Locating Celestial Pole in your images, and faking star trails

No more time to waste, folks, let's jump straight to how to do it.

What you need…

…To create star trail images

- A single image of stars. It's okay if the stars are a little bit trailed.
- An image processor like Photoshop.

…To locate the Celestial Pole (optional)

- Some sort of digital sky map and star database, which will help you identify the stars in your image, and get their declination (it's okay if you don't know what it is), to find the celestial pole. Stellarium is ideal.
- Your favorite graphing tool, to find the celestial pole based on coordinates of the stars. I'll be using GeoGebra.

How to fake star trails

Note: Unless you want to fool seasoned astronomers, you don't have to locate the celestial pole in your image. If that is the case *jump straight to step 15.* However, I feel it's a good exercise for an astronomer.

Locating the celestial pole

1. Shoot the area near Polaris for this example, with a telephoto lens (because it helps in identifying the stars). Folks living in Southern hemisphere may shoot the area near Southern Celestial Pole.

Figure 1: Image of the area near Polaris. Polaris is the brightest star in this picture (near the centre).

2. First, you need to locate the stars in your image. For this, set the date and time in Stellarium to the *exact* date and time the image was captured on. Furthermore, pause the date and time in Stellarium.

Figure 2: Stellarium's sky map near Polaris, which will help me to identify the stars. Compare this image with **Figure 1** (especially in areas surrounding the center)

3. Now open the original image with MS-Paint (yes, MS-Paint) to locate the pixel coordinates of stars. Finding Polaris should be easy. Now move the MS-Paint crosshair towards the centre of the star (try to be accurate), and read the pixel coordinates:

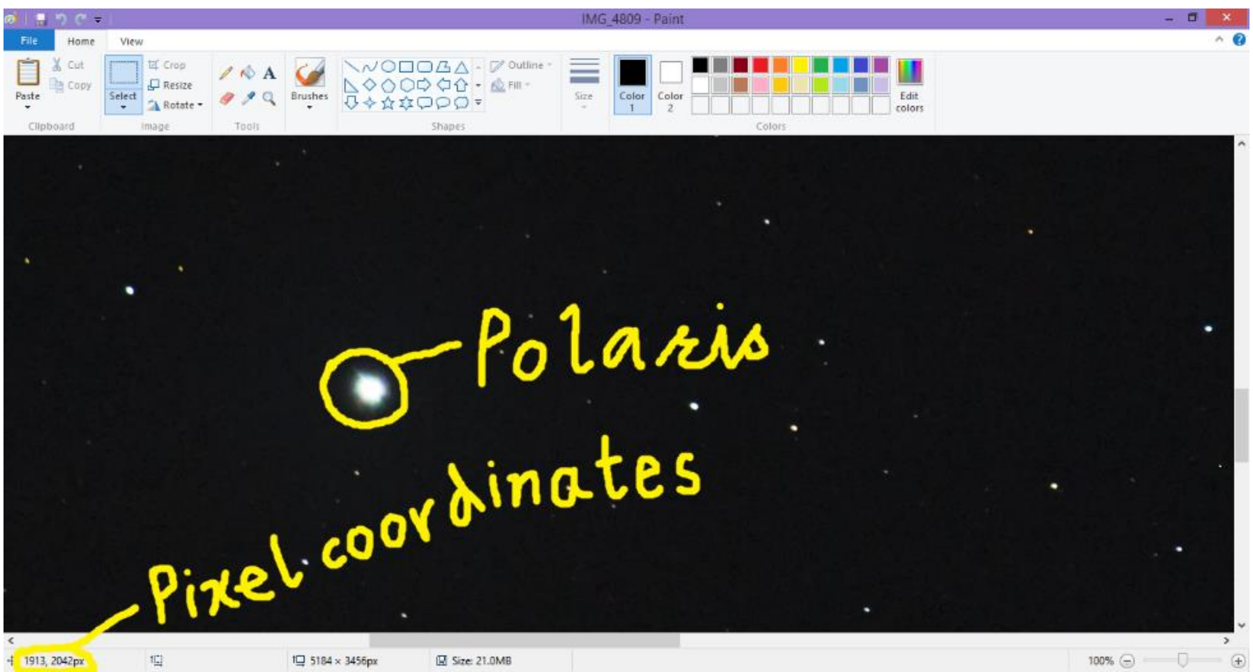

Figure 3: We have the pixel coordinates of Polaris as 1913, 2042px. Move the MS-Paint crosshair to the center of the star to note the pixel coordinates.

4. Do the same thing for two or more stars. Note that you must be able to recognize those stars in Stellarium, otherwise it's of no use. For best results, go for stars near the center.

Figure 4: The area near Polaris, as per Stellarium.

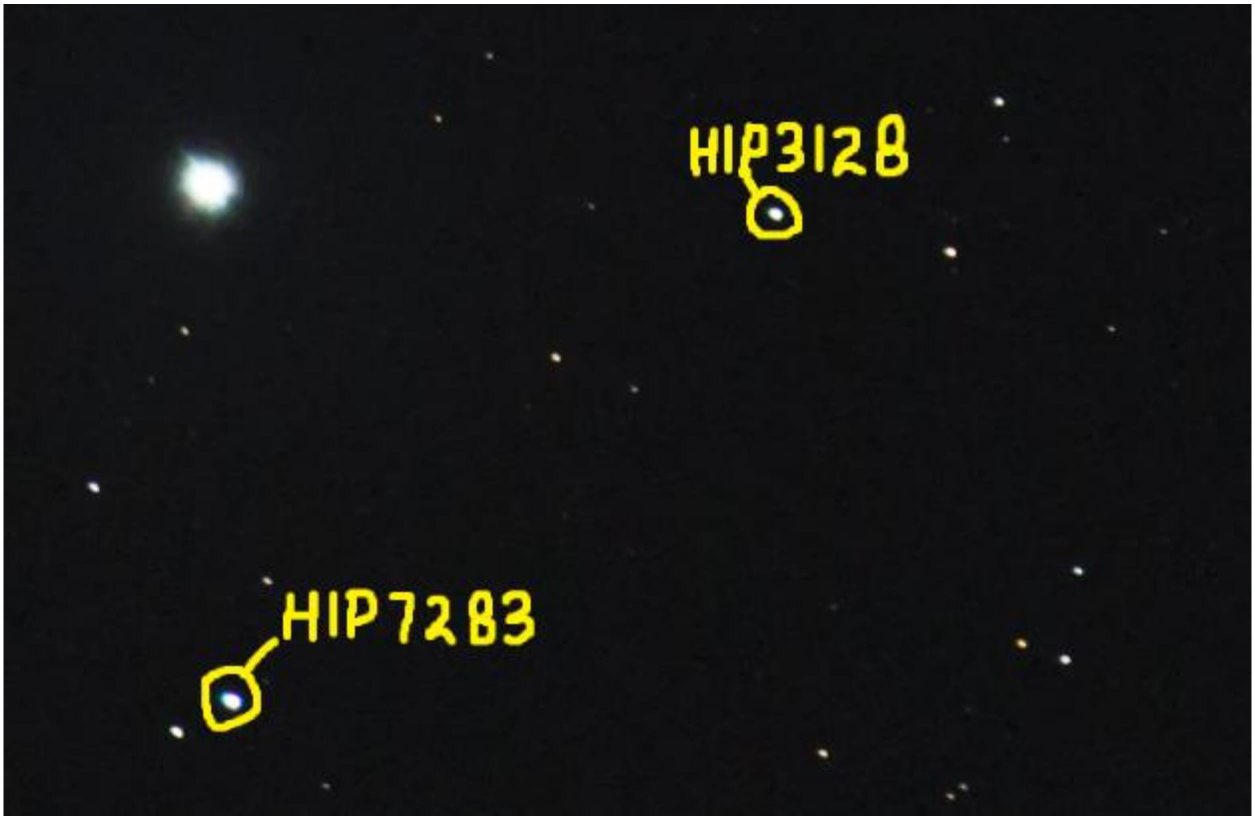

Figure 5: Crop from the original image. Compare carefully with **Figure 4**.

5. Now find the declination of stars you've located by Stellarium. You

Figure 6: You need to find out that number. Click on the star to get this info. Do it for all three stars.

6. Now you have the declination in the sexagesimal base. You need to convert it into decimal. It's simple, believe me. Say the declination is $+x°y'z''$. Then the number you need is $x + \frac{y}{60} + \frac{z}{3600}$. It's that simple. For example, for the declination of $+89°31'59.5''$, the number you need is $89 + \frac{31}{60} + \frac{59.5}{3600} = 89.53319444$.
7. So, finally, we should have a table like this:

Star Name	Pixel Coordinates	Declination (degrees)
Polaris	1913, 2042px	89.33191667
HIP3128	2268, 2060px	89.53319444
HIP7283	1928, 2365px	89.09716667

8. Now we need to figure out how many pixels away is the Celestial Pole from each of these stars. Here's the formula for it:

$$d = \frac{r_h(90 - s)}{2\tan^{-1} w_s/2f}$$

In this formula, s is the declination of each star, w_s is the width of the camera sensor in millimeters, f is the focal length at which this image was captured (in millimeters as well), and r_h is the horizontal resolution of your camera. For my camera, Canon EOS 700D, $w_s = 22.3mm$ and $r_h = 5184$. You need to do a quick Google search like "sensor dimensions of <camera name>" to get the width of your camera sensor. I know that w_s is 36mm, if you have a full frame camera.
9. We'll use that formula to determine the distance in pixels of celestial pole from each star. First, make sure than you're doing all calculations in degrees. Let's put in the values specific my camera, for Polaris:

$$\frac{5184(90 - 89.33191667)}{2\tan^{-1} 22.3/500} = 678.103$$

Rounding off, we get that Celestial Pole is 678 pixels away from Polaris. Note that these values are actually *approximate* values, and we'll see the effects of the error soon. Doing it for all the three stars, we get:

Star Name	Pixel Coordinates	Declination (degrees)	Distance from CP
Polaris	1913, 2042px	89.33191667	678px
HIP3128	2268, 2060px	89.53319444	474px
HIP7283	1928, 2365px	89.09716667	922px

10. Now you need to locate the celestial pole by a graphing tool. For this, we need to find some equations to input in our graphing tool. Suppose you have a star with pixel coordinates (p_x, p_y), and distance from celestial pole as d (in pixels). Then, the equation for that star is $(x - p_x)^2 + (y + p_y)^2 = d^2$. Simple. So we have this table in my case:

Star Name	Pixel Coordinates	Distance from CP	Equation
Polaris	1913, 2042px	678px	$(x - 1913)^2 + (y + 2042)^2 = 678^2$
HIP3128	2268, 2060px	474px	$(x - 2268)^2 + (y + 2060)^2 = 474^2$
HIP7283	1928, 2365px	922px	$(x - 1928)^2 + (y + 2365)^2 = 922^2$

11. Graph the equations in your graphing tool. Use 'circle graphing' option if available.

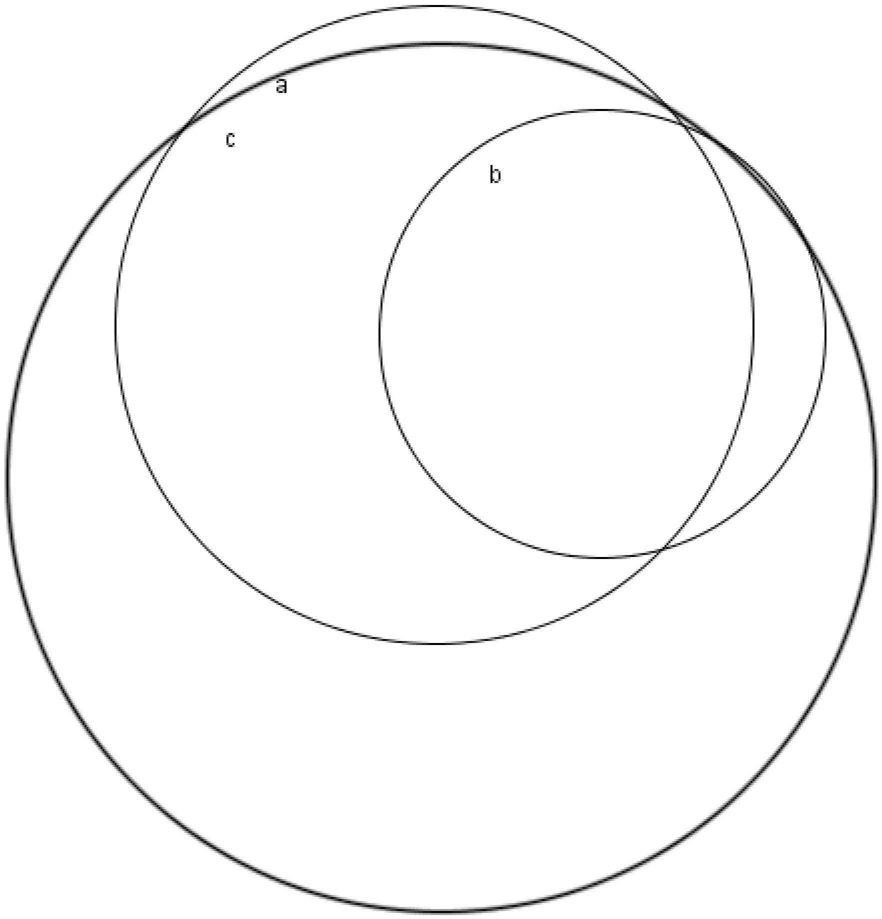

Figure 7: The three equations graphed.

12. We need to find a point which is nearest to *all* the three circles. Had we done the job with 100% accuracy, all the three circles would have intersected exactly at a point, which would be the celestial pole. We can identify the point visually as the point where the three circles *almost* intersect:

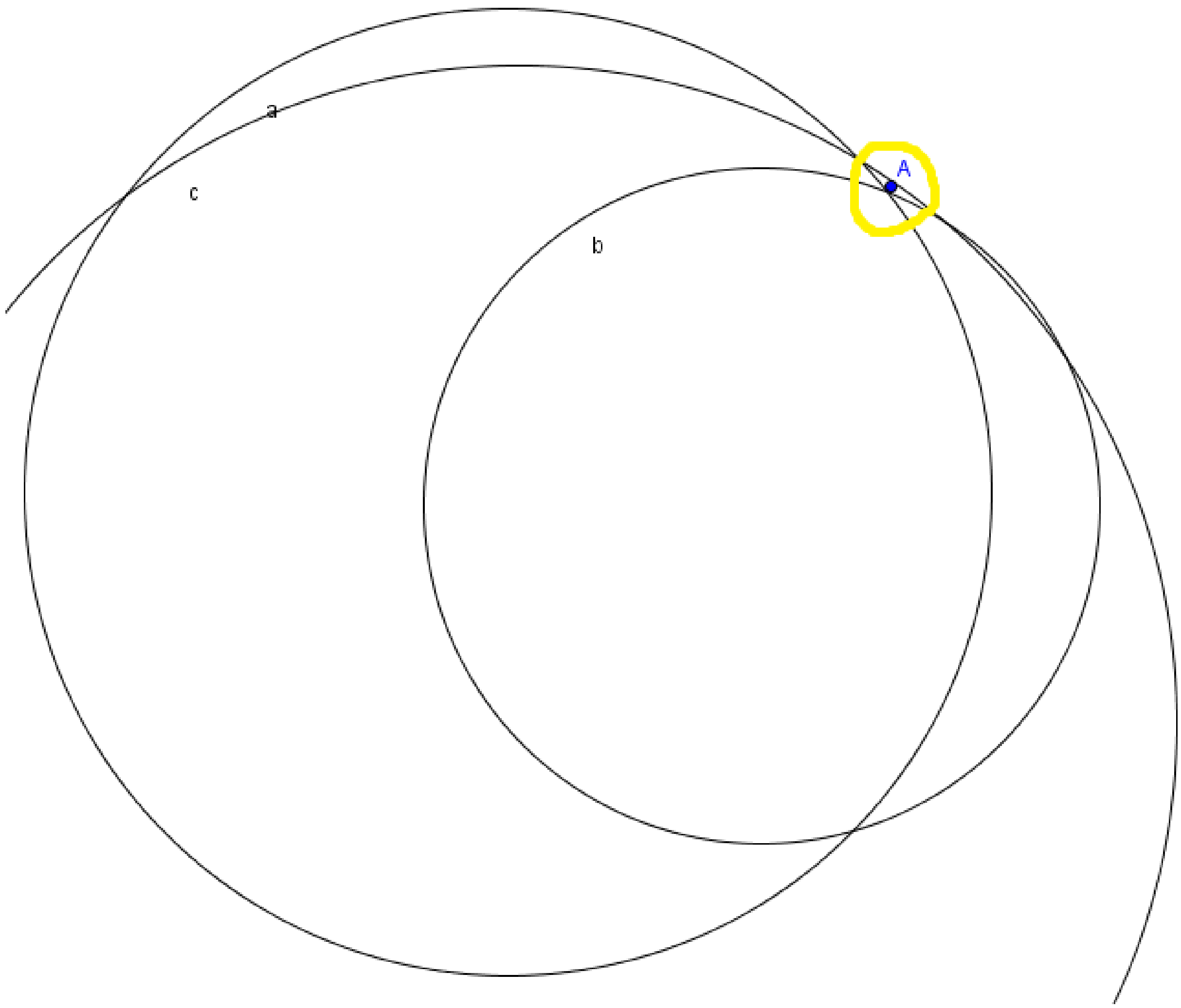

Figure 8: Identifying the point where the three circles *almost* intersect. While doing it for yourself, zoom in to be accurate.

13. Now that we have identified the point, the geometry tool would tell us its coordinates. In my case, the coordinates are (2449.86, -1613.45). This means that the pixel coordinates of the celestial pole are 2450, 1613px.
14. We need to crop the image, so that the celestial pole is in the center of the image. So we should crop it to 4900x3226px for the celestial pole to be in the center.
    NOTE: You can also *extend* the image so that celestial pole is in the center. But be sure to extend it so that the extended area is padded with black color. Extending becomes essential if the celestial pole is not present in your image at all, in which the celestial pole is identified by *negative* coordinates.

Faking star trails

You can create star trails either by Photoshop, or by ImageMagick. If you have ImageMagick, then you'll save yourself a lot of work.

Faking star trails With Photoshop

15. Fire up Photoshop with the cropped image. Select all of the background layer (Ctrl-J) and duplicate it (Ctrl-J). Set the blend method of duplicated layer to "Lighten". Select all of the duplicated layer by pressing (Ctrl-A). Then right-click inside the layer and click "Transform", or simply press Ctrl-T. Enter a value of "0.1" in the "Rotate" box and click on the "tick" arrow.

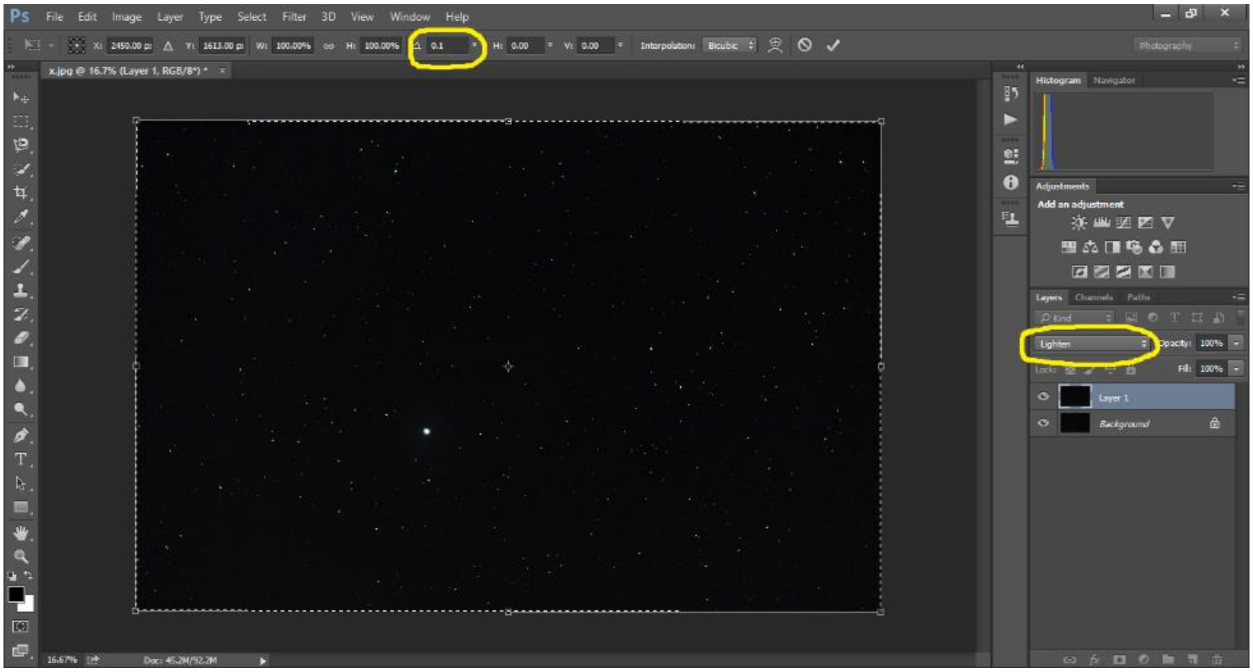

Figure 9

16. Right click on the duplicated layer and click "Merge Down."

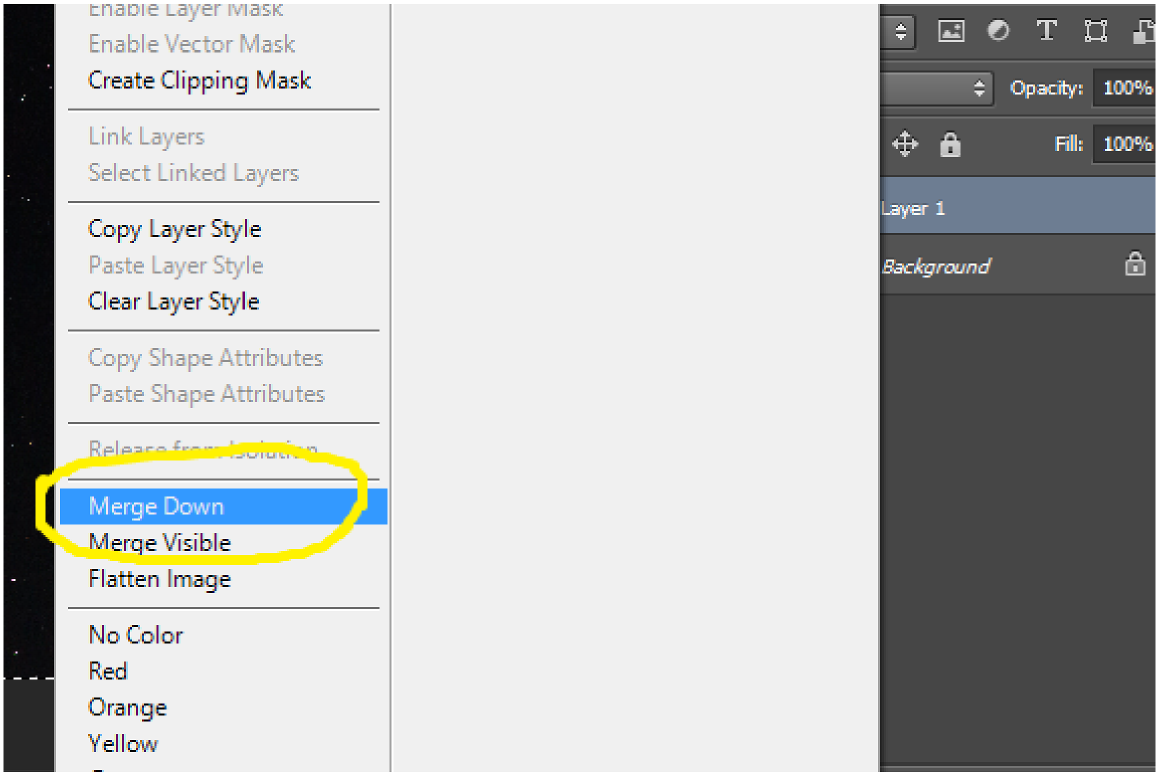

Figure 10

17. Now repeat step 15 again, but this time put a value of 0.2 in the "Rotate" box. Repeat step 15 yet again, this time using a value of 0.4 in the "Rotate" box. Keep doing this while multiplying the rotation angle by 2, until you reach an angle of 12.8.

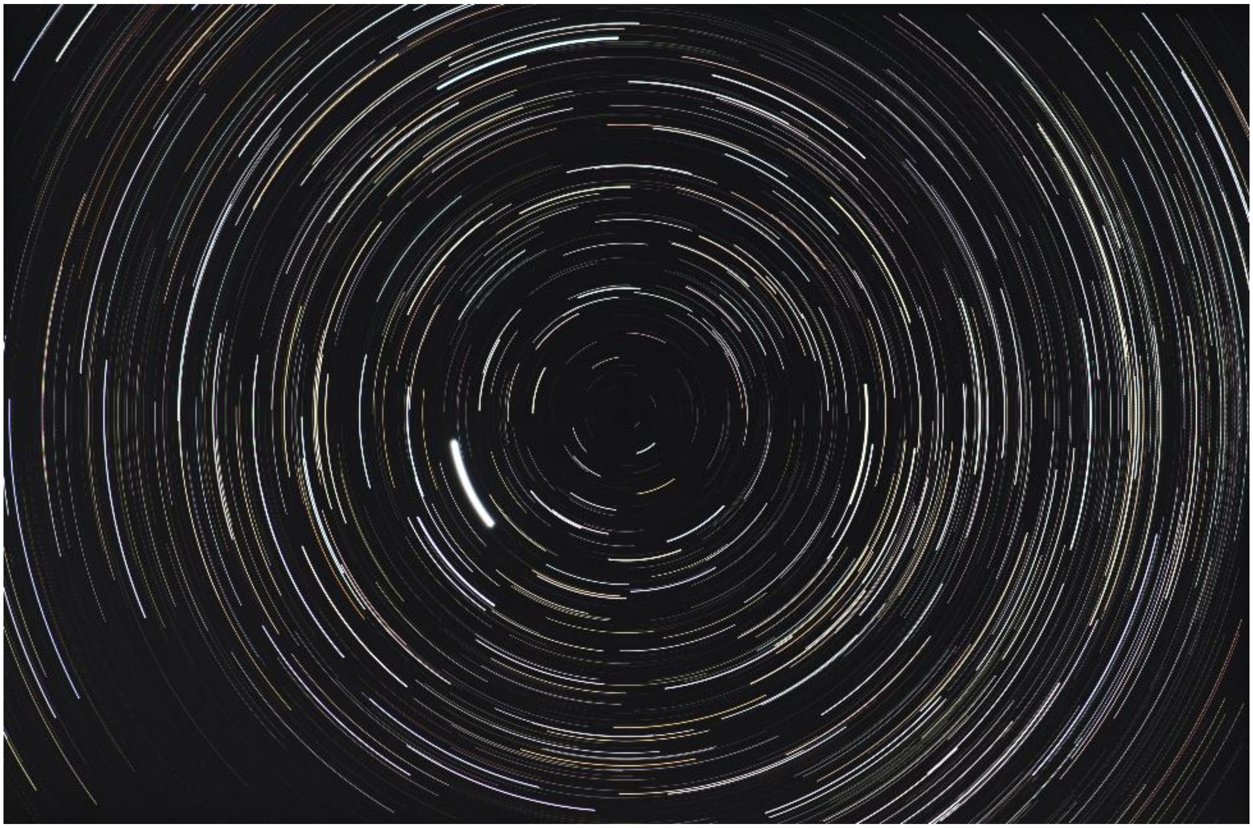

Figure 10: Beautiful 12.8 (actually 25.6) degree star trails. No post-processing done

18. If 12.8 degree of star trials suffice you, there you go. But you can achieve more star trails if you are patient. Duplicate the background layer twice. For the both the layer, select all of it (Ctrl-A), and then press Ctrl-T to transform the selection. Then put a value of “12.8” in the “Rotate” box for the first layer, and “-12.8” in the “Rotate” box for the second layer. Then merge all layers into one layer.
19. If you really want even longer star trails, do step 18 again, but use values “25.6” and “-25.6” in the “Rotate” box, for the layers. You can continue multiplying the rotation angle by 2 and perhaps create 360-degree full circle star trails, but you’ll then need to crop the image, because here’s what the final image would look like:

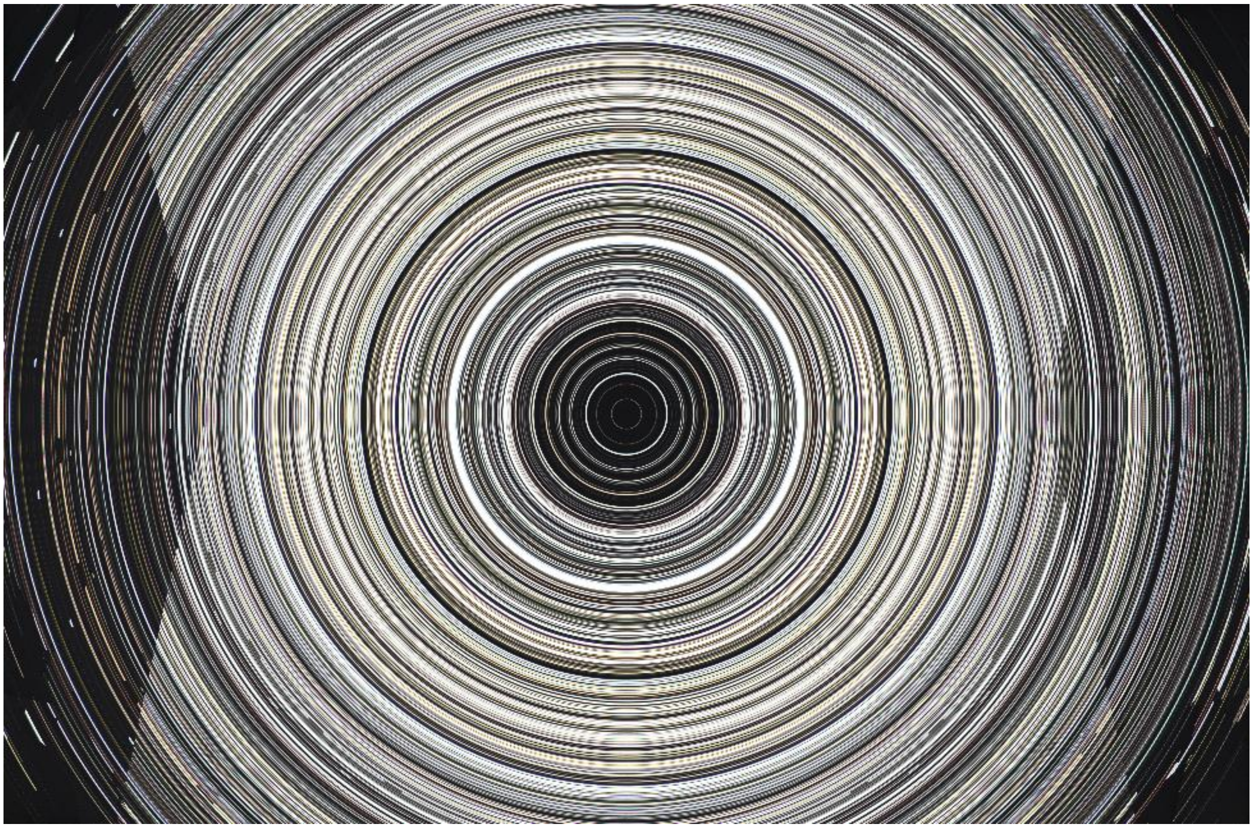

Figure 11: Why you need to crop images the images after you fake 360-degree star trails. You will have to do some more work to fill up the dark areas (I'll be happy to tell you more about it)

Faking star trails with ImageMagick

If you're of my type, then you prefer command-line based tools to reduce your work. These are the commands for creating a full 360-degree star trails. Run these commands (maybe after copying all of this and pasting into a .bat file) from the folder in which the original image is located. The original image **must** be named "x.jpg", and the output image will be named "z.jpg". You can easily use Find-and-Replace after copy-pasting these commands to make it work for .tif files as well. Or you can easily *remove some lines* to create shorter star trails (I recommend shorter, more realistic, and more colorful star trails).

```
convert x.jpg -background black -rotate .1 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center z.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -0.1 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 0.2 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -0.2 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 0.4 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -0.4 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 0.8 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -0.8 y.jpg
```

```
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 1.6 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -1.6 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 3.2 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -3.2 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 6.4 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -6.4 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 12.8 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -12.8 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 25.6 y.jpg
convert z.jpg -background black -rotate 25.6 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -25.6 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 51.2 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -51.2 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 102.4 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -102.4 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 204.8 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -204.8 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate 409.8 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
convert z.jpg -background black -rotate -409.8 y.jpg
convert z.jpg y.jpg -compose Lighten -gravity center -composite z.jpg
del y.jpg
```

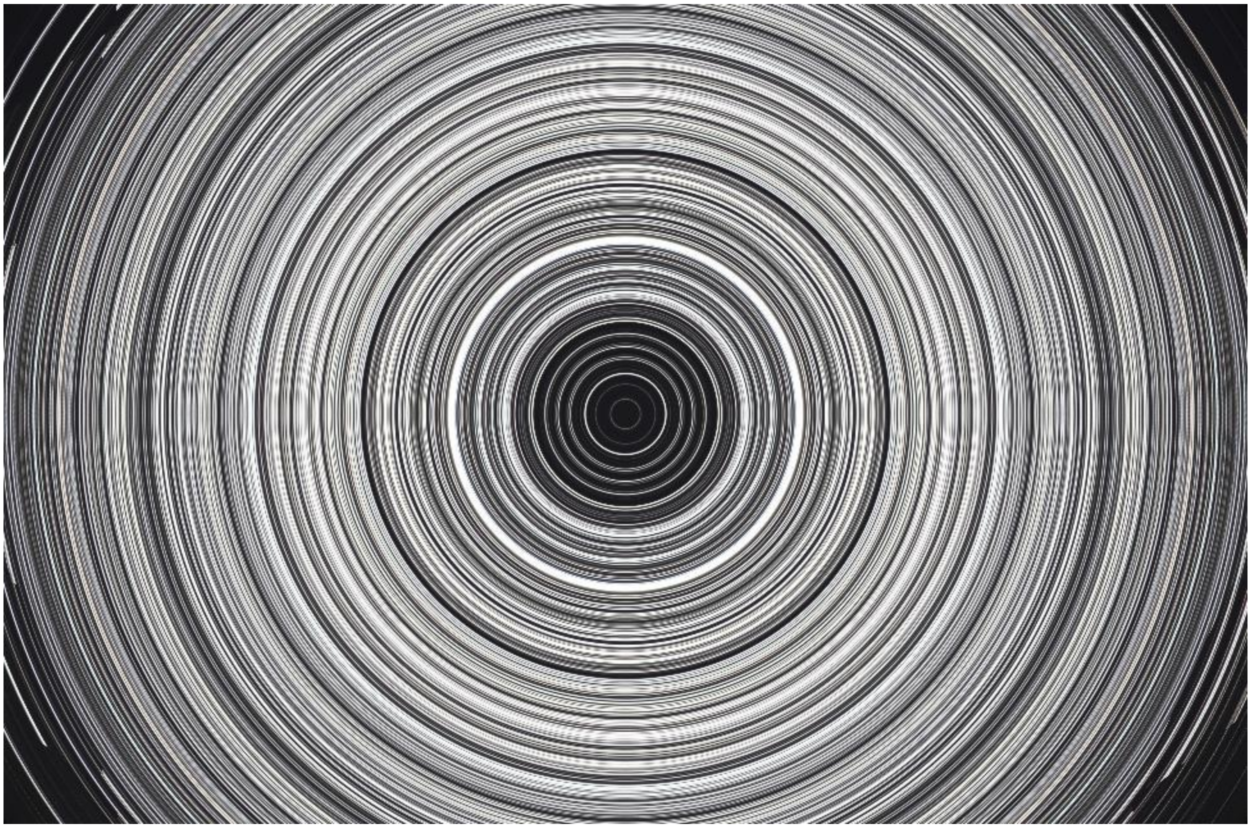

Figure 12: The result image "z.jpg" after the commands were run.

So this is pretty much it. Hope you enjoyed this tutorial. In future, I plan to release a tutorial of creating (aka faking) videos of star trails.