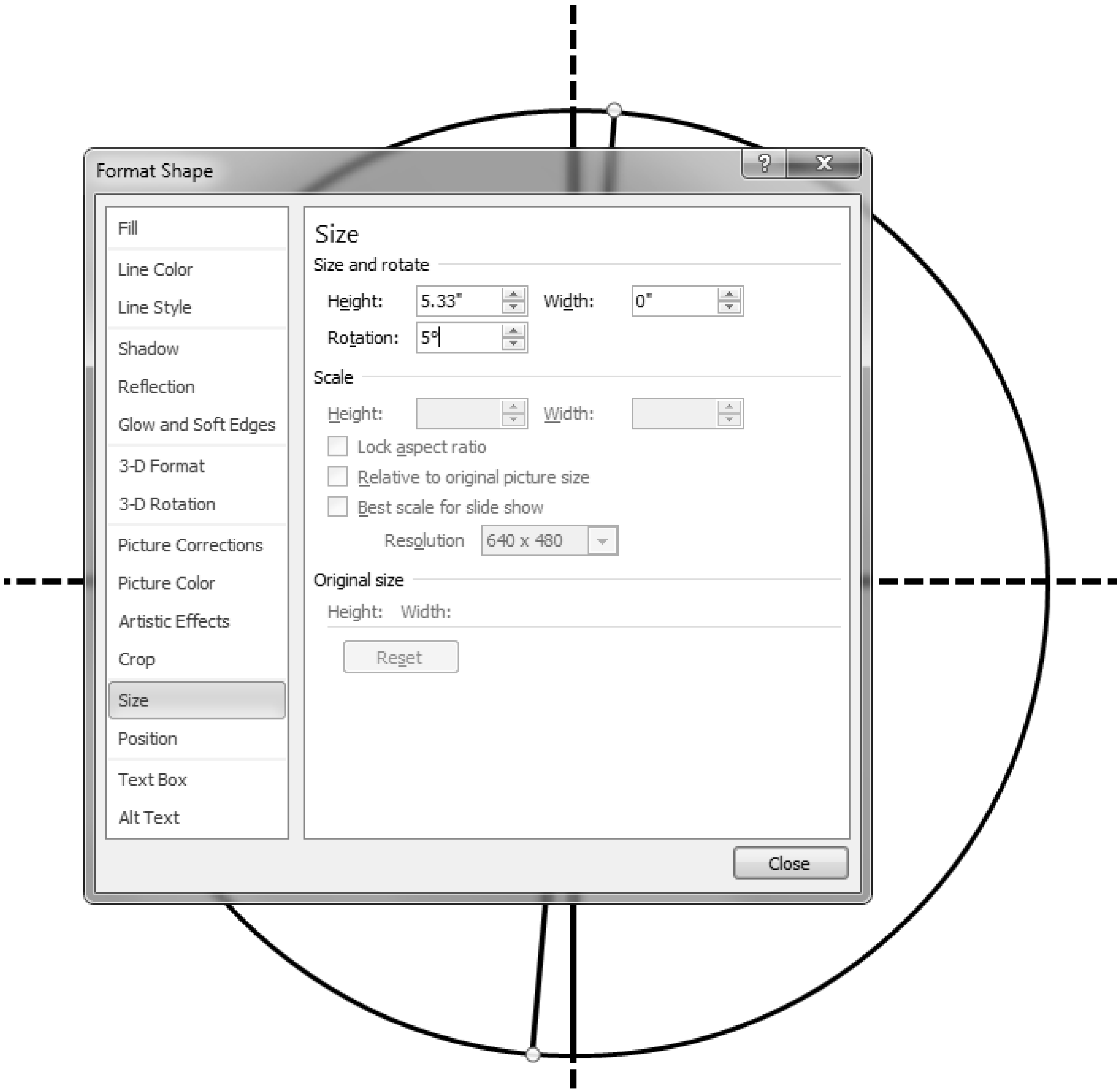

Figure 3: Rotate 5 Degrees Example

Other choices for the rotation in degrees can be easily made. After a useful set of rotations, say in increments of 1^o up to 5^o, a group of rotated lines can be grouped and then rotated as a group to create a growing pattern with more grouping and more rotations of the grouping, etc. (Increments of 1^o is the smallest available in my PowerPoint configuration, but perhaps it is possible to modify PowerPoint to provide finer resolution?)

The dashed reference lines can be eliminated, numbers added, and circles added to improve the appearance, character of lines adjusted (solid, dashed, etc.) and a centering circle also added for making a centered hole (of desired diameter to match the declination axis diameter) and eventually result in the final product shown in Figure 4.

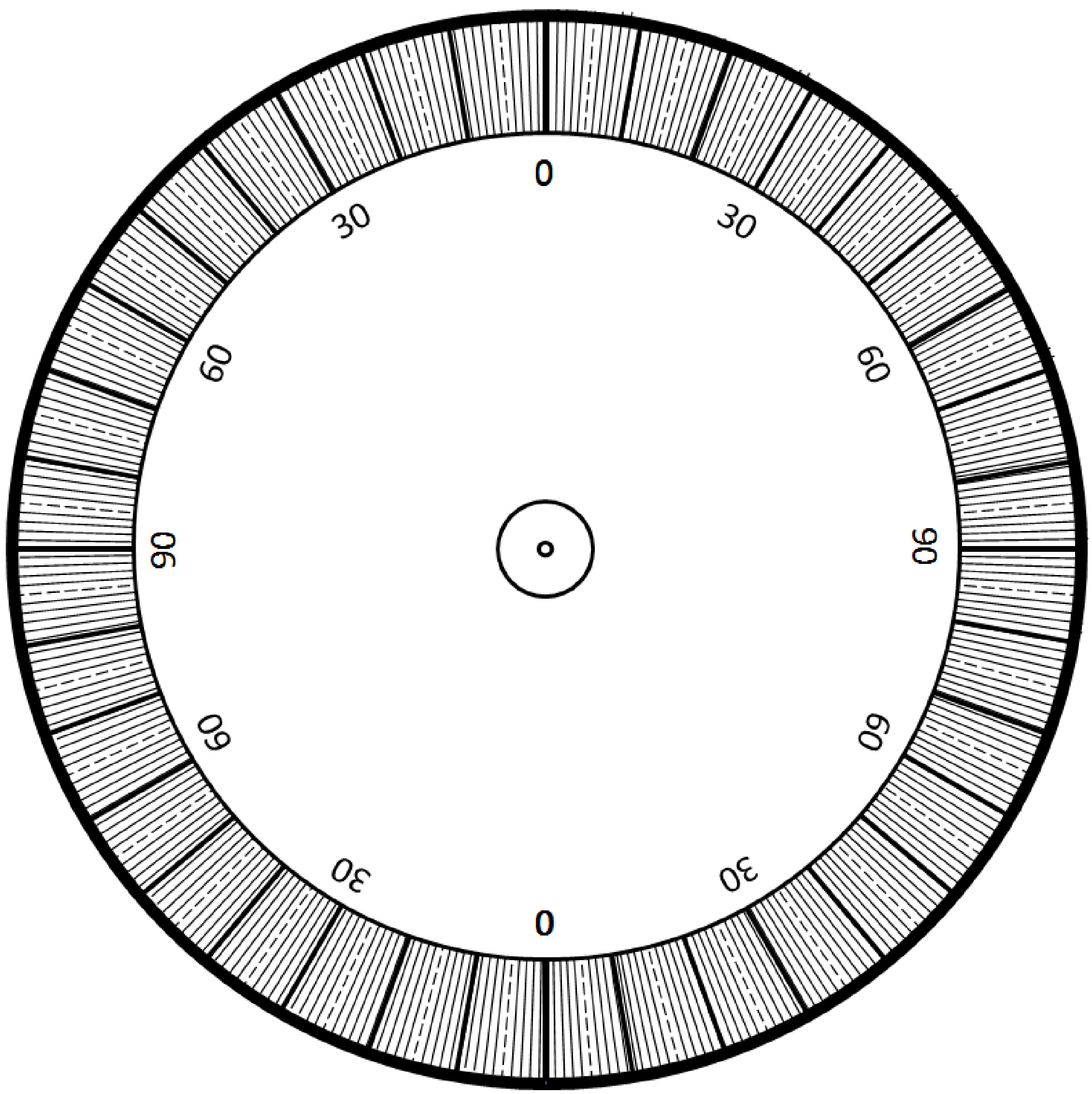

Figure 4: Final Declination Circle via PowerPoint

The PowerPoint process is somewhat tedious, and perfection, as suggested by slight distortions in Figure 4, is not easy. The ability of making a Right Ascension setting circle appeared far too cumbersome with PowerPoint but perhaps doable. As a result an improved process was sought and Wolfram's *Mathematica* was selected as my "ideal" program for making RA and DEC setting circle patterns (if interested, as suggest earlier, Google Mathematica for details).

Mathematica Approach: Since a Declination setting circle was made with PowerPoint, a Right Ascension setting circle was sought first via Mathematica, suspecting the Declination one would be easily deduced from the RA case.

Since my experience with Mathematica is based mostly on using its calculation facilities, and not fancy graphics, I began the process of developing a Mathematica program from a few basic steps that evolved naturally into more complicated but far more compact program lines which was at first not apparent. I include the early methods here, as the simplicity to complexity can then be perhaps appreciated more.

First I began with two circles of points, with each pair of inner and outer points representing 1 hour of RA, with the idea that the pairs could be connected by a line to represent a given RA gradation-mark, i.e. interval mark or hatch marks, for a total of 24 such gradation-marks space uniformly in a circular pattern to form 24 hour angles. The points were made "over-sized" for visual reference as shown in Figure 5.

```
hrdata = Table[{Cos[t], Sin[t]}, {t, 0, 2 π, 2 π/24}];
hrplot = ListPlot[hrdata, PlotStyle → {PointSize[0.03], Black}, AspectRatio → 1];
Reducedhrdata = Table[.8 {Cos[t], Sin[t]}, {t, 0, 2 π, 2 π/24}];
Reducedhrplot = ListPlot[Reducedhrdata, PlotStyle → {PointSize[0.03], Gray},
   AspectRatio → 1];
Show[hrplot, Reducedhrplot]
```

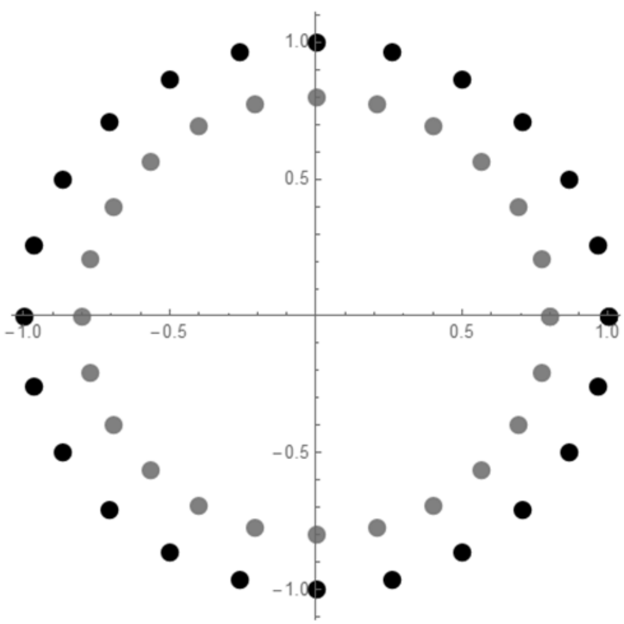

Figure 5: Mathematica Plot of Points Representing Hour Angles

Next, after some enlightening conservations with fellow Mathematica users, including Wolfram's "Vince", I decided to try using Mathematica's "GeometricTransformation" function with the “Graphics” function. I added in a test for the gradation-marks of only 0^h, 1^h, and 6^h by utilizing the “RotationTransform” as shown in Figure 6.

```
tt = 0;
w0 = Graphics[GeometricTransformation[{Thickness[.02], Line[{{.8, 0}, {1, 0}}]},
    RotationTransform[tt 2 Pi/24]]];
tt = 1;
w1 = Graphics[GeometricTransformation[{Thickness[.02], Line[{{.8, 0}, {1, 0}}]},
    RotationTransform[tt 2 Pi/24]]];
tt = 6;
w6 = Graphics[GeometricTransformation[{Thickness[.02], Line[{{.8, 0}, {1, 0}}]},
    RotationTransform[tt 2 Pi/24]]];
Show[hrplot, Reducedhrplot, w0, w1, w6]
```

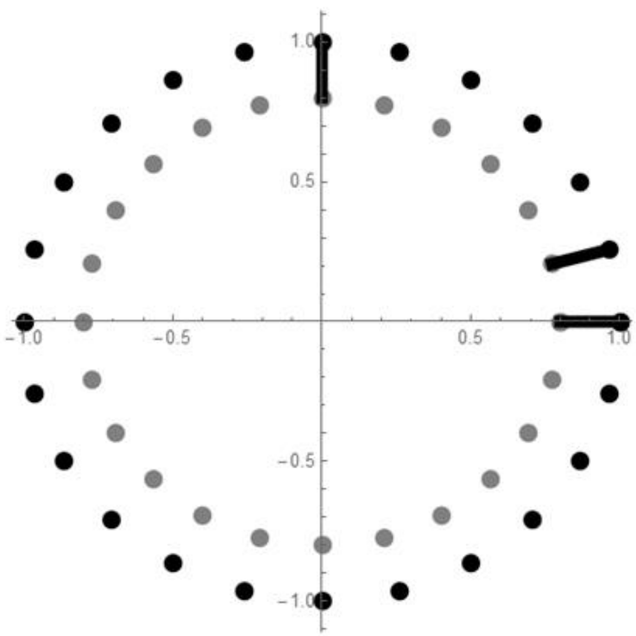

Figure 6: Testing Gradation-Marks for 0^h, 1^h, and 6^h

To help with the interpretation of the statements in the upper portion of Figure 6, consider “w6” where the arbitrary “tt” is set equal to 6, representing hour angle 6^h. In the “RotationTransform” function, the quantity “tt” multiplies the conversion of hour angle to radians with the conversion factor given by $\frac{2\,Pi}{24}$. Thus that specific process gives the vertical line segment with end coordinates (0.8, 0) and (1, 0) along the vertical axis corresponding to the angle Pi/2. Once this process is understood, it can be evolved into a more compact and complete process as shown in Figure 7 with numerical values added via the “Piecewise” function along with a center point represent by tiny crossed lines for the RA setting circle.

```
graph1hr =
 Graphics[{{Circle[{0, 0}, 1, {0, 2 Pi}]},
   {Line[{{-0.015, 0}, {0.015, 0}}], Line[{{0, -0.015}, {0, 0.015}}]},
   GeometricTransformation[
     Piecewise[
      {{{Black, Line[{{.8, 0}, {1, 0}}],
          Rotate[{Black, Text[Style[#, FontSize -> Scaled[0.05], FontFamily -> "Times"],
              {.75, 0}, {0, 0}]}, -Pi / 2]}, Mod[#, 1] == 0},
        {{Black, Line[{{.85, 0}, {1, 0}}]}, Mod[#, 5] == 0}, {Line[{{.9, 0}, {1, 0}}], True}}],
     RotationTransform[# 2 Pi / 24]] & /@ (Range[0, 24 - 2 Pi / 24])}]
```

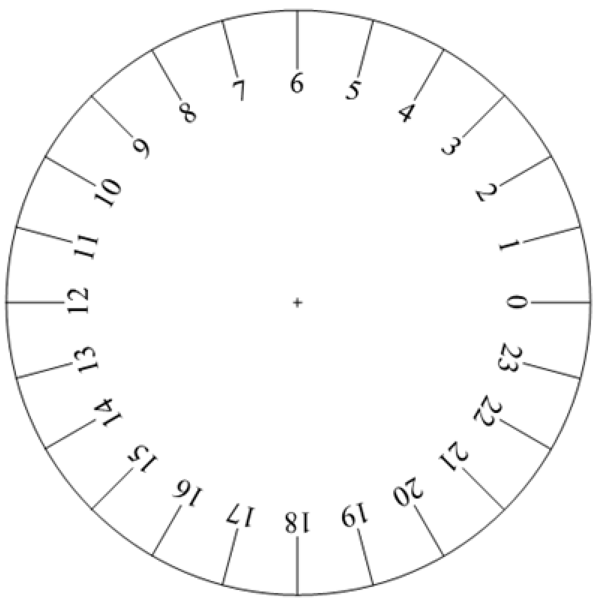

Figure 7: Further Evolution of the RA Setting Circle

With some additional alterations, the programming process can be evolved further with finer gradation-marks to the 10^m (i.e., 10 minute) range and then using still finer gradation marks to represent 2^m intervals for the hour angles. For the case presented here, the finest level for the gradation-marks were selected to be 2^m but could be made even finer if a larger diameter RA setting circle is desired with still finer gradation-marks. In addition hour angles in the opposite direction can also be added for different orientations of an RA setting circle on a mount's RA axis (or equivalent for Southern hemisphere). The final product with 2^m gradation-marks, along with hour angles running in the opposite direction, is shown in Figure 8.

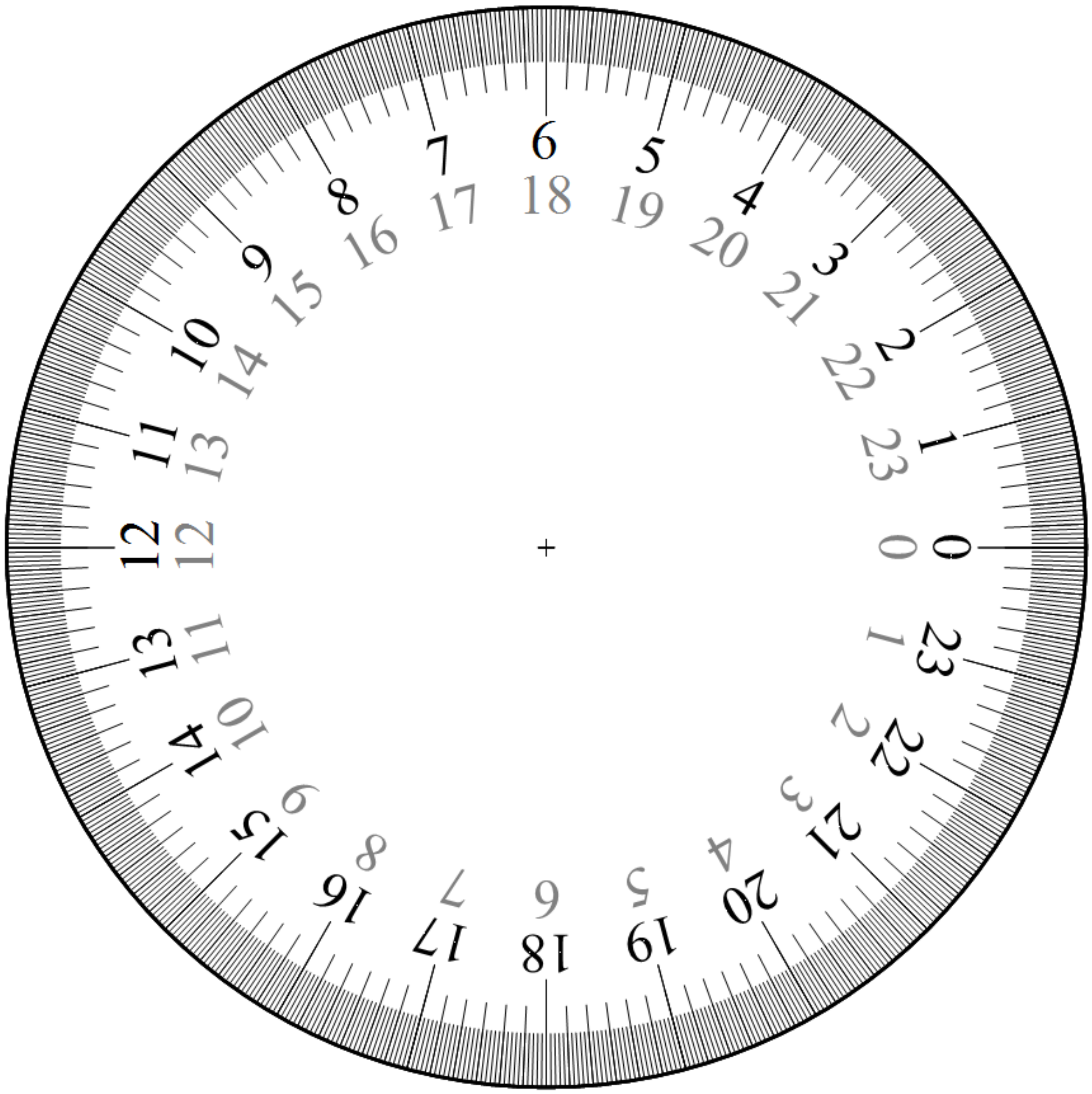

Figure 8: Final Mathematica Derived RA Setting Circle with 2^m Gradation-Marks and Opposite Running Hour Angles

The above Mathematica program lines can easily be altered to produce the corresponding Declination Setting Circle as shown in Figure 9. The DEC setting circle in Figure 9 has increments of 1^o (i.e., 1 degree). The setting circles can be printed on superior "paper" and mounted on various substances such as aluminum circular sheets, quality plywood, plastic, etc., or, perhaps, even laser cut into sturdy metal disks. The actual quality of producible resolution is far better than that shown here and limited here in order to limit document size.

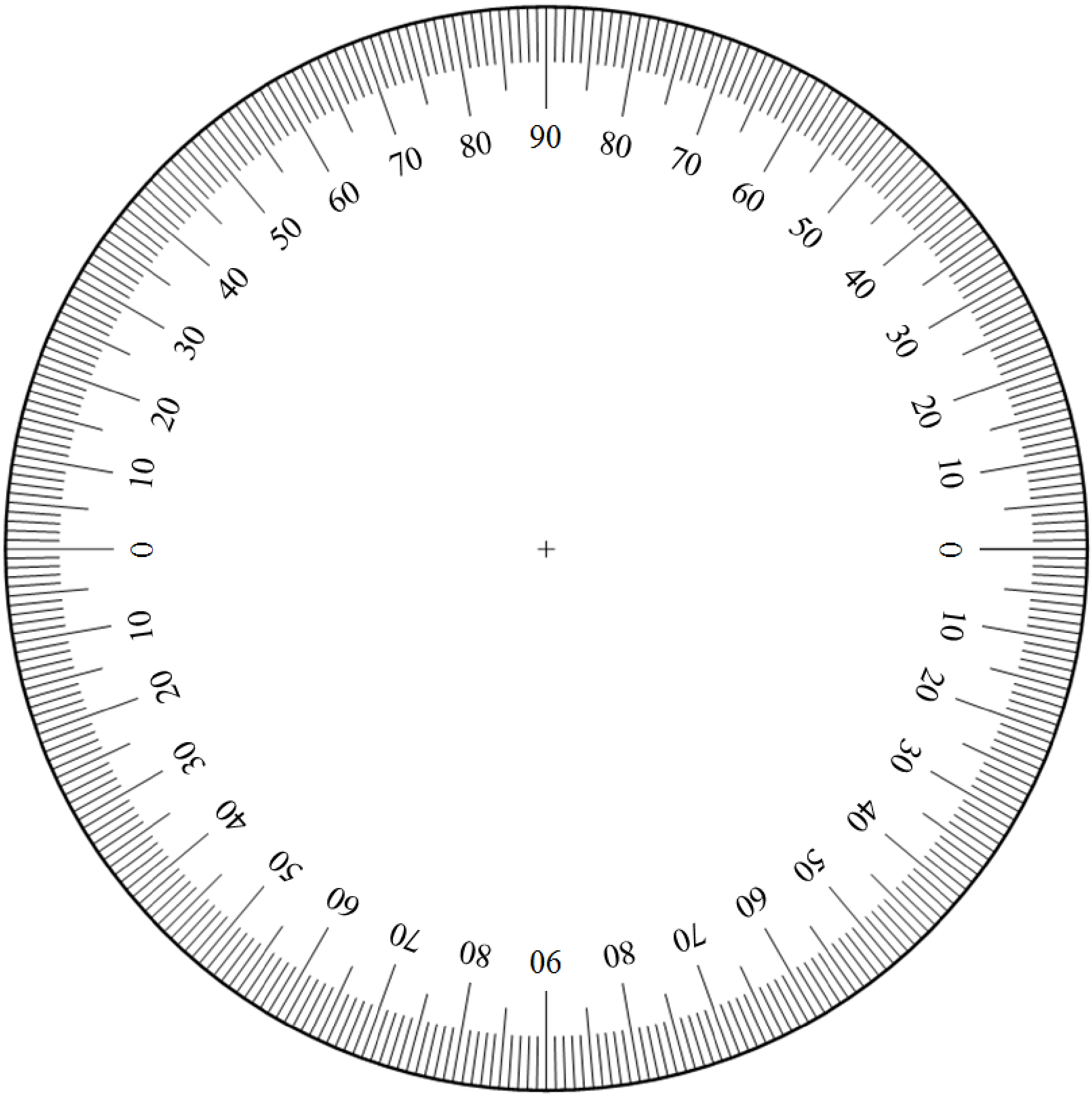

Figure 9: Final Mathematica Derived DEC Setting Circle with 1^o Gradation-Marks

As suggested in the above, the level of the gradation-marks can be made as fine or as course as desired. For equivalence between an RA and DEC setting circles "resolution", it is noted that $\frac{24^h\ RA}{360^o\ DEC}\ \frac{60\ ^m RA}{1^h\ RA} = \frac{4\ ^m RA}{1\ ^o DEC}$. Thus to make the "resolution" of the RA and DEC setting circles equivalent, the gradation-marks for the RA setting circle could have been 4^m instead of 2^m when the gradation-marks for the DEC setting circle is 1^o. But 2^m was shown to demonstrate adjustability in gradation-marks appropriate for a specific user.

Similar graphical results are probably available through the use of MATLAB graphics, or perhaps Excel, but I am not a user of MATLAB and am not very familiar with MATLAB's abilities.   For either the RA or DEC setting circles, a vernier scale can also be developed easily.

Future Plans: My 12 ½ inch, f/8, Newtonian, sits on a "old" Starliner Equatorial Mount with a clock drive and a manual slow motion on the DEC axis and is shown in Figure 10.

Figure 10: My 12 ½ inch, f/8, Newtonian,
on a Starliner Equatorial Mount with 2 Inch Shafts
(Tube is 9 ft. in Length, 15 in. OD, OTA Weight 57 lbs.)

The Starliner's original ~8 inch setting circles are definitely suitable for locating Deep Sky Objects, etc., using a nearby reference star. They are shown in Figure 11. Bigger is certainly better in my view when it comes to setting circles and a size significantly greater than 8 inches would offer better performance when locating difficult objects.

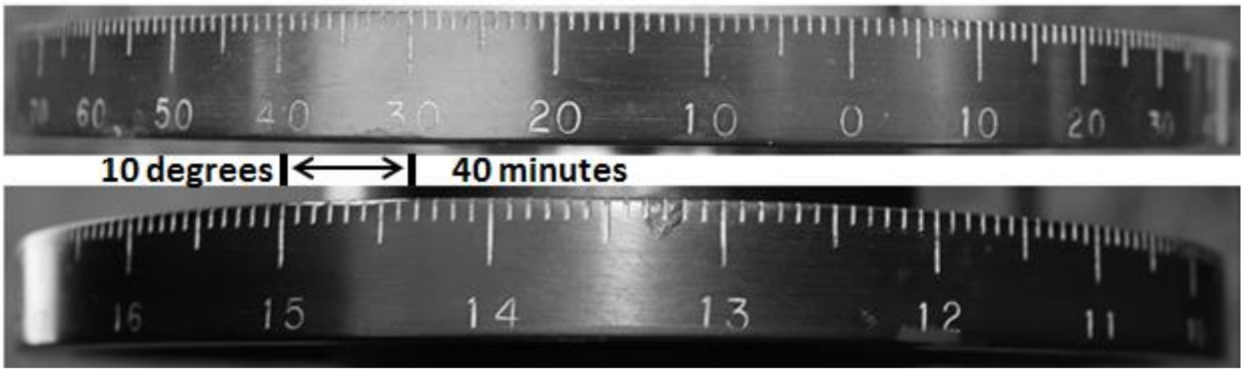

Figure 11: Edge-on View of Original Setting Circles on my Starliner Equatorial Mount

It was mentioned earlier that in terms of equivalent resolution $4\,^{m}RA = 1\,^{o}DEC.$ In Figure 11, left of center, as a coincidence, the 40^{o} of DEC happens to almost align with 15^{h} of RA in the photo, while the 30^{o} of DEC, with some "Kentucky windage", aligns roughly with 14h 20m of DEC. Thus, from Figure 11, the difference in DEC is 10^{o} while the difference in RA is 40^{m}, showing again that $4\,^{m}RA = 1\,^{o}DEC.$ The scales and numbers on the edge of the original Starliner setting circles are particularly beneficial and happen to be rather *attractive* and offer a readable view from nearly any eye position. My future plans are considering using the basic flat surface patterns for setting circles presented here, but on a larger scale, with verniers, for improving usage on my Starliner mount. Perhaps the patterns will be printed on quality thick photo-quality "paper".

The choice of the material for printing the patterns on will occur somewhat in parallel with the choice for the base material for the setting circles to be mounter on. There are many options including printing the pattern on aluminum disks on both sides. Another is to mount the patterns on the inside and outside of large diameter brake rotors found on a truck, such as my Silverado. The advantage of using the rotors is the brake surface of a rotor is very flat and of course very ridged. Perhaps more importantly the weight of a rotor, roughly 25 pounds for a 12 inch one, could be used in place of counterweights on the DEC axis and placed between collars so it can easily rotate by hand. And on the far end of the RA axis near the clock drive assembly, the weight of the rotor may help lessen the tendency of the mount and scope to tip forward while being rolled out to the site on the wheel arrangement in Figure 10. New diameters being considered may be as large as 16 inches and resolution scales shown on the examples here will be on a significantly finer scale for improving accuracy of my scope's pointing. Improvements in reading the setting circles will be acquired through an illuminating line instead of simple metal pointers. That planned for pointing feature will be provided by the basic design properties of a modified laser diode assembly.

Getting the RA and DEC Coordinates for Use With Setting Circles:

In the Past: In those perhaps now bygone days of the regular use of setting circles by many dedicated observers, the observer was faced with the problem of finding the coordinates of objects to be viewed. Several books gave listings of Deep Sky Objects coordinates, but when it came to the coordinates of Uranus, Neptune, Pluto, comets or asteroids, the observer frequently had to rely on interpolation of coordinates found in "Sky and Telescope" or the "Observer's Handbook" published by The Royal Astronomical Society of Canada and that introduced errors. And, in the example of finding M1 via the reference star Zeta Tauri , the coordinates for Zeta Tauri were usually read through interpolation of Star Charts such as the colorful and large star charts in say "*Atlas Coeli 1950.0*" by Antonin Becvar. And to determine the Sun's coordinates as a reference point for finding Mercury or Venus in daytime the Sun's coordinates were usually interpolated to a specific date from information in "Sky and Telescope" or the "Observer's Handbook".

Today: The coordinates for any Deep Sky Object can be found very easily on the Web. And those for moving objects, such as the Sun, Uranus, Neptune, Pluto, comets or asteroids, coordinates can be found for a specific day and exact time via "www.heavens-above.com" or other useful sites. The coordinates can be easily transferred to a document which is then printed and carried to the telescope site and used the old fashion way to find celestial objects.

Go-To Mounts Compared to My Starliner Equatorial Mount:

My Go-To Mounts: I admire the performance of two Go-To mounts I have but I am also disappointed in my older Go-To Mount having developed reliability problems and wonder if such issues will develop for my newer and expensive, Go-To Mount. In comparison, my "vintage", or historic, Starliner Mount continues to perform flawlessly over many years. The Starliner's clock drive operates smoothly and the manual slow motion on the DEC axis has remained backlash free for many decades. The eyepiece focusing drive unit for my 12 ½ inch, f/8, Newtonian is shown in Figure 12 and makes focusing a simple process with very modest "technology".

Figure 12: Electronic Focusing Controller and Drive Unit on my 12 ½ inch, f/8, Newtonian, with a 2 Inch OD, 40 mm fl Eyepiece in the Focuser and a 50 mm Finder Scope nearby

Perhaps it is worthwhile to note that the 40mm fl eyepiece in Figure 12 provides about 64X with my 12 ½ inch, f/8, Newtonian and provides a comfortable FOV of roughly 1 degree. That eyepiece FOV teamed with the resolution of the setting circles in Figure 11 makes it easy to locate Deep Sky and other difficult objects, as described earlier in the case of locating M1.

My first Go-To Mount is shown in Figure 13. It is a Meade LXD-55 Mount with their 6 inch refractor, purchased new about 14 years ago, compared to my 12 ½ inch, f/8, Newtonian, on my Starliner Equatorial Mount. The 6 inch refractor, like the 12 ½ inch Newtonian, has electronic focusing which I find essential for precise vibration free focusing.

Figure 13: Meade LXD-55 Mount with 6-inch Refactor Compared to my 12 ½ inch, f/8, Newtonian, on my Starliner Equatorial

The LXD55 has traditional, but tiny setting circles, and its DEC setting circle is shown Figure 14. It is only about 2 3/8 inches in diameter.

Figure 14: Meade LXD55 DEC Setting Circle a Little Over 2 Inches in Diameter

LXD55 setting circles are nearly useless except that they are barely or marginally suitable for finding Venus in the daytime. Unfortunately the reliability of the LXD-55 mount has deteriorated with time and sadly Meade no longer offers repairs. Backlash is an issue and can be corrected but that problem eventually returns. But the most annoying issue is the frequent signaling of an alignment failure. Remarkably, my Starliner Mount purchased new about 42 years ago, is nearly 4 time older than my LXD55 and has accrued far more than 100 times the observing hours as has the LXD55 but functions as when new. After many enjoyable hours of use, my Starliner Mount has shown no problems at all because of its simple clock drive and good engineering design.

My second Go-To Mount is a recent purchase, in Nov. 2017, and it is a Celestron CGEM DX Computerized Equatorial Mount with a rather massive tripod. It now carries a Celestron C14AF-XLT - 14" Aluminum SCT Fastar-Compatible Optical Tube. It is shown in Figure 15 along with my 12 ½ inch, f/8, Newtonian, on my Starliner Equatorial Mount, but unlike my Newtonian, the Celestron Mount does not have traditional setting circles and therefore has in my view a naked look to it. But RA and DEC can be read electronically on the hand controller.

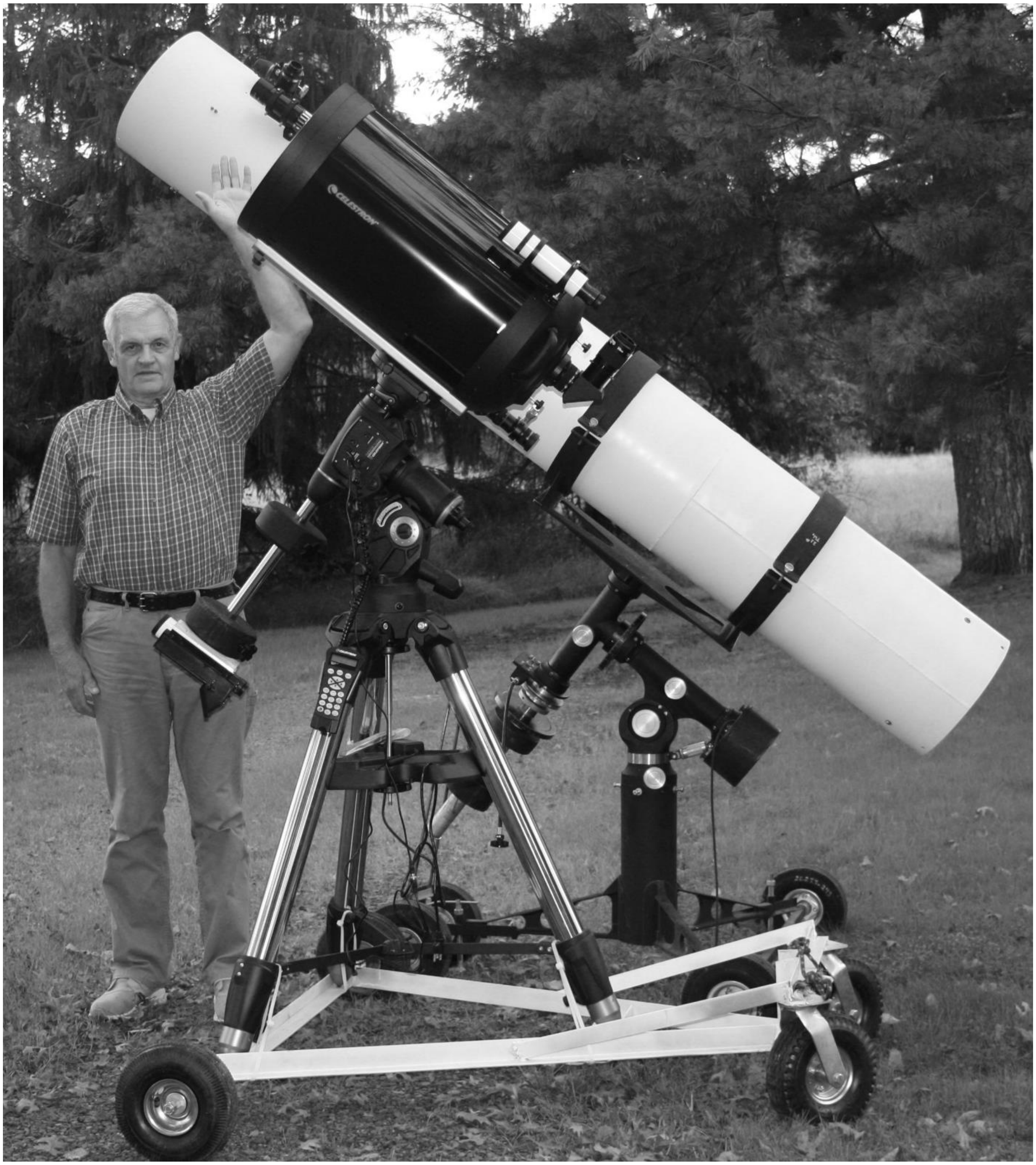

Figure 15: My Celestron C14AF-XLT on a CGEM DX Computerized Equatorial Mount compared to my 12 ½ inch, f/8, Newtonian, on my Starliner Equatorial Mount

My Celestron C14AF-XLT is about 30 inches long and 16 inches in OD and its weight gives me a comfortable margin below the CGEM DX Mount's weight limit. Unlike my Starliner Mount, both the LXD55 and CGEM DX mounts have a polar scope for alignment of the RA axis. That is a sorely missed feature on my Starliner Mount but its comfortable azimuth and altitude adjustments, for polar alignment, make the alignment easy but not as accurate as with the polar scope on my CGEM DX Mount but more than sufficient for visual use with setting circles for locating objects near a reference star.

Of all the mounts I have, or have had, none are more beautiful in appearance and match the simplicity of function and reliability offered by my magnificent Starliner Mount.

Telescope Performance:

Limits Imposed by Light Pollution: In my experience, whether you rely on setting circles on traditional mounts, such as my Starliner, or quality Go-To mounts and large apertures, relative large aperture systems are not a solution for light pollution and special filters are not much help either. With Philadelphia to the South and New York to the East Northeast, with their suburbs too, and Doylestown with its burgeoning car dealers' with bright groups of car-lot lights, such as the Fred Beans Dealerships to the West Southwest, all of those light sources have ruined telescopic viewing in my area. In addition, an opportunity for naked eye viewing of the Milky Way, even near zenith, is often obliterated with higher humidity air and associated scattering of artificial light. The annoying growth in light pollution in Eastern Pennsylvania has made me journey to other areas using my smaller "portable" scopes to see darker skies which we once had here when I was young . My Celestron C14AF-XLT on a CGEM DX Mount is not very portable. My 12 ½ inch, f/8, Newtonian, on my Starliner Equatorial Mount is definitely not portable. I've wanted a permeant mount under a dome for decades, but light pollution makes such an investment not fruitful enough and nearly, if not certainly, useless.

Solution: For maximum performance with any of my scopes, or mounts, I "gotta" get out of Eastern Pennsylvania and move to dark sky areas. My targeted areas for being under dark skies in the future are located in New Mexico. But I don't yet know exactly where in New Mexico?

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