Astronomical Events and Their Impact on Knowledge Transfer in Optics and Photonics

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ABSTRACT

We present our twenty years of experience in the live broadcasting of astronomical events, with the main focus on total lunar eclipses. Our efforts were motivated by the great impact and high number of viewers of these events. Visitors from over a hundred countries watched our live broadcasts. Our viewer record was set on July 27, 2018, with the live transmission of the total lunar eclipse from the Feldberg, the highest mountain in the Black Forest, attracting nearly half a million viewers in five hours.

An especially challenging activity was the live observing of the Mercury transit on 9 May 2016, which we presented as 'live astronomy' with hands-on telescope. The main goal of this event was to awake our students enthusiasm for optics and astronomy.

Furthermore, we report on our experiences with the photography of optical phenomena such as polar lights and green flash.

Figure 1: Total Moon eclipse 2018 over the Black Forest / Feldberg, Germany. Photography by Dan Curticapean

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1. FUNDAMENTALS OF THE TOTAL LUNAR ECLIPSES

MOON PARAMETERS [1]- [9]

Mass	**7,34 10^{22} kg** **(1/81 Earth)**
Radius	**1738 km**
Volume	**2197 km^3** **(1/50 Earth)**
Surface area	**3,793 10^7 km^2** **(1/13,5 Earth)**
Distance to Earth	
Apogee	**406740 km**
Perigee	**356410 km**
mean	**384403 km**
Distance to Sun	
max	**152 10^6 km**
min	**147 10^6 km**
Age	**4,6 Billion years**

Escape Velocity	**2,38 km/s** **(11,2 km/s Earth)**
Temperature at the Equator	
day	**127°C**
night	**-173 °C**
Orbital period	
siderial	**27 days 7 h 43 min**
synodical	**29 days 12 h 44 min**
Mean Velocity	**3700 km/h**
Inclination to Ecliptic	**5,145°**
Albedo	**0,12**

Figure 2: Moon over Offenburg / Germany at 26.July 2018 – one day before the Total Lunar Eclipse.
© Photography by Dan Curticapean

2. THEORETICAL CONSIDERATIONS

Total lunar eclipses (Figure 1) are very impressive natural events and have already found their way into ancient mythologies as they are quite rare. The moon appears unnaturally red and a lunar eclipse is relatively long.

Total lunar eclipses always occur when the Sun, Earth and Moon (in this order) are aligned in a straight line. Lunar eclipses always occur at full moon since the moon must cross the node position exactly at full moon [1] - [2].

Geometry of the moon umbra

The umbra geometry of Sun, Earth and Moon is the key to understanding lunar eclipses. Considering the positions of Sun and Earth, the umbra is a cone with a length of 1.4 million km and a radius of ca. 4500 km at the moon orbit. This geometry provides a particular characteristic for lunar eclipses, which is called the magnitude (or totality). It is defined as the ratio between the immersion depth in the umbra and the moon radius. Therefore, lunar eclipses can have more than 100% magnitude. The maximal totality is at about 188 % (see literature) [3]. A lunar eclipse can last up to three hours, of which it can be in totality for approximately 1 hour 40 minutes [3]. The geometry of the moon penumbra is a divergent cone, expanding into space.

Considering the particular of umbra and penumbra, we can distinguish three types of lunar eclipses [1] - [7]:

Total lunar eclipse: The moon occurs during the darkness completely into the umbra of the earth.

Partial lunar eclipse: Only a part of the moon is covered by Earth's umbra, the remaining part is still in the penumbra.

Partial penumbral eclipse: The moon appeared only partially into the penumbra.

Total lunar penumbra eclipses are almost impossible. In this setting, the moon should appear only in the penumbra of the earth and not in the umbra. Such total penumbral eclipses are extremely rare because the ring of the penumbra is approximately as wide as the diameter of the moon.

Moments or Phases during a total lunar eclipse (Figure 3) [4], [7]

Contact 1 - Penumbral lunar eclipse begins

Contact 2 - Partial umbral lunar eclipse begins

Contact 3 - Total umbral lunar eclipse begins

Contact 4 - Maximal umbral lunar eclipse magnitude

Contact 5 - Total umbral lunar eclipse ends

Contact 6 - Partial umbral lunar eclipse ends

Contact 7 - Penumbral lunar eclipse ends

As mentioned before, the moon appears red or orange-red during the totality phase. This effect, which is an impressive spectacle of nature, is caused by Earth's atmosphere. Two phenomena are responsible for this effect: On one hand, Earth's atmosphere acts like a lens, and on the other hand, the molecules in Earth's atmosphere scatter short wavelength light (green, blue) more than light of long wavelength (red).

To evaluate the brightness of lunar eclipses, a measurement scale was introduced by the French astronomer Danjon. This scale comprises five different values.

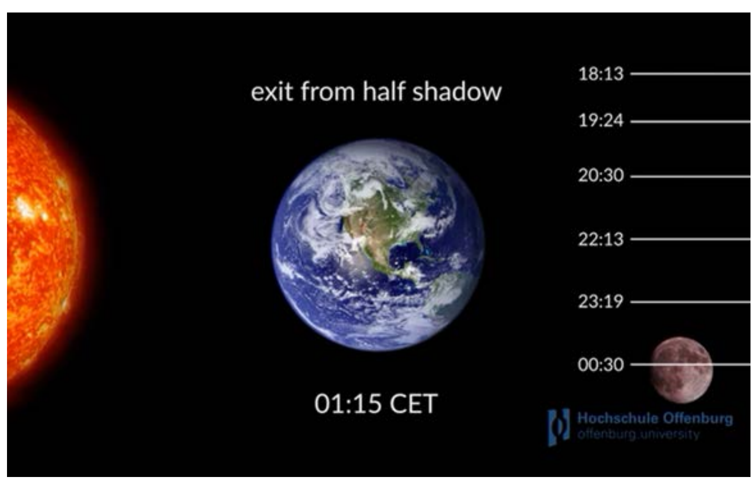

Figure 3: Moments of the lunar eclipse 27.July 2018. Feldberg /Germany

Danjon Scale (see definitions [4], [5])

L = 0 - ”Very dark eclipse (Moon is almost invisible, especially at mid-totality)” [4], [5]

L = 1 - ”Dark eclipse, gray or brownish in coloration (Details are distinguishable only with difficulty)” [4], [5]

L = 2 - ”Deep red or rust-colored eclipse (Very dark central shadow, while outer umbra is relatively bright)” [4], [5]

L = 3 - ”Brick-red eclipse (Umbral shadow usually has a bright or yellow rim)” [4], [5]

L = 4 - ”Very bright copper-red or orange eclipse (Umbral shadow has a bluish, very bright rim)” [4], [5]

The Danjon Scale can also be considered as a measure of the purity of the Earth's atmosphere. For instance, lunar eclipses in years with numerous or heavy volcanic eruptions are very dark and black, yielding lunar eclipses with L values of 0 or 1.

There are more solar eclipses than lunar eclipses. However, solar eclipses are confined to their comparatively small visibility regions, whereas every lunar eclipse can be witnessed from one half of Earth’s surface. Thus, lunar eclipses subjectively appear to be more frequent. [8] - [9]

3. BROADCAST OF TOTAL LUNAR ECLIPSES

Scientific and Technical Implementation

After twenty years, in which we collected further experience in broadcasting lunar eclipses, it became clear to us that our project required a continuous new concept and a modern broadcasting format to be successful.

Together with some students who wanted to work on the topic of live broadcasting, we have therefore analyzed the concepts of the last live broadcasts of the lunar eclipses of 21 December 2010, 15 June 2011 and 27 September 2015.

The following aspects were considered when planning the new transmission: advertising, scientific background, and a modern easy broadcasting concept on any accessible platform. A platform that can cover the bandwidth when a large number of Internet viewers access the stream.

Figure 4: Telescope on computerized mount with camera

The decision was then relatively simple, we will split the stream and simultaneously broadcast it on the Facebook page of the university and on our own Youtube channel on the subject of lunar eclipses.

Goals of the Event

The goals we had set for the project – transmitting the longest lunar eclipse of this century – were ambitious, yet realistic. Concerning the technical side, we wanted to improve the stream to 4K resolution. From an editorial perspective, we wanted to keep a live broadcast that blends an informational purpose with minimal entertaining elements.

This time we did not want to present a lot of information about lunar eclipses, such as their origin, duration and the different types. This background information is intended to reach viewers through other channels. Nevertheless, we wanted to awaken the audience's interest in astronomy. In addition, a major objective was to increase the reach of viewers from all over the world. On top of it all, we faced the challenge of broadcasting the longest total lunar eclipse of the twenty-first century.

Figure 5: Announcement of the livestream on different internet platforms

Broadcast of Evnents

This time we decided to stream without a studio, due to the fact that the location was offering a fantastic scenery. So we only took two outside cameras and drove onto the Feldberg, the highest mountain in the Black Forest. For internet access we used the mobile LTE (Long Term Evolution, aka 4G) option, which which the bandwidth should be sufficient to transfer in 4K. To ensure that the bandwidth was sufficient, we carried out a test transmission two days before the lunar eclipse.

The moon was recorded with a Blackmagic URSA Broadcast that had a MEADE LXD75 [10] Schmitt-Cassegrain telescope (8´´, F=2000 mm, f/10) attached as a lens (Fig. 6).

We used the second camera to record the surroundings, and a microphone to record the ambient noise. The two video signals from the cameras and the ambient noises were mixed in a digital video mixer.

Via a livestream server, the video signal was converted into an internet-ready stream, which was then forwarded to our YouTube Channel and thus accessible worldwide. At the same time, we directed the stream onto the Facebook page of our university, though with substantially less success in terms of viewership.

Figure 6: Penumbral Lunar Eclipse ends, Contact 7 Screenshoot from the Livestream

This total lunar eclipse with 163 % totality and lasting 103 minutes was the longest total lunar eclipse of the twenty-first century.

The recorded broadcast can be viewed on YouTube, using the search phrase "Lunar Eclipse Live 2018 Offenburg University." Following the live broadcast, we were highly encouraged to note that it had already been viewed by nearly half a million people. To be sure, a favorable aspect contributing to this success was the time of the eclipse, on Friday evening between 9 pm and 12 midnight, one of the best broadcasting times of the week.

4. PARTIAL SOLAR ECLIPSE

We also used the partial solar eclipse of 20 March 2015 to attract students' interest in astronomy and optics. Together with the Center for Physics at Offenburg University we organized an on-campus viewing of the eclipse.

We interrupted the lectures for one hour and followed the event live on campus together with the students. We set up telescopes, distributed special glasses with sun filters and observed the partial solar eclipse with a self-made Camera Obscura. We were also supported with telescopes provided by alumni of the university, turning the event into an intergenerational meeting on the side.

The event was reported in the local press and attended by more than 300 students on campus. With the help of the Ortenau District's astronomy association, many children from schools in the region were also able to attend.

Figure 7: Partial Solar Eclipse over Offenburg / Germany

Badische Zeitung vom 21. März 2015

Public Viewing mit der Schweißermaske

300 Studierende verfolgen Sonnenfinsternis an der Hochschule Offenburg / Volksfest-Atmosphäre beim Astronomischen Verein Ortenau auf dem Kulturforum

SOFI-BRILLEN AUSVERKAUFT

KREATIVE STUDENTEN

ANDRANG BEIM AVO

It should be noted that the observation of the Sun and the Mercury transit should never be carried out with the naked eye! Special solar filters must be used for the eye and for the telescope!

Figure 8: Detail from the regional newspaper reporting about the partial solar eclipse

We recommend to use a Camera Obscura to observe the Sun and solar eclipses. This way the Sun is not directly looked at and the eyes are protected. A white sheet of paper was used as the back wall and the aperture, a pin hole as "optics" in a large cardboard box as shown in Figure 9.

Fig. 9: Oversized, self-made Camera Obscura for observing the partial solar eclipse

5. LIVE OBSERVATIONS OF THE MERCURY TRANSIT ON THE UNIVERSITY CAMPUS

The transit of Mercury in relation to the Earth (Fig. 10) can be seen every time the Earth, Mercury and the Sun are aligned in a line, similar to a solar eclipse. Mercury only covers a maximum of 0.004 percent of the Sun's surface and appears as a small black dot invisible to the naked eye.

The transit takes a few hours. 13 or 14 Mercury transits usually occur per century. The next Mercury transit to be observed from Earth will be on November 11, 2019 [11].

On 4 June 2014, a planet transit was also observed from outside Earth for the first time: the Mars rover "Curiosity" shot photographs of the Mercury transit [12].

On the Offenburg University campus we used the opportunity to watch the transit live with our telescope. During the Mercury Transit we also held a lecture for interested students on this topic. Parts of the transit were recorded and then posted on the Facebook page of the university.

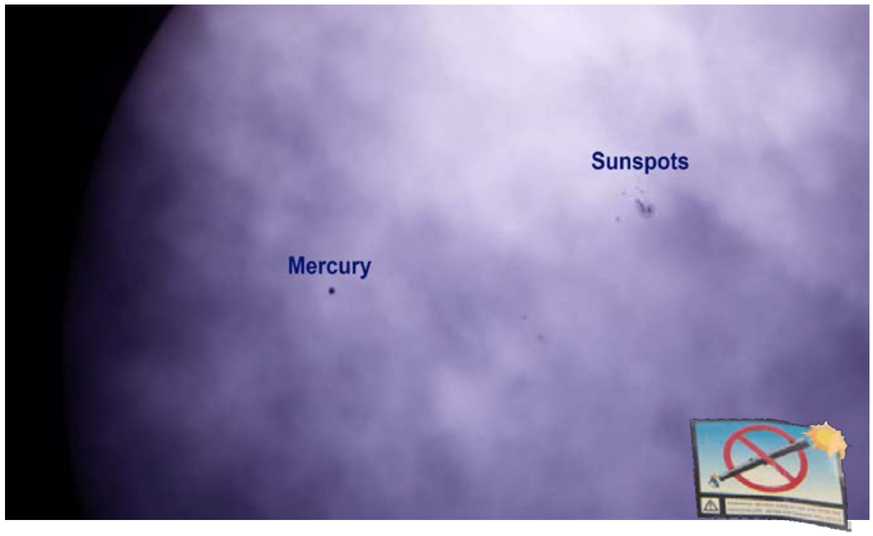

Figure 10: Mercurytransit on 09.Mai 2016, Location Campus Offenburg University.

6. GREEN FLASH

In this chapter we describe how to observe and photograph green flashes (Fig. 11). Green flashes can possibly be seen at sunset and especially at the seaside, given favorable weather conditions. However, certain light conditions and high contrasts can make it difficult to impossible for green flashes to be observed. The eye cannot adapt fast enough to the dynamics of the light conditions. The author recommends using a smartphone and watching the sunset indirectly with the camera display (standing with the back towards the Sun). This way the sunset will be observed indirectly and when the sun disappears on the horizon, one can turn around quickly and observe the sky over the sunset, thus significantly increasing one's chance to observe the green ray.

Photographing a green flash is a bit easier if you use time lapse. However, it should be noted that the light conditions change rapidly at sunset. If the contrast is too high, the green flash is not visible. Therefore, the image should be underexposed with two stops.

Figure 11: Green Flash
Photo by Brocken Inaglory - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=2098468

7. AURORA BOREALIS

Another highly impressive astronomical event are the polar lights [13]. If in earlier times people believed that the northern lights were phenomena of the gods, they have been very intensively occupied with their scientific observation and description over the last 200 years. First scientists believed that the northern lights were reflections of sunlight on ice crystals in the clouds. One of the first to link the northern lights to the Earth's magnetic field was the astronomer and mathematician Edmund Halley, but he could not explain the glow of the northern lights. The glow of the aurora could only be explained years later by the Swedish physicist Anders Jonas Ångström. The first photographs of polar lights were taken on 1 February 1892 by Martin Brendel and Otto Baschin [14].

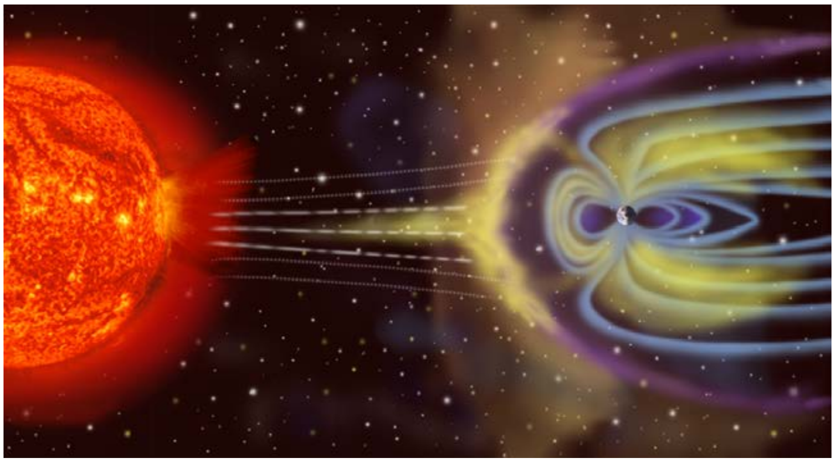

Fig. 12: Schematic representation of the Earth's magnetosphere in interaction with solar wind. © NASA - http://sec.gsfc.nasa.gov/popscise.jpg

Today we know that the polar lights are caused by the solar wind which hits the Earth's magnetic field. The solar wind is electrically charged plasma with an average speed of 500 to 800 km/s and a density of about $5 \cdot 10^6$ particles per cubic meter. The solar wind consists of charged particles mainly of electrons and protons and these encounters the Earth's magnetic field. Most of them are deflected from the magnetic field, but some particles in the areas of the magnetic poles succeed in ionizing oxygen and nitrogen atoms in the higher layers of the atmosphere. The recombination produces the light effects of the auroras. Figure 12 schematically shows the aurora' s appearance. In the northern hemisphere, the aurora is scientifically known as Aurora Borealis and in the southern hemisphere it is called Aurora Australis [15].

To observe Aurora Borealis, it is necessary to go north as far as possible. A prediction is reasonably possible [16], but it is based on regular observations of solar activity and the formation of sunspots. Furthermore, the solar cycles that last eleven years play an essential role. A representation of the solar activity and the last cycles is shown in Figure 13.

The color of the Aurora Borealis [17] is produced by the type of atoms excited in the Earth's atmosphere (magnetosphere). In general, the color of Aurora Borealis is green and is caused by the stimulation of oxygen atoms at an altitude of 90 km - 100 km. Red aurora are produced by the oxygen atoms at an altitude of over 300 km. The excitation of the nitrogen atoms produces the purple and violet Aurora Borealis. Red and purple Aurora Borealis are much rarer.

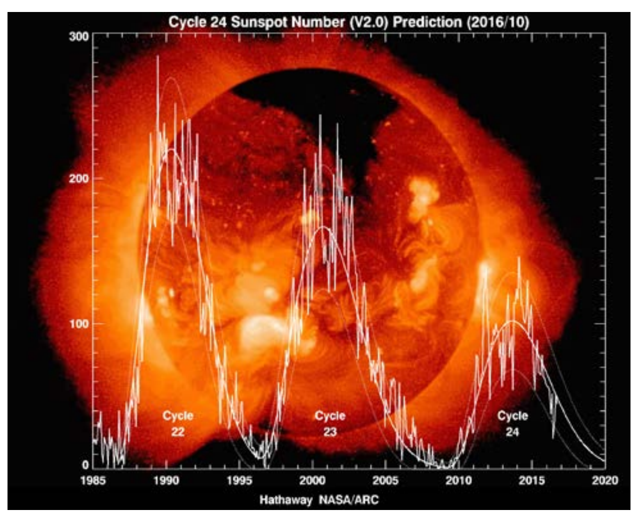

Fig. 13: Cycle 24 Sunspot Number (V2.0) Prediction (2016/10) © By David Hathaway, NASA, Marshall Space Flight Center - http://solarscience.msfc.nasa.gov/predict.shtml

To be able to observe the Aurora Borealis, the weather has to play along and in the winter months it is very favored by the polar night to observe the Aurora Borealis successfully.

Considering all this and after attending John Shaw's talk about how to observe and photograph Aurora Borealis through the window of an airplane [18], the author was motivated to do the same. Flying back from San Francisco to Frankfurt after attending Photonics West in 2016 and in 2019, given that it was February and the flight was over the North Atlantic, the author also had the opportunity to photograph polar lights. The results are shown in Figures 14 and 15.

It is to mention that the Aurora Borealis was not directly visible with the naked eye, but only indirectly with a digital camera through an exposure time of 0.5 s.

The exposure parameters were: Fig. 14: t = 0,8 Sek; f/2,8; ISO 6400, f = 67 mm
Fig. 15: t = 5,0 Sek; f/2,8; ISO 1600, f = 24 mm

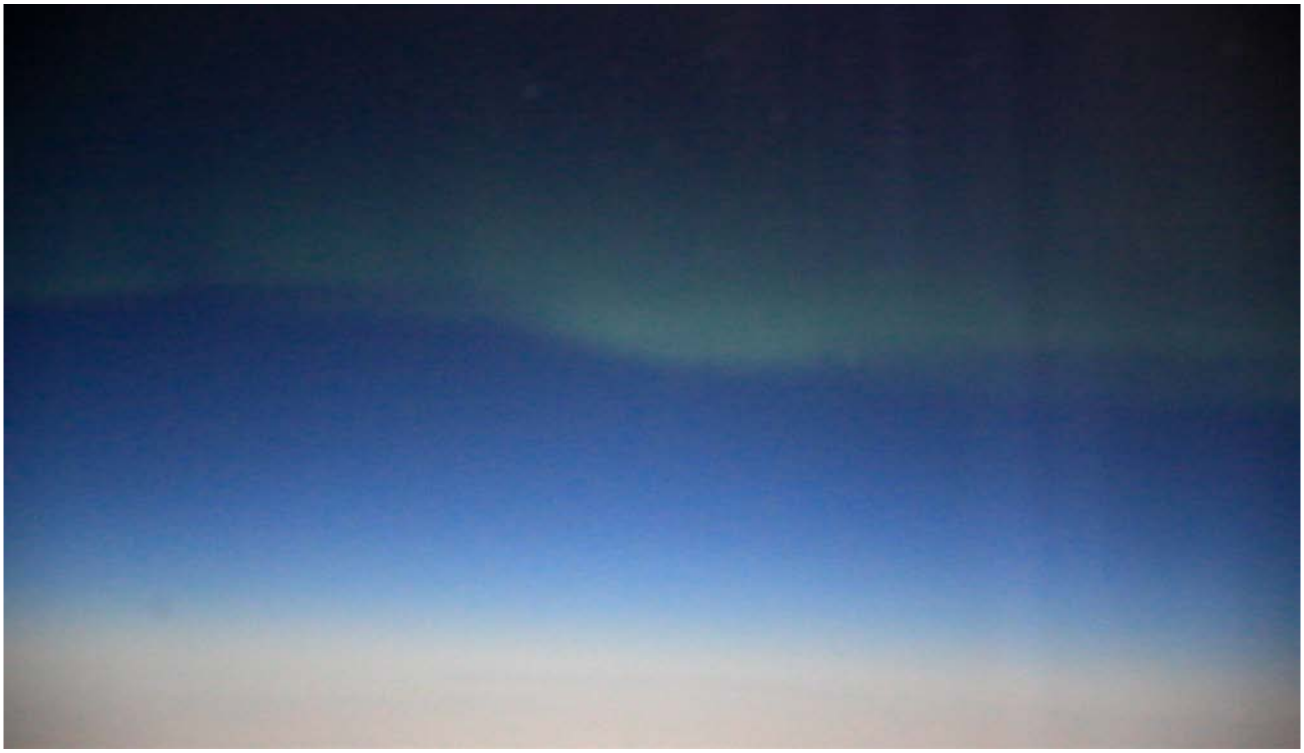

Figure 14: Aurora Borealis at 24.Februar 2016, 5:59 MEZ, Location between Grönland and Island

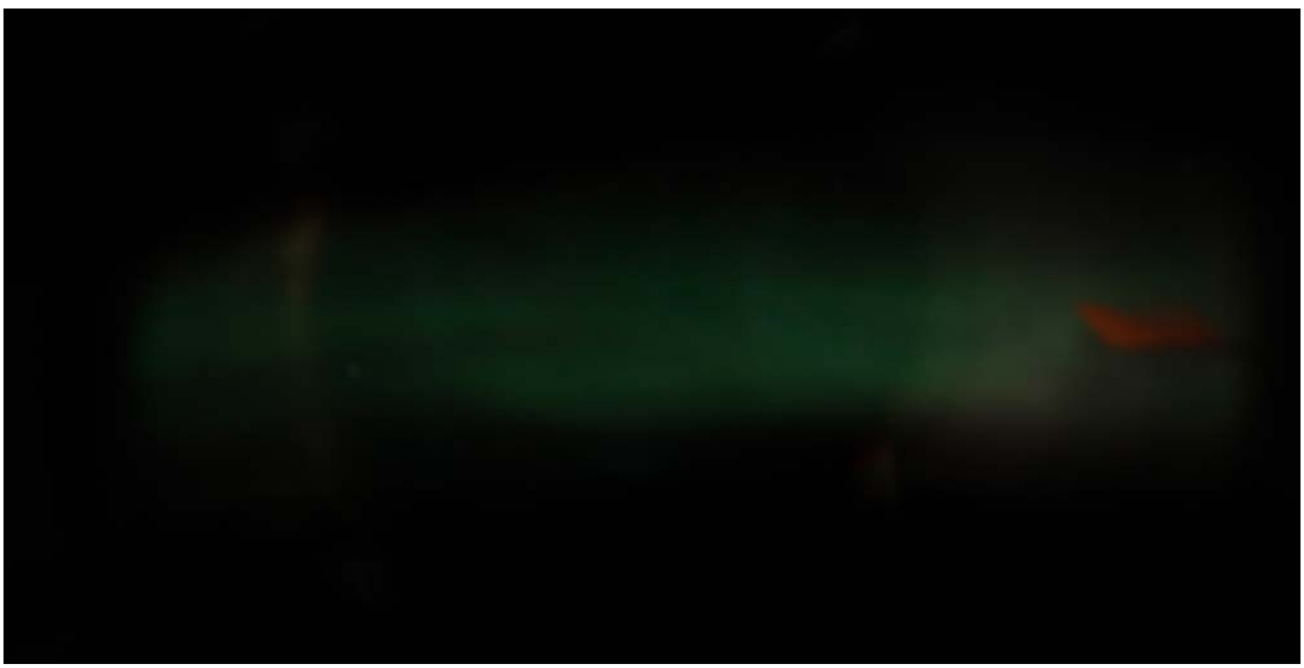

Figure 15: Aurora Borealis 08.Februar 2019; 6:58 MEZ; Location: Labrador Sea

8. RESULTS AND EVALUATION

We produced a live broadcast and streamed the Total Lunar Eclipse in HD and 4K. For our technical possibilities, this was a premiere. The over half-million viewers far exceeded our expectations.

With our activities in the presented projects we were able to awaken students' interest in astronomy, physics, optics and photonics.

A digital Moonbook [19] was developed by our students and is available for download on your iPad with iBooks or on your computer with iTunes.

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