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Joseph A. Shaw, "Observing the mid-latitude aurora," Proc. SPIE 11099, Light in Nature VII, 1109906 (30 August 2019); doi: 10.1117/12.2531275

Event: SPIE Optical Engineering + Applications, 2019, San Diego, California, United States

Observing the mid-latitude aurora

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ABSTRACT

The aurora is a beautiful night sky optical phenomenon that is readily seen at high-latitude locations, but with more effort can also be seen and enjoyed at mid-latitude locations. Guidelines for when and where to look are presented, along with a rich array of photographic examples of mid-latitude auroras exhibiting all the usual range of green, red, and purple colors.

Keywords: Atmospheric optics, aurora, optics in nature, northern lights

1. INTRODUCTION

Of all the beautiful optical phenomena visible in nature, the aurora is one of the few that cannot be explained with geometric or wave optics concepts. Auroral light arises from atomic emission triggered by collisions of electrically charged particles from the sun with gas atoms and molecules of gases, primarily oxygen and nitrogen, in the extreme outer reaches of Earth's atmosphere at altitudes of 100-400 km.[1-6] These charged particles from the sun flow across space in what is referred to as the "solar wind," are captured in Earth's magnetic field and travel down the field lines until they reach a sufficiently low altitude to collide with upper-atmospheric gases and emit some of their energy as the visible light of the aurora. These collisions occur primarily in a region called the auroral oval, centered on the Earth's magnetic north pole and marking the region where the aurora is most likely to occur. During times of calm solar activity, the auroral oval encircles a high-latitude region over Alaska, northern Canada, Greenland, Iceland, Scandinavia, and northern Russia. During periods of high solar activity, the auroral oval stretches to lower latitudes, providing an opportunity for us to observe these colorful and dynamic optical displays in the midlatitude night sky without worrying about matching the timing of our trip to high-latitude regions with the ever-changing solar conditions.

The colors of the aurora correspond to optical wavelengths of oxygen and nitrogen emission lines. Figure 1 shows a spectrum of possible aurora emissions, but the most common aurora color is the green atomic oxygen emission line at 557.7 nm. It is also reasonably common to see fringes of red or purple in the auroral curtains. The purple arises from a combination of red and blue nitrogen emission lines. Pure red oxygen emission is also seen, especially during particularly energetic solar storms.

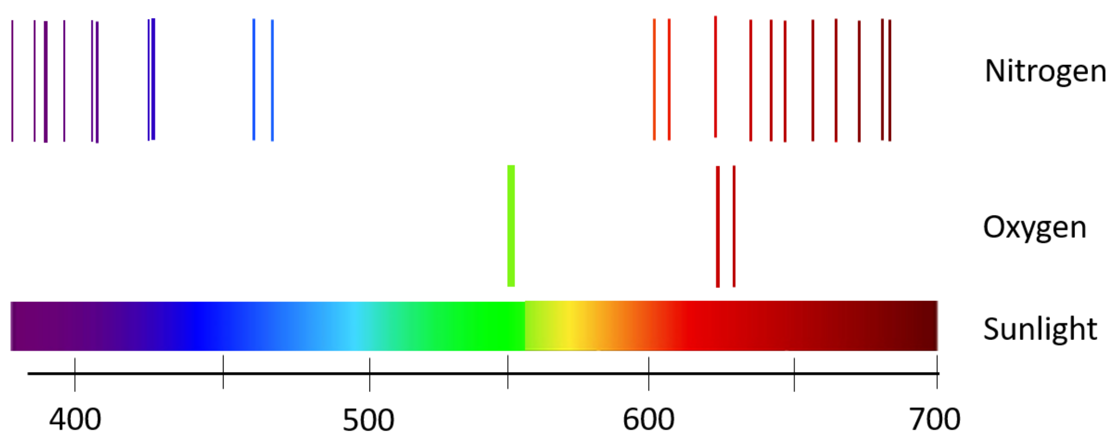

Figure 1. Wavelength spectrum (nm) of nitrogen and oxygen emission lines that produce the colors in the aurora.

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Light in Nature VII, edited by Katherine Creath, Vasudevan Lakshminarayanan,
Joseph A. Shaw, Proc. of SPIE Vol. 11099, 1109906 · © 2019 SPIE
CCC code: 0277-786X/19/$21 · doi: 10.1117/12.2531275

The purpose of this paper is to teach readers how to see the aurora at subpolar latitudes and to show photographs of midlatitude auroras as a guide for what to expect. The key to seeing mid-latitude aurora is to be familiar with some basic parameters that help you know when and where to look. These parameters are discussed in this paper with the intent of educating readers to see the aurora in locations that are not normally considered places to go for aurora viewing.

2. WHEN CAN YOU SEE THE AURORA?

Regardless of location, there are fundamental issues of timing that strongly impact the probability of seeing aurora anywhere. First and foremost, we need a dark sky free of manmade light pollution. This means that when searching for auroras, you really need to get away from city lights and into the darkest possible conditions. It also means that at high latitudes there is zero chance of seeing auroras during the summer period when the sun never goes far below the local horizon. This leads to the false concept that the aurora is a winter phenomenon. While that is true in places like Alaska (where I grew up), it is not at all true for mid-latitude locations that have darkness for multiple hours even on short summer nights. In fact, some of my best mid-latitude aurora observations have occurred in the summer because of the high probability of cloud-free summer skies and the comfortable summer night temperatures where I live (in the US state of Montana). In any season, the best chances for aurora activity occurs close to local midnight, so aurora observing is not favorable to going to bed early.

Fundamentally, auroras are driven by solar activity, which is linked to the 11-year sunspot cycle illustrated in Figure 2. Additionally, in any given year the probability of aurora tends to peak near spring and fall equinox. At high latitudes spring equinox is also near the end of the auroral observing season as the bright summer sky rapidly takes over the night. Conversely, at high latitudes fall equinox is near the beginning of the auroral observing season as the nighttime darkness returns. At middle latitudes both equinoxes are excellent observing times, often with relatively comfortable outdoor temperatures compared to the deep-winter conditions at higher latitudes.

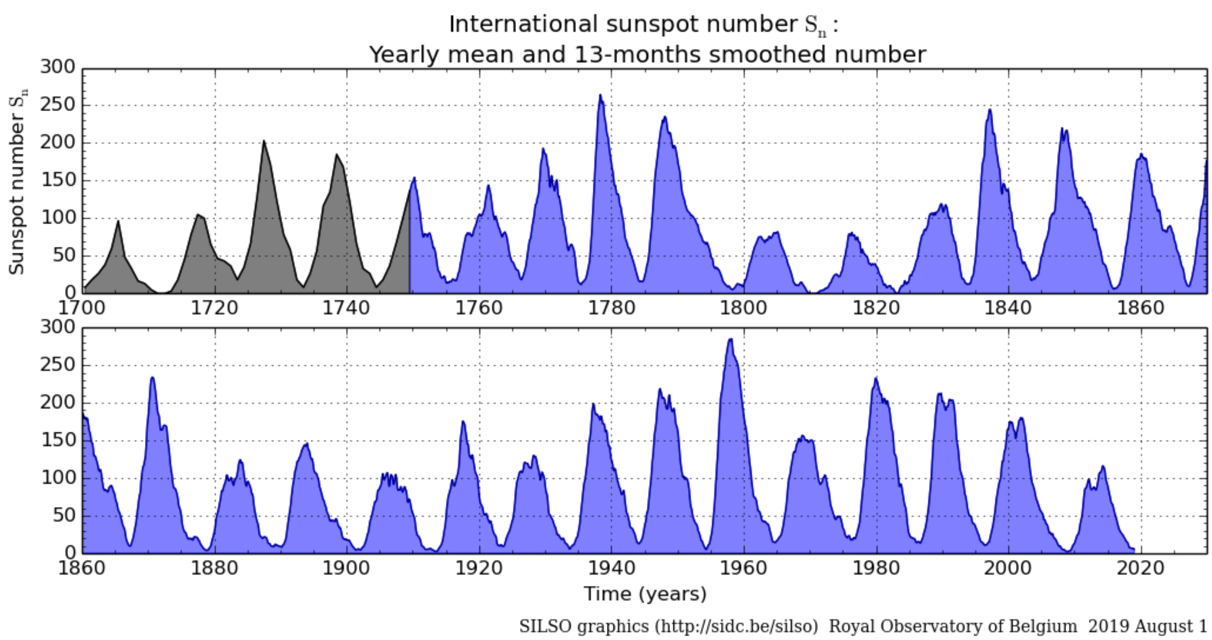

Figure 2. The sunspot number follows a cycle with a period of approximately 11 years. The highest probability of auroral activity coincides with the peaks of this cycle. Figure courtesy of the Royal Observatory of Belgium.[8]

3. WHERE CAN YOU SEE THE AURORA?

The aurora oval referred to in the Introduction is illustrated with satellite data in Figure 3 for extremely quiet solar conditions (left) and active solar conditions (right). The aurora may be visible in a very limited high-latitude region for the quiet conditions shown on the left side, but it would very likely be visible over a much larger region for the active conditions on the right side. In the latter case, the aurora could be visible well below the US-Canada border, for example.

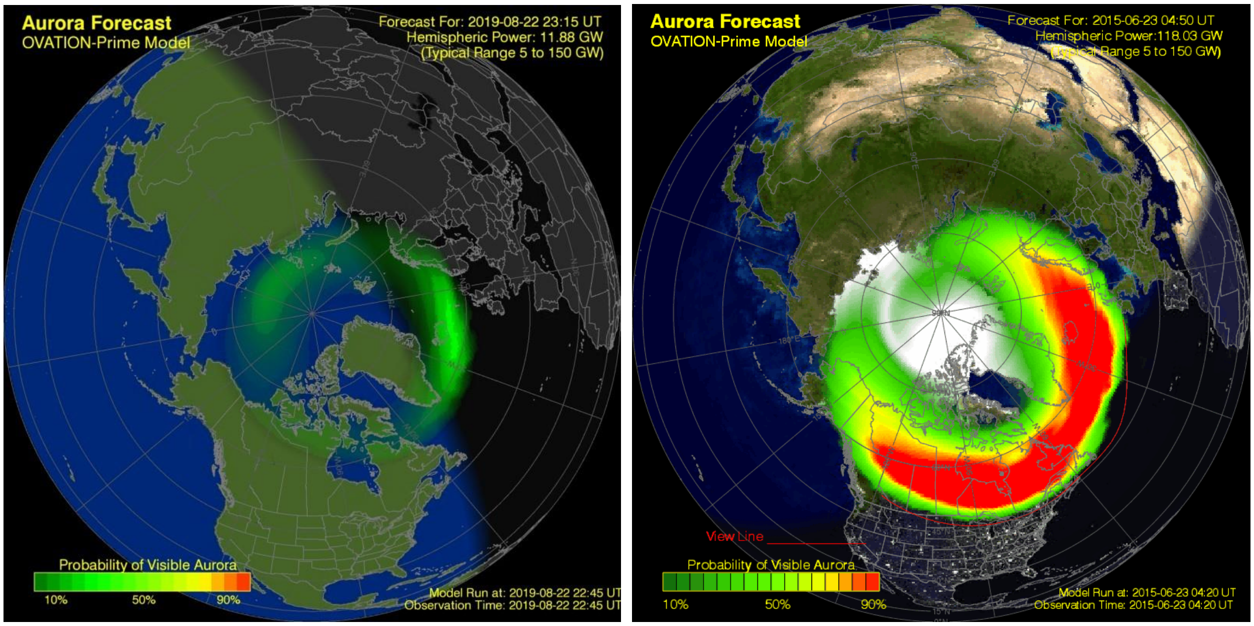

Figure 3. Plots of the auroral oval forecast in real time by the NOAA Space Weather Prediction Center (swpc.noaa.gov) for extremely quiet auroral conditions active auroral conditions (right).

Also evident in Figure 3 is that the auroral oval is centered on the magnetic north pole, not the geographic north pole. This means that what really matters is your geomagnetic latitude rather than your simple geographic latitude. Figure 4 illustrates the importance of geomagnetic latitude rather than geographic latitude. This figure includes colored lines of constant *Kp*, which is an index that measures the strength of magnetic fluctuations (this often corresponds to aurora probability, although I have seen situations where the *Kp* index was sufficiently high but other conditions prevented the formation of a visible aurora). So, for example, notice that with $Kp = 7$, the aurora could be visible as far south as 41°N latitude in the United States (just south of Chicago), while the same conditions would result in an aurora only visible down to approximately 54°N in Europe (i.e., northern England or near the Germany-Denmark border). A similar set of maps can be seen at the NOAA Space Weather Prediction Center website[9] for the southern hemisphere, but the only significant land masses other than Antarctica that lie within even the high-Kp reach are Tasmania, far southern Australia, and the South Island of New Zealand. The vast majority of the Southern Hermisphere is therefore well outside of where we could reasonably expect to see the aurora without going to Antarctica.

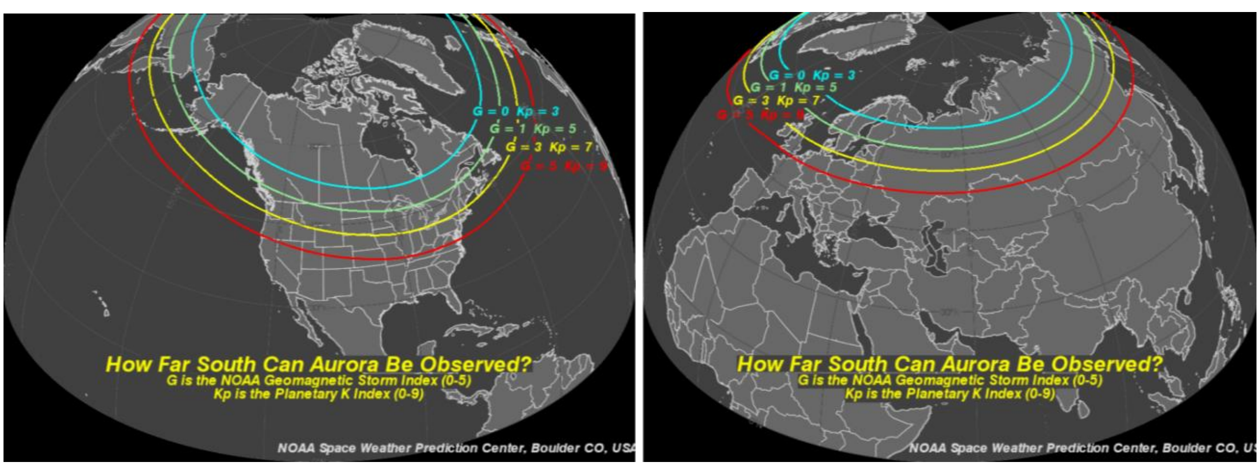

Figure 4. Lines of *Kp* index, which helps determine the low-latitude reach of the aurora. Because of the location of the magnetic north pole in northeastern Canada, the geomagnetic latitude of the central-eastern US is more favorable for aurora viewing than is much higher-latitude locations in Europe. Images courtesy of the NOAA Space Weather Prediction Center.[9]

Finally, you should not forget that trans-oceanic airplane flights follow a great circle route that typically takes you to much higher latitudes than either your origin or destination. As is discussed further in my book on this subject,[6] Northern Hemisphere trans-Pacific or trans-Atlantic flights frequently cross into the auroral zone and are excellent opportunities for seeing the aurora. The best aurora viewing is typically from the window seat on the northern side of the airplane, although in extremely active conditions you can even see the aurora on the southern side. Before (or even during) your flight, you can check the aurora forecast or the solar conditions online at sites such as the NOAA Space Weather Prediction Center,[9] the University of Alaska Geophysical Institute,[10] Aurorasaurus,[11] or a quasi-commercial site such as spaceweather.com.[12] These same websites are fabulous sources of information any time you are seeking aurora-viewing opportunities, not just when you are preparing for an overseas flight.

4. AURORA EXAMPLES

In this section I show some photographs of auroras observed primarily at mid-latitude locations to illustrate the possibility and variety of such observations. The first example in Figure 5 is a high-latitude aurora I photographed at the Poker Flat Research Range near Fairbanks, Alaska (65.12°N), an ideal location that is almost always beneath the auroral oval (in fact, going much further north usually takes you back out of the auroral oval). This example is shown first as a reference for how the aurora can look in very good high-latitude conditions, with multiple auroral curtains, arcs, and colors.

Figure 5. Aurora photographed at Poker Flat Research Range north of Fairbanks, Alaska (~65.12°N) with multiple curtains and arcs showing green oxygen emission and purple (red and blue) nitrogen emission using a Nikon D800 camera, Nikon 16-mm lens, f/2.8, ISO3200, 8 s exposure.

Figure 6 is a green oxygen-emission aurora I photographed through an airplane window on a flight from Fairbanks, Alaska to Minneapolis, Minnesota, on 8 Aug. 2013 over Alberta, Canada. I was looking northeast toward the higher-latitude sky where the sun was still high enough to produce sunset colors on the distant horizon. This aurora became barely visible as soon as we flew far enough south to find a dark night sky (in northern British Columbia ~59°N), it got really good as we flew through northern Alberta, and it remained visible until the sun began rising, so it would be reasonable to expect that this aurora could have been visible to an observer somewhere near the US-Canada border – at the northern edge of the mid-latitude region we are discussing.

The aurora in Fig. 7 is a more typical mid-latitude display (Bozeman, MT USA, 45.67°N) with a faint green arc positioned low on the northern horizon. On this particular night I could readily see and identify this arc as a green aurora, although sometimes a weak aurora like this one appears simply as a whitish glow that could easily be mistaken for distant light pollution. In such cases, I typically use my tripod-mounted digital camera to quickly record a photo and confirm the existence of color, thereby confirming whether it is or is not an aurora. With experience, it becomes easy to recognize this as an aurora even when your eyes cannot quite detect the color. Under marginal conditions like these, a mid-latitude aurora typically has less brightness and less apparent motion than what can be seen at higher latitudes.

During a particularly energetic solar storm, a mid-latitude aurora can exhibit comparable brightness and motion to a high-latitude display. The example shown in Fig. 8 (Bozeman, MT, 45.67°N) was so active that I was actually facing south when I recorded this image with a wide-angle lens. On this night (15 May 2005), the entire sky was covered with aurora that was easily as bright and dynamic as a good high-latitude display. This is not the usual mid-latitude experience, but it illustrates just how good it can get under the right conditions. This particular photo was recorded near the end of the display (1:23 am MDT) and clearly shows a green oxygen-emission curtain with a red oxygen emission fringe along the top edge.

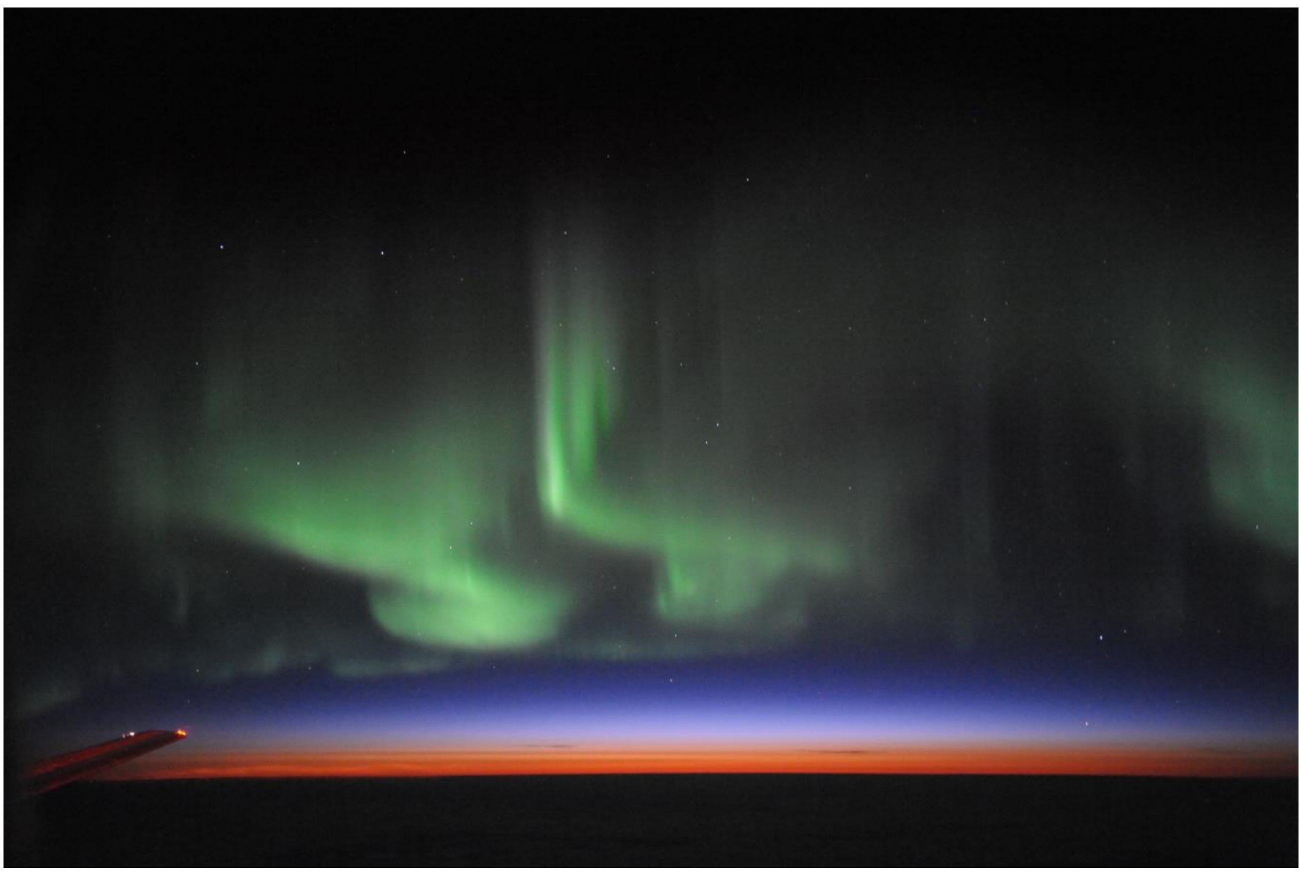

Figure 6. Green aurora photographed from an airplane over Canada northwest of Minnesota at approximately 0815 UTC on 8 Aug. 2013 using a Nikon D700 camera and Nikon 28-mm lens at f/2.8, ISO6400, and 2 s hand-held exposure.

Figure 7. Weak green aurora seen on the northern horizon from Bozeman, MT on 9 Sep. 2011 at 11:40 pm MDT (UTC-6) and recorded with a Nikon D300 camera, Nikon 20-mm lens at f/2.8, ISO1000, and 4 s exposure.

Figure 8. Strong mid-latitude aurora observed in Bozeman, MT on 15 May 2005 at 1:23 am MDT and recorded with a Nikon D70 camera, Nikon 10.5-mm lens at an unknown ISO and f# and 25 s exposure.

A richly purple-hued aurora is shown in Fig. 9, with the purple light being created by a combination of red and blue nitrogen emission. There is also a region of green oxygen emission near the bottom of this display. This was readily visible to the naked eye, but only after I got dark adapted after being outside for tens of minutes, although the camera recorded more purple light than was visible by eye. This photograph was recorded in my front yard just east of Bozeman, Montana, at 45.67°N latitude (pretty much the definition of middle latitude, although in the U.S. Montana is conserved a northern state). There was not a lot of motion in this display, but I still could see some horizontal sweeping of the vertical bands just visible in the photo (such banding can be inadvertently removed by recording photos with a long exposure time). If you are wondering why I was out in my front yard an hour and a half after midnight, the answer is that I had seen some weaker aurora earlier in the evening and had gone outside frequently to check the sky.

An entirely different hue is shown in Fig. 10, which is a rare nearly all-red aurora. Oxygen emission produces a pure red that is much different from the nitrogen purple in Fig. 9 (see Fig. 1), but once again the common oxygen-green light can be seen at the bottom of this display. This kind of nearly pure red aurora is quite rare and only happens during the most elevated solar conditions. This red aurora occurred in November 2004, just after solar maximum (i.e., the peak of the 11-year sunspot cycle). In fact, I have observed many of my best auroras in years on the downward-trending side of the sunspot cycle.

Figure 9. Purple and green aurora observed from Bozeman, MT on 7 June 2013 at 1:42 am MDT, recorded with a Nikon D700 camera and Nikon 50-mm lens at f/1.8, ISO1600, and 5 s exposure.

Figure 10. Oxygen red aurora observed at Bozeman, MT on 7 Nov. 2004 at 1:48 am MDT and photographed with a Nikon E5000 camera and 7-mm lens at ISO100, f/2.8, and 60 s exposure.

The final example is of an optical display in the night sky that looks like a weakly colored aurora, but it is, in fact, a unique optical phenomenon that was only very recently discovered and explained. This whitish arc, sometimes accompanied by a green picket-fence structure, was discovered by citizen-scientist observers and described in the scientific literature in 2018,[13] with further explanation in 2019.[14] This new phenomenon, closely related to the aurora, was named STEVE, at least in part as an acronym for Strong Thermal Emission Velocity Enhancement. For this to occur, electrons pour into the ionosphere, where atoms lose electrons due to solar and cosmic radiation, causing friction that heats particles to creates the whitish-pinkish glow in a process that is reminiscent of the process leading to visible light from an incandescent light bulb. It is worth noting here that I first photographed STEVE in May 2016 when it was first being noticed by the people who eventually published the paper announcing its discovery.[13] I knew it was not a normal aurora because of the odd coloration, but I did not know what it was. Inquiries to some aurora physics colleagues did not produce an answer, so I was surprised and pleased to learn more about it when the 2018 paper appeared in the literature. One particularly noteworthy thing about STEVE from the viewpoint of this paper is that it is visible at much lower latitudes than the usual aurora, so you should watch carefully for this newly discovered optical phenomenon during your own quest to see the mid-latitude aurora.

Figure 11. STEVE observed from Bozeman, MT on 28 May 2017 at 10:44 pm MDT and recorded with a Nikon D800 camera, 16-mm fisheye lens at f/2.8, ISO2500, and 4 s exposure.

5. CONCLUSION

The aurora is a beautiful optical phenomenon that can be observed in nature when the proper conditions occur, with elevated solar activity, favorably oriented magnetic fields, and an observer located in dark-sky conditions at an appropriate latitude. Most often that means traveling to (or being at) high latitudes near 65°, but in this paper I have described how to find conditions that lead to visible aurora at much lower latitudes. The likelihood of such a mid-latitude aurora observation certainly decreases the lower in latitude we go, but by paying close attention, you can see mid-latitude auroras that are rich in color and beautiful to behold. STEVE was introduced as a recently discovered optical phenomenon that is similar to the optical aurora, but different in origin and much easier to see at lower latitudes. The reader is encouraged to pay close attention to the appropriate web sites and enjoy these beautiful optical phenomena that too many people assume cannot be seen outside the polar regions.

ACKNOWLEDGMENTS

Financial support during the preparation of this manuscript came from three different sources, as outlined below.
1. This material is based upon work supported in part by the National Science Foundation EPSCoR Cooperative Agreement OIA-1757351. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.
2. NASA EPSCoR grant NNX14AN40A
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