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Seminar Review

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I review the paper titled 'The Mysterious Green Streaks below STEVE' by Professor Joshua Semeter of Boston Univerisity's ECE Department This paper gives an introduction to the phenomenon known as STEVE, the Strong Thermal Emission Velocity Enhancement, which appears very similar to classical auroras but has a number of different and unique characteristics. It goes over some interesting features of STEVE and talks about the contributions of citizen scientists, photographers, and how people can contribute to the project going forward. It discusses some approaches taken to analyze STEVE and some of the physics behind it. It stresses that our current understanding is not enough and more research is required.

Word Count: 1813

INTRODUCTION

This paper review was created using the American Political Science Review template, which may make it look interesting. The paper is titled 'The Mysterious Green Streaks Below STEVE' and is primarily authored by Professor Joshua Semeter of Boston University and Michael Hunnekuhl, a citizen scientist and an independent researcher in Germany.

WHAT IS STEVE?

Strong Thermal Emission Velocity Enhancement (STEVE) is an optical phenomenon that occurs in the subauroral ionosphere and is characterized by extreme ion drift speeds. STEVE appears as a mauve or whitish arc extended in the east-west direction and is often accompanied by a region of green emission structured into quasi-periodic columns known as the "picket fence." In contrast to normal auroral phenomena, STEVEs are characterized by this picket fence structure and are recently gaining ground

Anonymised submission.

This is a manuscript submitted for review.

FIGURE 1. The STEVE Phenomenon (Credits: NASA)

in the scientific world because of the interesting physics that applies to them as well as the role of ordinary citizens and citizen scientists in recording and analyzing these phenomena.

This study used high-resolution imagery from citizen scientists to examine the fine-scale features within the green emission region of STEVE, with a focus on narrow streaks of emission that form underneath field-aligned picket fence elements at altitudes of 100-110 km. These streaks propagate in curved trajectories with a dominant direction towards STEVE from the poleward side and have a duration of approximately 20-30 seconds and a cross-sectional dimension of less than 1 km. The uniform coloration of all STEVE green features suggests a common optical spectrum dominated by the oxygen 557.7 nm emission line. The authors suggest that the source of these streaks is likely to be direct excitation of ambient oxygen by superthermal electrons generated by ionospheric turbulence induced by the extreme electric fields driving STEVE. They also propose a causal connection between these streaks and the overlying field-aligned structures, based on coupling of thermal and gradient-drift instabilities and analogous dynamics observed in chemical release and ionospheric heating experiments

ROUGHLY, HOW ARE STEVE CAUSED?

It is hypothesized that STEVE are created by a process known as "substorm injection," which involves the acceleration of charged particles from the Earth's magnetosphere into the upper atmosphere. These particles then collide with atoms and molecules in the atmosphere, causing them to emit light, which is what we see as an purple aurora. However papers by Professor Nishimura from Boston University suggest that particle injection combined with an 'upward ion current' giving rise to field currents might

FIGURE 2. STEVE with 'Normal' Aurorae (Credits: Semeter et al)

be the reason for the formation of STEVE.

The paper explains how the problem of analyzing STEVE is being tackled. STEVE is unique in that many of these phenomene have been observed, but not in any regulated form. Rather, recordings of STEVE phenomena are available on the internet, such as on YouTube or other video-sharing websites. The uncontrolled nature of these observations is primarily why STEVE are so hard to analyze; a large portion of the process is correcting and reducing blurry, unstable, and often low-quality videos to a stable form for analysis. On top of that, STEVE phenomena also exhibit more dynamic and complex behavior rather than the simple picket fence, and these phenomena have also been recorded. As such, research of STEVE in the early stage revolving around time-sequential analysis of video data rather than pure physics.

Further complications arise because of STEVE appearing with regular aurorae, as shown in Figure 2. Because of the inherently erratic nature of STEVE observations (such as observer perspective, camera exposure times, magnetic field topology, and radiative lifetime effects), regions of interest are often hard to spot and therefore research in this field is nascent, as shown in Figure 3.

FIGURE 3. Some interesting regions of STEVE (Credits: Semeter et al

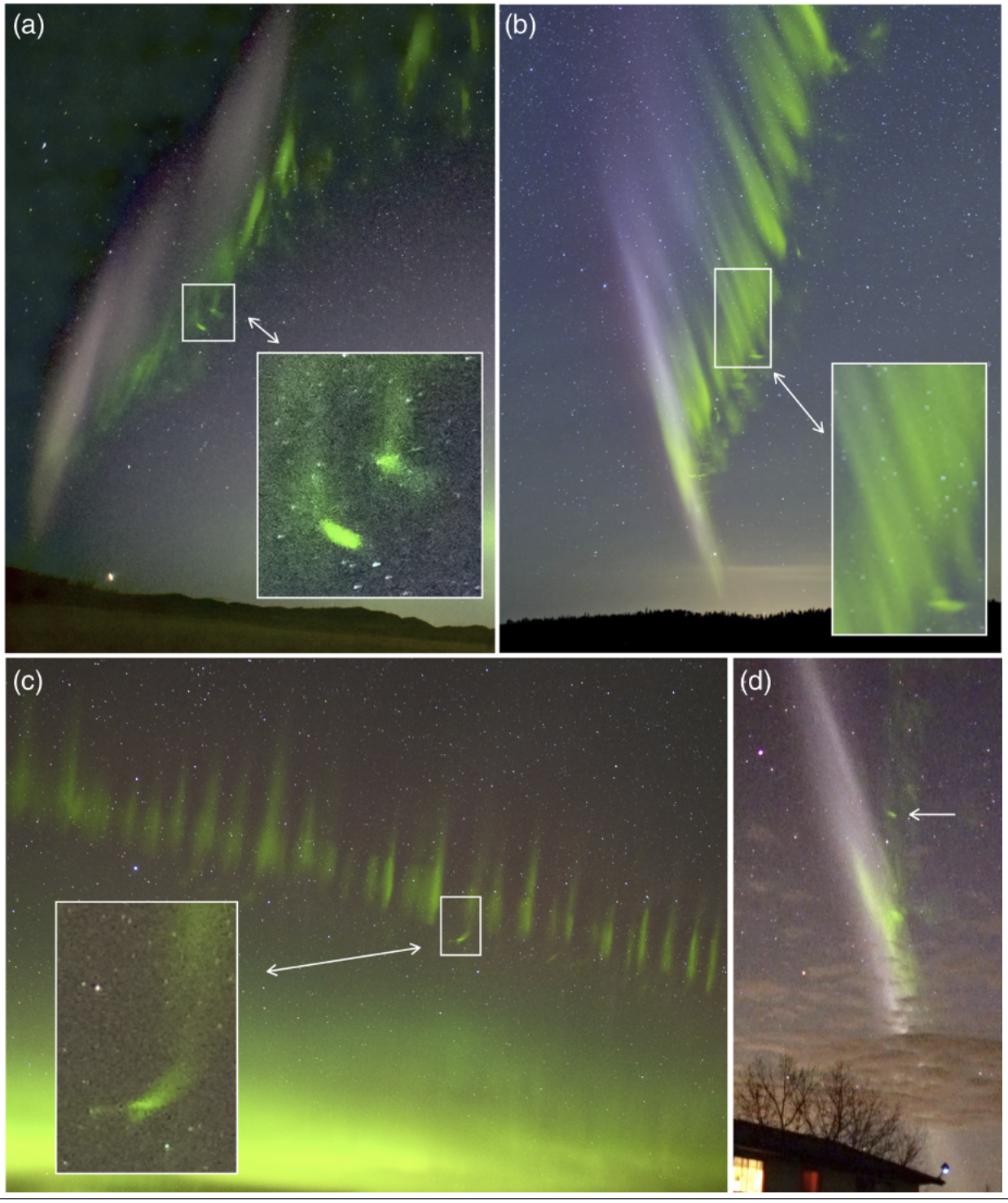
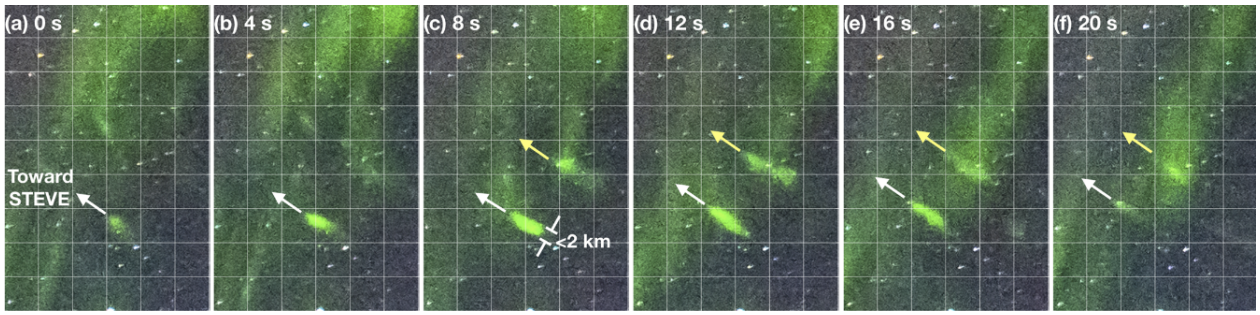


FIGURE 4. STEVE Triangulation (Credit: Semeter et al)



TECHNIQUES FOR OBSERVING STEVE

Some basic approaches have been proposed in order to extract data from STEVE. The most basic approach is triangulation, which involves taking time-synchronized images from two different locations, to calculate the height of STEVE and other auroral features. This technique involves analyzing the positions of stars in the images in relation to topographical landmarks on the horizon to establish the timing of the images and using fine-scale features in the images to determine the relative time offset between them. There are challenges in using this technique, including the possibility of errors in the time stamps recorded in the image metadata and the sensitivity of the triangulation results to small synchronization offsets between the images. However, this method allows for the precise calculation of the height of STEVE and other auroral features, which can provide important information about the physical mechanisms behind these phenomena. Such a method is shown in Figure 4.

After estimating the height of the STEVE phenomenon, the next step is to plot its trajectory across the night sky. Using high-cadence and high-resolution images to study the formation and evolution of STEVE and other auroral features. These images show that STEVE and other auroral features can exhibit complex spatial and temporal variability and that they are influenced by a number of factors, including motion blur, emission afterglow, and spatio-temporal variability in the excitation source. Scientists are using these images to better understand the physical mechanisms behind STEVE and other auroral features and to develop models that can accurately predict their behavior. This is shown in Figure 5.

One particularly good observation is then analyzed. Some techniques that relate image processing and geometry such as the small angle formula are used in order to estimate the dimensions and velocity

FIGURE 5. STEVE Trajectory using a green feature (Credit: Semeter et al)

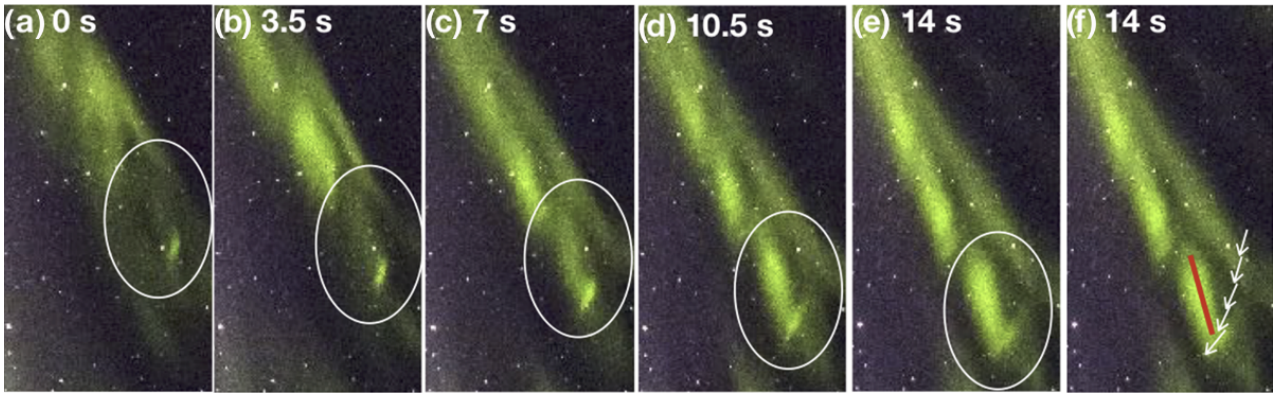


FIGURE 6. Photochemical model (Credit: Semeter et al)

$$O(^3P) + e(E) \rightarrow O(^1S) + e(E - 4.19\,\mathrm{eV})$$

$$O(^1S) \rightarrow O(^3P) + h\nu_{557.7}$$

of STEVE. It was noted that the recording of the STEVE observation showed a small amount of motion blur, which was consistent with a moving camera. Methods to correct this were then applied.

One of the most interesting results that came out of this observation was the observation that a particularly bright feature in the observed STEVE moved transverse to the rest of the phenomenon. In fact, this observation was precisely what led to Nishimura's paper. This is shown the circled part of Figure 5. It shows the development of a magnetic field transverse to the STEVE phenomenon.

THE PHYSICS BEHIND STEVE

The latter third of the paper then moves onto the discussion of the physics of STEVE. Though initial theories suggested that STEVE was produced by the penetration of magnetospheric electrons with kinetic energy greater than 1 keV (consistent with commonly-accepted aurora theories), spectroscopic measurements and morphological considerations have argued against this hypothesis. Instead, it is now

believed that STEVE and other auroral features are likely produced by direct excitation of oxygen atoms in the ionosphere by superthermal electrons, which are energized locally. The 557.7-nm spectroscopic line has emerged as the dominant factor in STEVE. A photochemical model has also been proposed as the suggested mechanism behind STEVE, but this has yet to be confirmed. It is merely proposed as a tool to help investigate observations. This is shown in Figure 6.

Magnetic Field Lines

The other interesting physics examined in the paper is the evolution of different magnetic field features in STEVE. Figure 7 shows the field lines, presented as negatives, in the same particularly good observation. It it speculated that collisions between electrons and charged particles lead to the development of these inner magnetic fields.

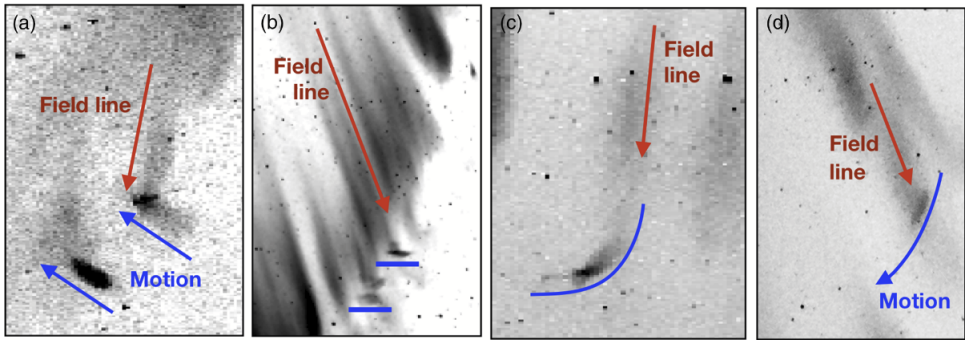
Turbulent Heating

The fundamental question at the heart of STEVE physics is whether the phenomenon known as turbulent heating produces these picket fence structures. Combined with the natural drift of charged particles across the sky, turbulence in the 'atmosphere' of the STEVE system may lead to the picket fence. However, this is also a topic of debate and the reasons behind STEVE are not fully understood. This mechanism may be possible due to the large electric fields and currents present at STEVE extremes. A callback to experiment, where barium ions were excited with sunlight in a lab under controlled conditions, is done. However, all of the methods proposed are simply suggestions and no concrete plan of attack has been formed.

CONCLUSION OF THE PAPER

The paper, which focused on the picket fence structure, concludes by saying that none of the current theories can accurately explain STEVE. It then recapitulates the above discussions and concludes that oxygen is likely the primary agent responsible for these excitations.

FIGURE 7. Magnetic Field Lines (Credit: Semeter et al)



The paper then praises the efforts of citizen scientists in understanding STEVE. It says that specific gaps in our current understanding can be filled by collaborating with STEVE. Also, it can also be that the picket fence is formed due to many solar and atmospheric phenomena coming together, so even the results proposed in the paper may not be accurate. It concludes by saying that 'more research is required'

MY THOUGHTS ON THE PAPER

I personally believe that this paper presents a decent introduction to STEVE; but it starkly contrasts the seemingly easy methods to analyze STEVE dimensions and velocity with the physics behind it. It is a very interesting research topic and it has great potential. It feels like there is a mountain of information available if one could figure out the one key thing missing. There seems to be a lot of low-hanging fruit in the field.

STRENGTHS OF THE PAPER

- Gave an introduction to STEVE
- Described how STEVE differed from aurorae
- Explained the essential challenges of STEVE observations, namely, the challenges associated with getting data from uncontrolled observations

WEAKNESSES OF THE PAPER

- Did not fully explain the metholodogy used with triangulation. It felt more like 'we did this work' rather than 'this is how we did this work'
- Gave only a very rief overview of the physics that may cause STEVE.
- Did not seem to get the strangeness of this phenomenon across.

CONCLUSION

- The research question: namely, 'what are the picket fence structures in STEVE?' was presented but in my opinion was not particularly well-analyzed. The paper went from image analysis to an overview of the physics without providing a definitive answer.
- The methodology used: namely, triangulation and image processing, was well-presented. I would have preferred if a bit more mathematics was used but maybe the audience of this paper was intended to be leading physicists in the field.
- The results: namely, the rise of the magnetic fields inside STEVE as well as the height and dimensions of these phenomena, were well-addressed and graphed. I felt this was the strongest point of the paper and conveyed the information of the strange behavior of STEVE.
- The overall contribution to the field is amazing. This paper is a decent introduction to STEVE; though it lacks depth, that was not its purpose. This topic is very interesting and as someone who will work on it next semester, I feel that reading this paper is a must for anyone interested in this phenomenon.