Bioluminescence in the KM3NeT neutrino telescope

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Abstract

The KM3NeT-neutrino telescope is a large detector under construction in the Mediterranean Sea. Its main objectives are the observation of cosmic high-energy neutrinos and the determination of the neutrino mass hierarchy. However, the deep sea is an extraordinary location and environment and entails uncontrolled phenomena like bioluminescence. Bioluminescence is the emission of light by organisms. This light is detected by the KM3NeT-detector when bioluminescent organisms collide with the structure of KM3NeT. It is interesting to study the signal of the bioluminescence, because it tells a lot about life in deep-sea and it can be a nuisance in the quest to observe and research neutrinos. Characteristics of bioluminescence like the amount of detected bioluminescence over a long period of time, the location of the increased bioluminescence in the detector, the number of bioluminescent bursts that happen at the same time, the duration of these bursts and the periodicity of the detected bioluminescence are investigated. Finally in the analysis of the data it has been found that some parts of the detector are showing unexpected behaviour, examples of this behaviour are shown.

Contents

Chapter 1

Introduction

In physics most experiments are conducted in a controlled environment like a laboratory. An exception is being made with the KM3NeT-telescope, which is situated deep in the Mediterranean Sea. This extraordinary location and environment entail uncontrolled circumstances and phenomena, that on its own are interesting and worth studying as well. One of these phenomena is bioluminescence.

Many sea animals rely on vision in order to gather their food supply or scare of predators. In deep-sea solar light is lacking and organisms rely on self-produced light sources, these organisms are said to be bioluminescent[1]. Often when sea animals collide with a structure or when they detect a predator, luminescence is catalyzed by enzymes and light is emitted by the organism.[2] Because the KM3NeT is a large structure in the deep-sea, bioluminescent organisms frequently collide with it and the light that is emitted is observed by the detectors in the telescope. This signal is important to understand and characterize, because it tells a lot about life in deep-sea and it can be a nuisance in the quest to observe and research neutrinos.

In its present state the KM3NeT detector has three 600 m long lines with each 18 different measuring points, of which two lines are working properly. The data that is taken from these measuring points for a period of approximately two months is in this study used to characterize the bioluminescence in the deep-sea. The second chapter contains background information about the KM3NeT detector as well as information about the background radiation that is present in the deep-sea. The results of analyzing this data are presented and discussed in the third chapter and in the fourth and final chapter one can find a conclusion of this study.

Chapter 2

Background information

The main objectives of the KM3NeT neutrino telescope are the discovery and subsequent observation of high-energy neutrino sources in the universe and the determination of the neutrino mass hierarchy[3]. In order to achieve this a large structure is being deployed in the Mediterranean Sea. This structure detects the Cherenkov light that is emitted by charged particles emerging from the interaction of neutrinos with water molecules[4]. Besides the detection of the Cherenkov light the KM3NeT also detects background radiation. The two main sources of this background radiation are ^{40}K-decay and bioluminescence in the deep-sea. In order to accomplish the two aforementioned main objectives as good as possible it is important to be able to filter out the background noise and therefore understand and characterize the bioluminescence in KM3NeT.

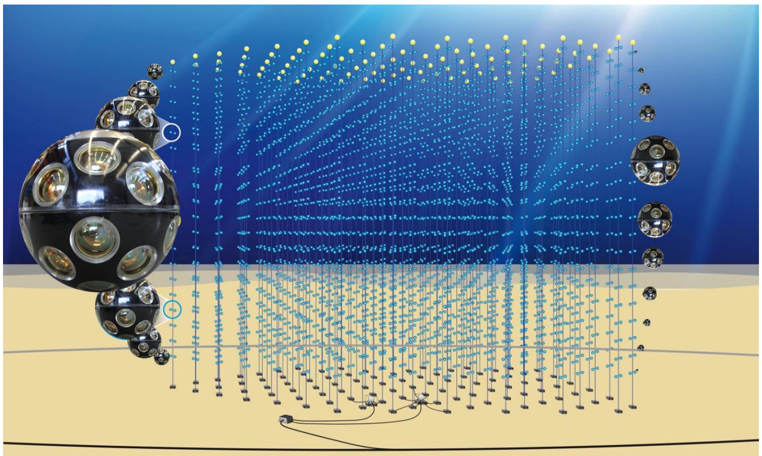


Figure 2.1: *An artists impression of the KM3NeT telescope*

2.1 The KM3NeT detector

The KM3NeT-detector will be constructed on different locations in the Mediterranean Sea, namely KM3NeT-Fr off-shore Toulon (France) and KM3NeT-It off-shore Portopalo di Capo Passero (Italy)[5]. When finished the KM3NeT will cover several cubic kilometers in the deap-sea. At the moment three strings on the KM3NeT-It site are deployed, of which two strings are working properly. The data from these two strings is used in this report to study the bioluminescence. Data is gathered by spheres with photo-multiplier tubes (PMTs) in them that detect light, the spheres are attached to a string and the gathered data is send to shore.

2.1.1 Detector infrastructure

The basic detection unit of the KM3NeT telescope is called a Digital Optical Module (DOM). Each DOM (see figure 2.2) has a diameter of 43 cm and houses 31 photomultiplier tubes (PMTs) of 7.6 cm diameter, that can detect light. The basic working principle of a PMT is that a photon hits a cathode, as a result of this the cathode ejects an electron from its surface into the tube. This electron is directed towards a dynode with a positive potential, which in collision with the electron emits multiple low energy electrons. This process is done repeatedly and at the end of the cascade a pulse of these electrons is measured, in this way a photon can be detected. The PMTs are arranged in five rings of six PMTs plus a single PMT at the bottom pointing vertically downwards, see figure 3.5.

Figure 2.2: *A Digital Optical Module (DOM) housing 31 photomultiplier tubes (PMTs)*

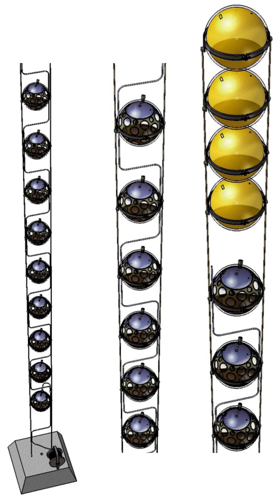


Figure 2.3: *A Detection Unit (DU)[6]*

Eighteen of these DOMs make up one Detection Unit (DU), see figure 2.3. The DOMs are attached to a vertically suspended string, the distance between the DOMs is approximately 36 m. Each DU is anchored to the seabed and the bottom DOM is attached 80 m from the sea floor. A subaqueous buoy is attached on the top of the DU to reduce the horizontal displacement of the top relative to the base for the case of large sea currents[7]. In KM3NeT-It the detection units have on average 95 meter between them horizontally. The DOMs are also equipped with compasses that measure the displacement of the detection unit and thus measure the strength of the sea current.

When finished the KM3NeT telescope will consist of building blocks, one on each location. One building block contains 115 detection units and thus 2070 DOMs.

2.1.2 Data acquisition

The data used in this study is taken in 6 hour interrupted measurements, so called runs. The runs used in this study are run 5009 (taken on 23/12/2016) till run 5350 (taken on 24/02/2017). The all-data-to-shore approach that is being used, means that all the data that is taken by the detector is send to shore via a computer network. On-shore the data is read-out, aggregated and filtered by the KM3NeT Trigger and Data Acquisition System [8]. The maximum hit rate that can be measured by the PMTs is 20 kHz.

2.2 Background radiation in the deep-sea

2.2.1 ^{40}K-decay

The main contribution to the detected signal is the hit rate from the ^{40}K-decay.
In the sea water the radioactive isotope ^{40}K decays into ^{40}Ca. During this process electrons are emitted with very high energy, these electrons can subsequently emit Cherenkov radiation that is detected by the PMTs in KM3NeT. The hit rate of the light caused by ^{40}K-decay is constant over time and homogeneous and can be used for calibration of the DOMs.

This background signal does not compromise the desired signal detection, because the signal from neutrinos is correlated between different detectors and the signal from the ^{40}K-decay is not.

2.2.2 Bioluminescence

In contrast to ^{40}K-decay the hit rate from photons of a bioluminescent source on a PMT is not constant. Bioluminescent organisms emit light in bursts, during these bursts the hit rate detected by the PMTs is very high. The contribution of the bioluminescence to the signal is called the burst fraction.

Definition burst fraction

A PMT in the KM3NeT telescope detects a lot of photons, the rate at which these photons are detected is called the hit rate. A histogram like figure 2.4 is made for every run of six hours by determining the hit rate of the photons on the PMT over every 100 milliseconds and presenting this as a function of time.

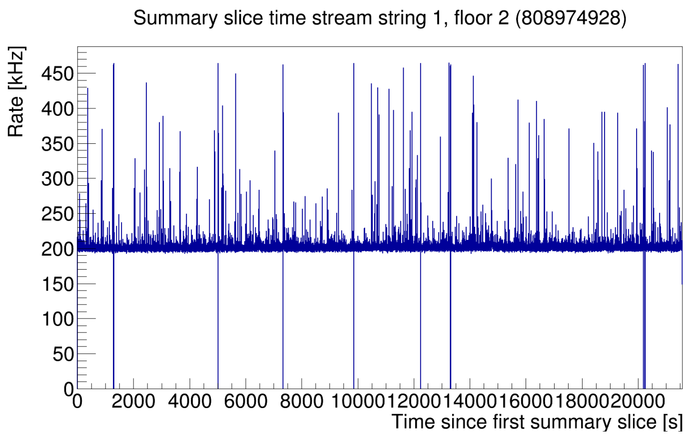


Figure 2.4: *Example of the hit rate of one run (6 hours) of one PMT as a function of time*

In order to determine the burst fraction, the histogram of the rate as function of time is transformed into a histogram with the distribution of the rates, like figure 2.5, for every PMT. In this histogram two main contributions can be distinguished; the K40-decay in the sea water and the bioluminescence.

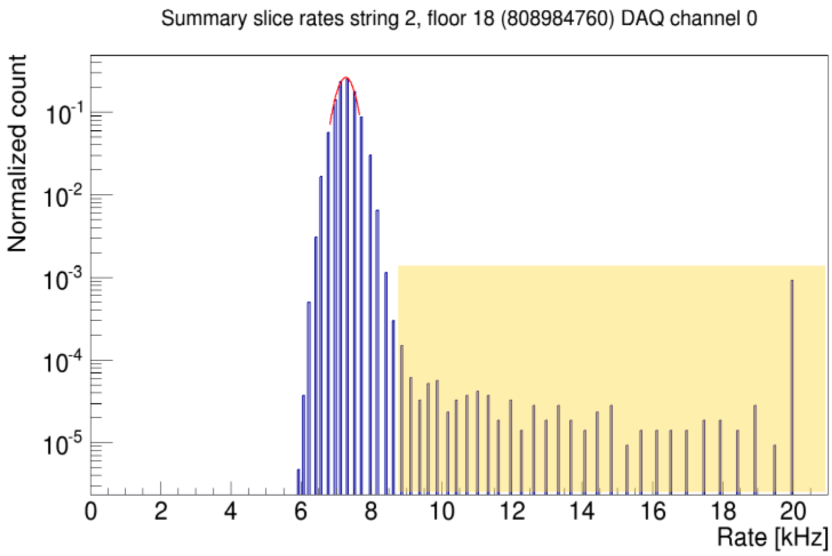


Figure 2.5: *Example of a rate distribution of one PMT. The marked yellow part is the burst fraction.*

First, the peak on the left is the contribution of the ^{40}K-decay in the sea water. The ^{40}K-decay has a constant hit rate and the distribution can be fitted with a Gaussian function. From this fit the mean hit rate (the maximum of the Gaussian fit) for a PMT can be determined[9].

Secondly, the contribution of the bioluminescence, called the burst fraction, can be distinguished. The bioluminescence is not constant and appears in bursts with high hit rate. The burst fraction is defined as 120% above the mean hit rate, this is approximately four times the width of the fitted Gaussian for most PMTs. The burst fraction is determined by normalizing the histogram from figure 2.5 and integrating over the part that has higher rate than 120% of the mean hit rate.

Chapter 3

Characteristics of bioluminescence

In this chapter the results of analyzing the data are presented and discussed. Different characteristics like the burst fraction over time, the local burst fraction per PMT, simultaneous bursts on multiple PMTs, burst duration and the periodicity of bursts in KM3NeT are being investigated.

3.1 Bioluminescence peak

A few examples of peaks from a bioluminescent source are depicted in figure 3.1. A typical peak starts with a very steep slope and then fades out. The maximum value of the peak depends on the intensity of the burst; if more light is emitted by a bioluminescent source it means that the hit rate on the PMT is higher and so the peak has a greater maximum.

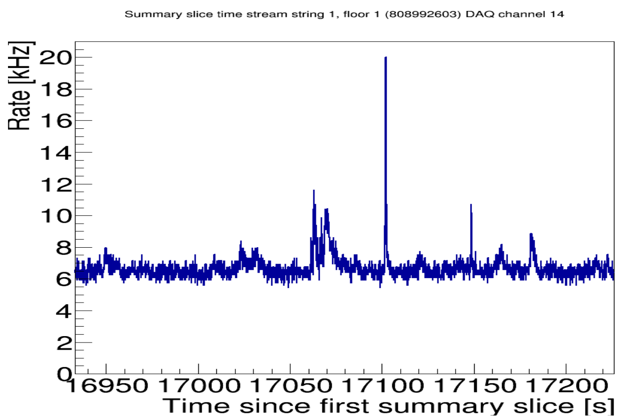


Figure 3.1: *Example of typical bioluminescence peak. On the y-axis is the hit rate of the photons on the PMT and on the x-axis time*

3.2 Burst fraction

3.2.1 Burst fraction per DOM

In order to see long term changes in the bioluminescence, the burst fraction is shown per DOM as a function of run number in figure 3.2. For some runs it is not possible to correctly determine the burst fraction, because these runs are for example used to calibrate the DOMs or certain parts of the detector are not working properly for a period of time, these runs are represented by blank spaces in the figures.
Some periods in figure 3.2 stand out due to higher burst fractions, the four most notable increases in burst fraction are discussed below. In section 3.2.2 the burst fraction is investigated per PMT for each of these periods.

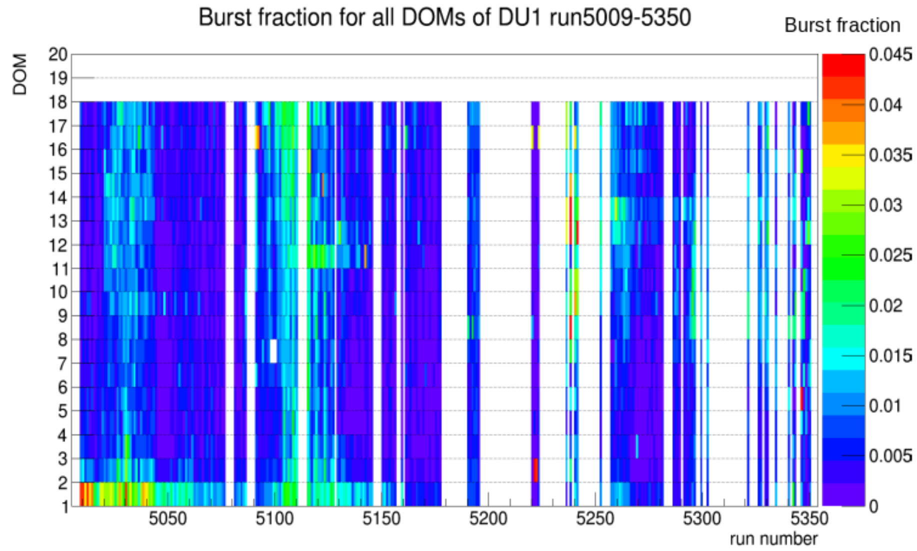
In DOM 1
First, in the beginning of the data the DOM closest to the sea floor (DOM 1) has higher burst fraction compared to the other DOMs. More details about this can be found in section 3.2.2 and figure 3.6.

Around run 5030
Secondly, the burst fraction around run 5030 (28/12/2016) is increased on all DOMs of both DUs (see figure 3.7 for the burst fraction per PMT). This probably means that around that time there was more sea current.

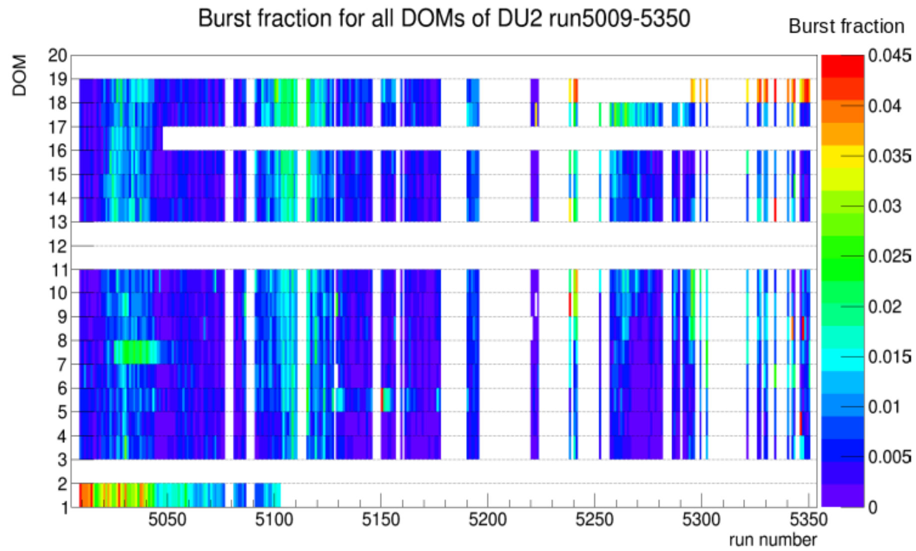
Around run 5115
Thirdly, around run 5115 (16/01/2017) the burst fraction is increased on both DUs on all DOMs (see figure 3.8 for the burst fraction per PMT). In contrast to the period around run 5030, compass data is available for this period, this is shown in figure3.3. Comparison of the compass data around this period and the increase in burst fraction shows that the increase in burst fraction is probably caused by a current stream. Figure 3.3 shows that around 16/01/2017 the compasses in the DOMs in both DUs show a change, which indicates that the sea current is changing direction and therefore more bioluminescent organisms collide with the structure and consequently more bioluminescence is detected. This corresponds with the increased burst fraction as seen in figure 3.2.

In DOM 7
Finally, there is a remarkable increase in burst fraction in DOM 7 of DU2

from around run 5024 till run 5045 (from 27/12/2016 till 01/01/2017). This could be caused by bioluminescent bacteria or a organism that is stuck to the DOM, but one can not be sure of the cause. In figure 3.8 the specific PMTs with increased burst fraction of this DOMs are displayed.

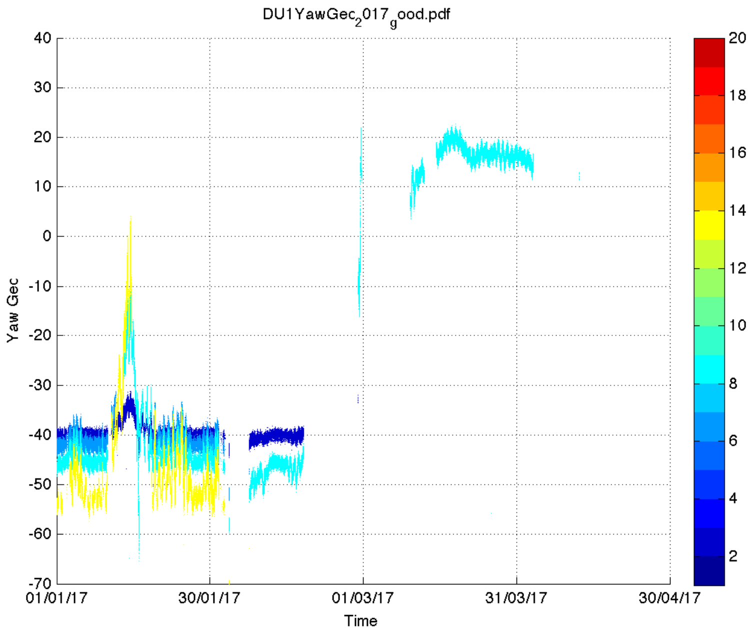


***(a)** DU 1*

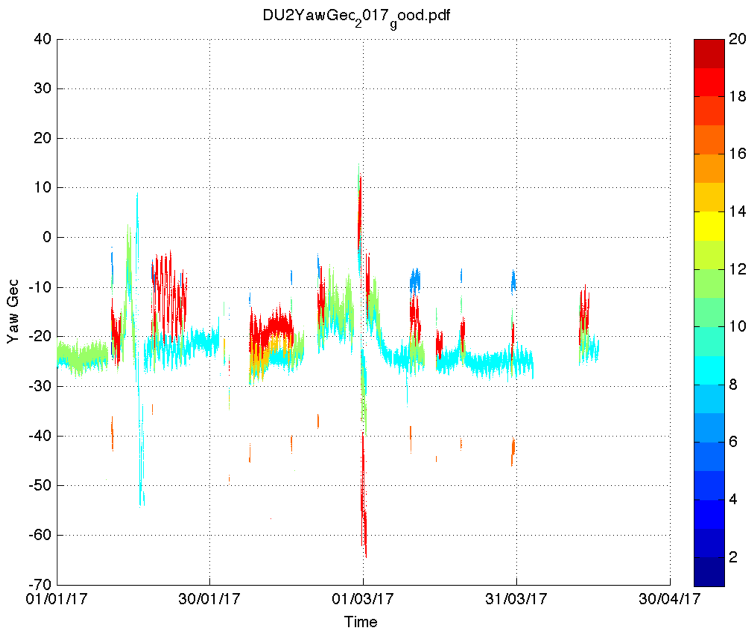


***(b)** DU 2*

***Figure 3.2:** Burst fraction per DOM as a function of run number for both DUs. The data starts at run 5009 (23/12/2016) and ends with run number 5350 (24/02/2017). The burst fraction is on the z-axis (color scale), for example a burst fraction of 0.02 means that in 2% of the bins the hit rate is higher than 120% of the mean hit rate*



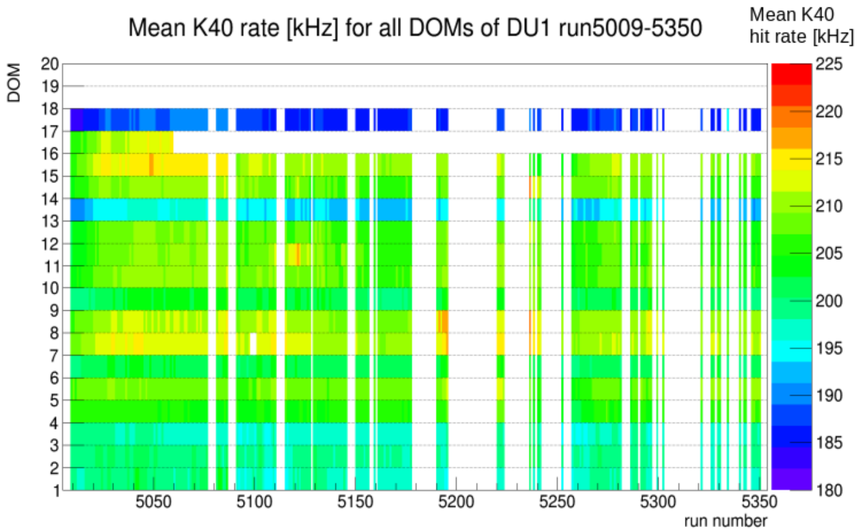
(a) *DU 1*



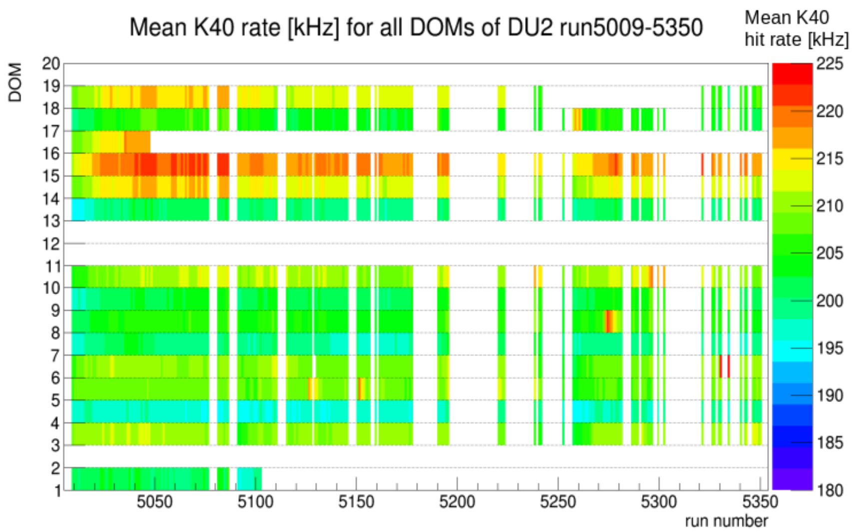
(b) *DU 2*

Figure 3.3: *Yaw of the DOMs as a function of time. On the y-axis is shown the yaw of the DUs, the yaw is most likely an effect of the sea current. Every DOM is shown in a different color. These figures are made by Giorgio Riccobene and were obtained by private communication*

To make sure the increased burst fraction in the aforementioned periods of time are not due to a change in mean hit rate or malfunctioning PMTs, the mean hit rate or in other words the mean ^{40}K-rate per DOM is shown as a function of run number in figure 3.4.



(a) *DU 1*



(b) *DU 2*

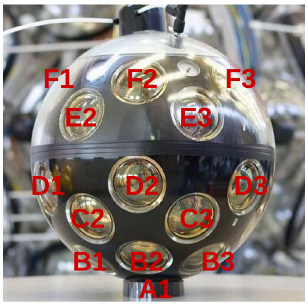
Figure 3.4: *Mean ^{40}K hit rate per DOM as a function of run number for both DUs. The data starts at run 5009 (23/12/2016) and ends with run number 5350 (24/02/2017). The ^{40}K hit rate is on the z-axis (color scale) in kHz*

The mean hit rate of the ^{40}K-decay in the sea water has variations of approximately ten percent, but does not show the same pattern as the burst fraction (see figure 3.2), which means that the burst fraction is independent of the ^{40}K-hit rate and the burst fraction is well-defined.

3.2.2 Burst fraction per PMT

In some periods of time the burst fraction is increased in all DOMs or in one particular DOM (see section 3.2.1), to better understand this increase in burst fraction and localize it on the DOM, the burst fraction is studied per PMT in this section.

Each figure contains one histogram that represents one DOM of the 36 DOMs that are currently deployed. Some DOMs are not working and are represented by blank histograms. Each square in a histogram represents one PMT. A DOM houses 31 PMTs in five rows and one on the bottom of the DOM facing the sea floor[7]. Figure 3.5 shows how the PMTs are ordered in the figures per histogram.



(a) *In a DOM*

F1	F2	F3	F4	F5	F6
E1	E2	E3	E4	E5	E6
D1	D2	D3	D4	D5	D6
C1	C2	C3	C4	C5	C6
B1	B2	B3	B4	B5	B6
		A1			

(b) *In the histograms*

Figure 3.5: *The positioning of the PMTs*

In DOM 1

From the start of the data (run 5009 taken on 23/12/2016) there is an increase in burst fraction in DOM 1, the DOM closest to the sea floor. Figure 3.2 illustrates a typical distribution of the burst fraction per PMT of one of these runs. The lower PMTs facing the sea floor on DOM 1 have a highly increased burst fraction whilst the upper PMTs of the same DOM do not show an increased burst fraction compared to PMTs on the other DOMs. Furthermore the lower PMTs of the second DOM also show an increased burst fraction. This pattern is consistent for an extended period of time and indicates that there is a bright bioluminescent source underneath the lowest DOM.

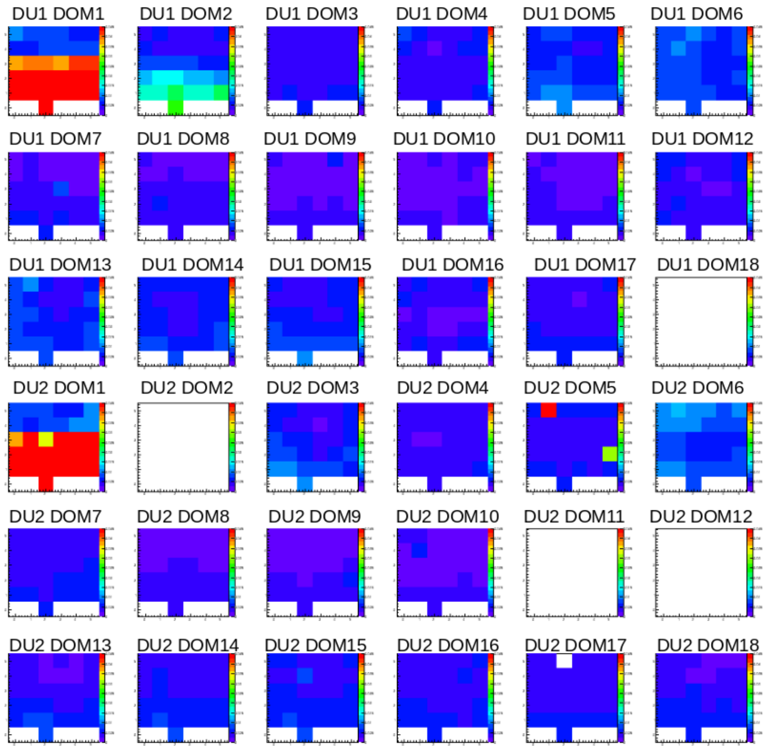


Figure 3.6: *Burst fraction per PMT of run 5014 (24/12/2016). The scale of the z-axis (burst fraction) goes from 0 to 0.045, similar as in figure 3.2*

Around run 5030

Figure 3.7 shows the burst fraction of each PMT for every DOM of run 5030 (28/12/2016). There still is increased burst fraction on the side facing the sea floor of the lower DOMs, but from approximately run 5020 to 5040 the increase in burst fraction is visible on all PMTs. This excludes one highly luminescent organism as the source of the increased burst fraction in this period and possibly means that the high burst fraction is caused by an increased sea current.

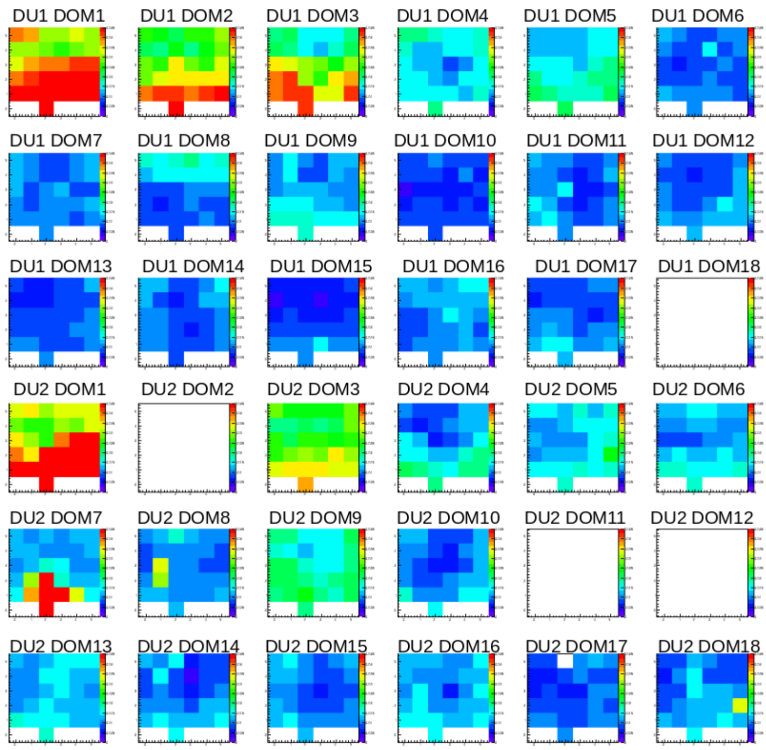


Figure 3.7: *Burst fraction per PMT of run 5030 (28/12/2016). The scale of the z-axis (burst fraction) goes from 0 to 0.045, similar as in figure 3.2*

Around run 5115

According to figure 3.8 the burst fraction of all PMTs on all DOMs is increased, which confirms the theory that this increase in burst fraction is due to a change in direction of the sea current (see section 3.2.1), which causes more bioluminescent organisms to collide with the structure of KM3NeT.

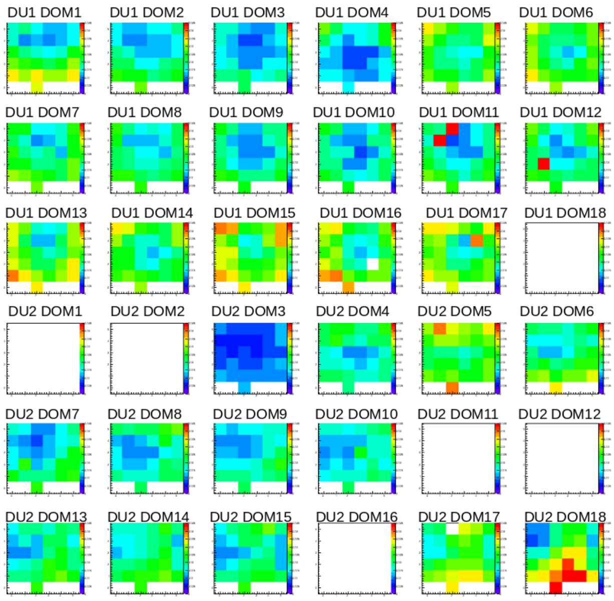


Figure 3.8: *Burst fraction per PMT of run 5115 (16/01/2017). The scale of the z-axis (burst fraction) goes from 0 to 0.045, similar as in figure 3.2*

In DOM 7

For a period of roughly four days (from 27/12/2016 till 1/1/2017) the burst fraction in DOM 7 of DU 2 is increased. Figure 3.7 also shows the burst fraction per PMT of DOM 7. The increase in burst fraction only is measured in the bottom PMTs that face the sea floor. This means that there is one source close to bottom of DOM 7 that is very luminescent.

3.3 Simultaneous bursts

Another characteristic of the bioluminescence is on how many PMTs there is a burst at exactly the same time. If multiple PMTs detect a burst at the same time, then it could mean that the bioluminescent source is bigger or more luminescent than if it is just detected on one PMT. Figure 3.9 depicts on what percentage of the hits there is a burst (a hit rate higher than 120% of the mean hit rate) at exactly N PMTs at the same time.

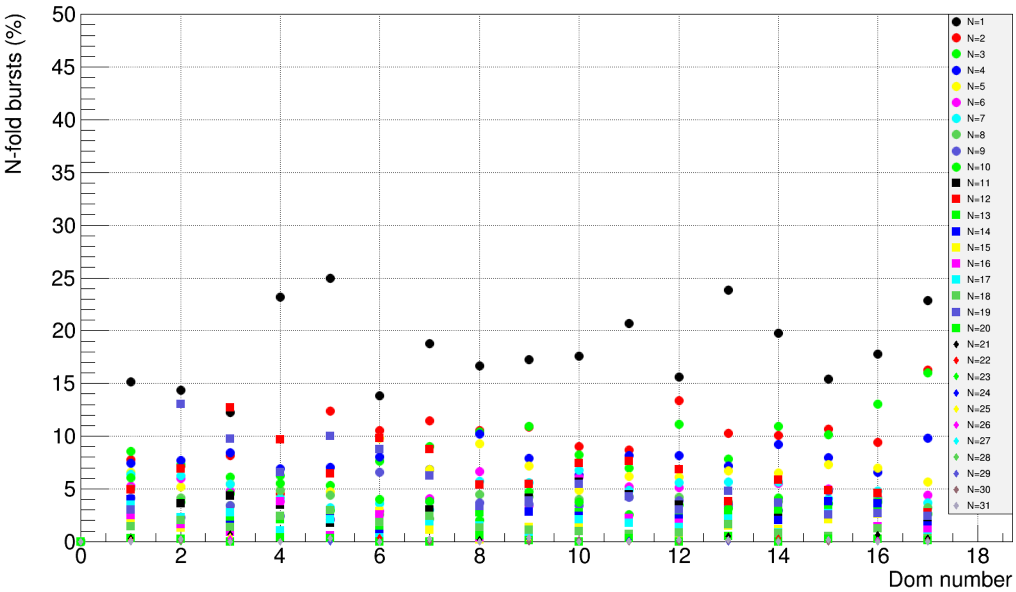


Figure 3.9: *On the y-axis is the number of burst that happened at N PMTs at the same time as a percentage of the total number of bursts per DOM.*

The highest percentage of the bursts happen only at one PMT at the same time, which is probably caused by a combination of the following three things: the source of the burst is so small it is only detected by one PMT, there are random fluctuations in the signal or a PMT is malfunctioning.

3.4 Burst duration

The duration of the bursts caused by bioluminescence is another interesting characteristic and has been studied for ANTARES[10], in this section a similar analyses will be done with data retrieved by KM3NeT. The burst duration is determined by calculating the peak widths of the bioluminescence peaks from the timestream histogram of one six hour run, see for example figure 2.4. In these histograms the hit rate is averaged over time intervals of 100 ms, so bursts with a duration shorter than 100 ms will not be taken into account. Also the definition of a burst (a hit rate higher than 120% of the mean ^{40}K-hit rate) does not take in consideration the fact that two bursts can overlap, but it counts two overlapping bursts as one long burst.

Figure 3.10 shows the distribution of the burst durations (top) and the duration-weighted counterpart (bottom). Other runs show similar distributions. Most of the bursts have a duration of 100 ms and 200 ms. This differs from the results from ANTARES, but can be explained by the difference in the definition of a peak. The definition used in this study requires the peaks to be less high and so random fluctuations are more present. Beside this side effect the distribution of the burst durations looks similar; most bursts are between 1 and 10 seconds long and the probability that when a peak is measured the peak has duration between 1 and 10 seconds, is most probable.

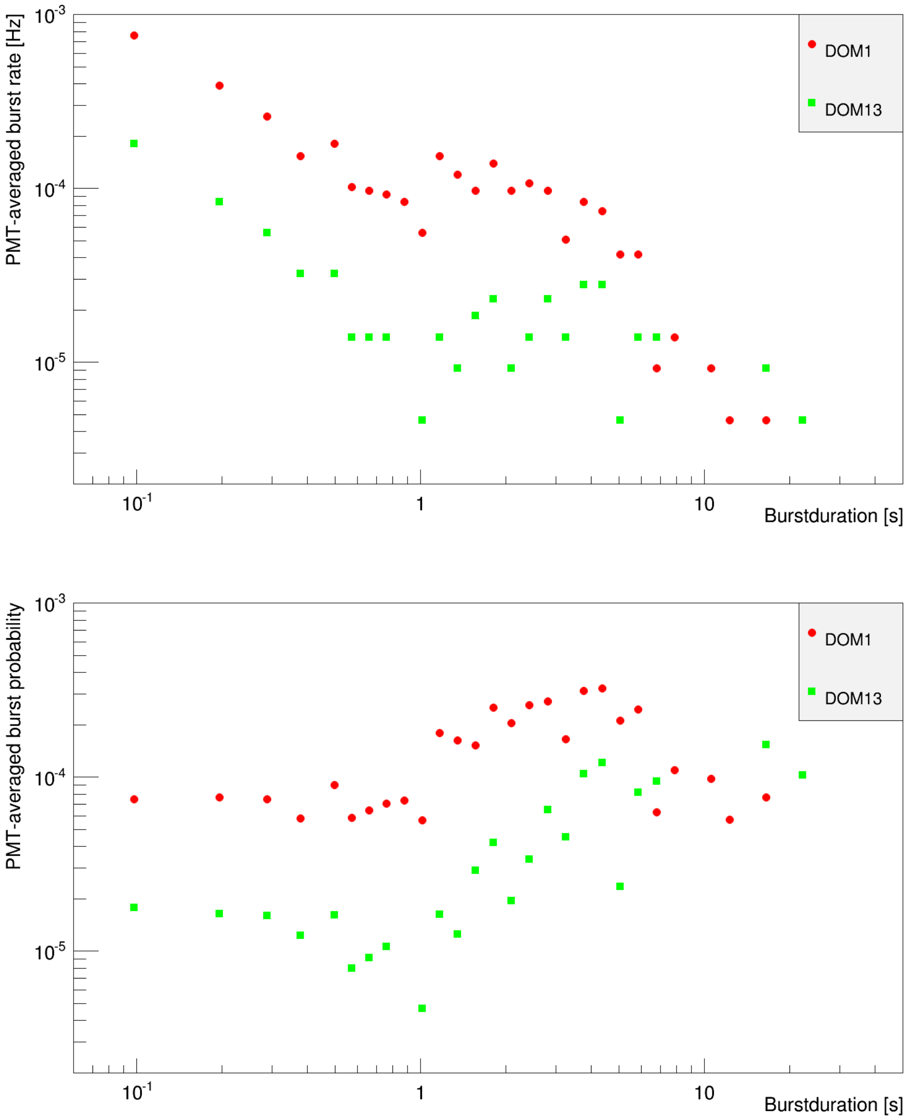


Figure 3.10: *The duration of bursts averaged over the PMTs of one run (run 5035) for the DOM closest to the sea floor (DOM 1) and a DOM in the middle of the detection unit (DOM 13). On the top the PMT-averaged burst rate is shown on the y-axis, on the bottom the PMT-averaged probability. The bottom graph is calculated from the top one by multiplying each bin content with the corresponding burst duration[10].*

3.5 Periodicity

The final characteristic of the bioluminescence in KM3NeT-It investigated in this study is the periodicity of bursts. Due to the rotation of the earth a Coriolis force causes wind drifts that generate currents in the deep sea, which could be expected to lead to a periodicity in the bioluminescence signal. The period of this depends on latitude and should be around 20h for the KM3NeT-It site[11]. In order to be able to find these kind of changes in burst fraction for longer periods of time, data from multiple runs has been merged into a single long timestream, see figure 3.11.

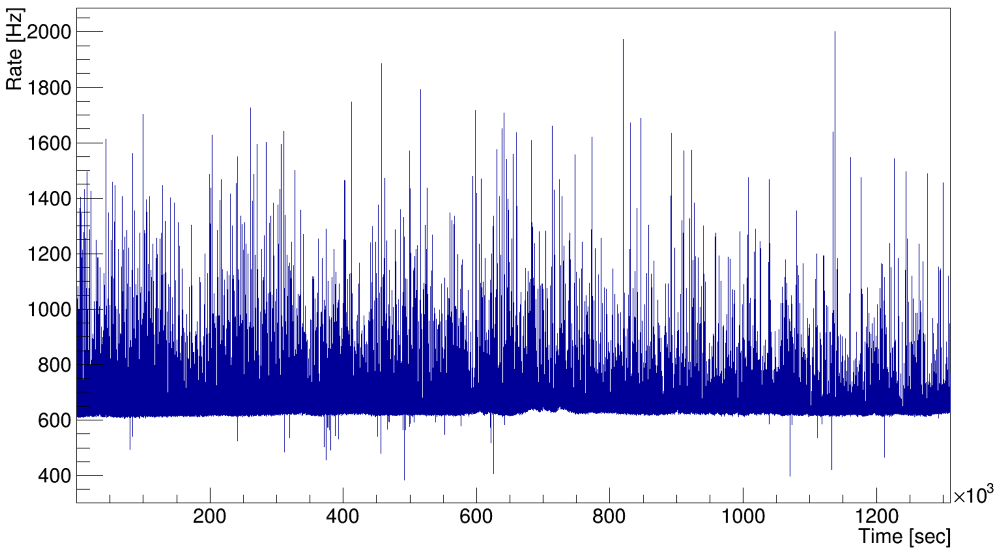


Figure 3.11: *Merged timestream from run 5009 (23/12/2016) till run 5069 (07/01/2017) of DU 1 DOM 1 PMT 19. In every run data were taken for approximately 10 seconds less than six hours, this time between runs have been filled with the average of the previous run, in order to avoid finding this periodicity. These runs are the longest period in which measurements were taken uninterruptedly*

On this merged timestream a Fast Fourier Transform (FFT) was performed to find any periodicity in bursts. Figure 3.12 shows the FFT of three timestream of different PMTs. The PMTs shown were chosen as having a large bioluminescence contribution for the sake of a seeing a clear distinction between a possible periodicity and noise.

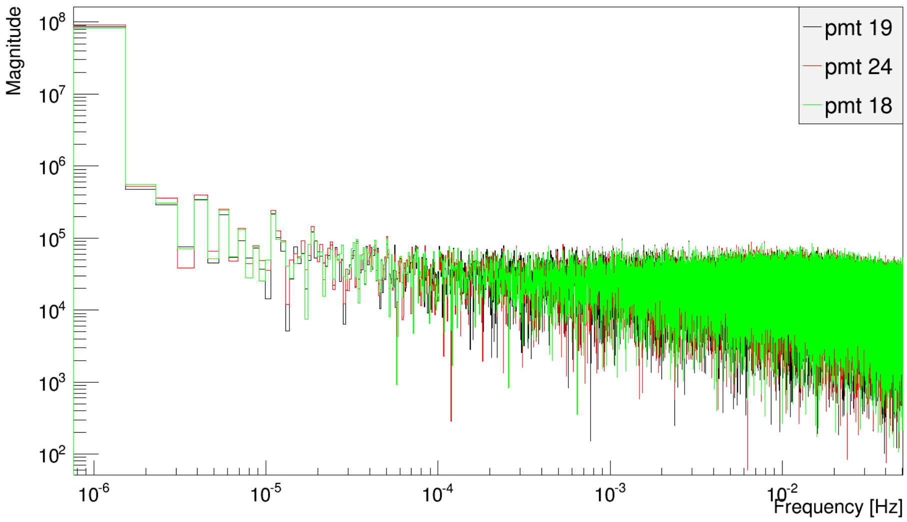


Figure 3.12: *Fast Fourier Transforms of the timestreams DU 1 DOM 1 PMT 19, 24 and 18. This shows the periodicity in these timestreams. The first bin reflects the average value of the timestream*

The FFTs of these three PMTs all show the same pattern, so the peaks are not caused by random fluctuations. In order to confirm this a timestream has been generated by picking random entries from a distribution. Subsequently a Fourier Transform has been made of the timestream and in this way a random noise FFT has been generated. In figure 3.13 this noise is shown on the FFT of the signal of PMT 24 in order to compare these two.

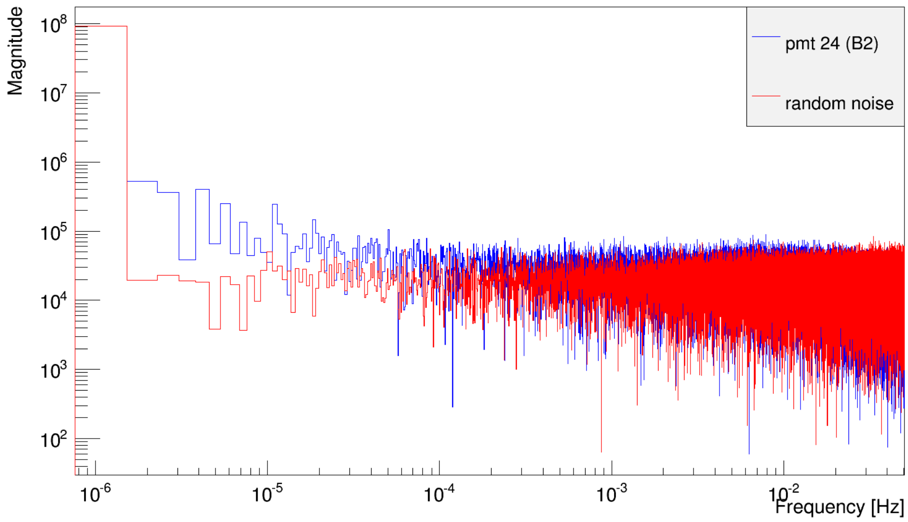


Figure 3.13: *The FFT of the timestream of PMT 24 (blue) and the FFT of a random timestream (red). A frequency of 10^{-5}Hz corresponds to a period of 27.8 hour, 10^{-4} Hz corresponds to 2.8 hour and so on.*

The comparison between the FFT of the random noise and the FFT of PMT 24 shows a distinction between peaks that are most likely due to bioluminescence and peaks that are caused by noise. There are some distinguishable peaks around a frequency of 10^{-5} Hz. A previous study found a significant 20.5 h periodicity in the bioluminescence[11]. Figure 3.14 shows where the peak of this 20.5 h periodicity would be with respect to the FFT of a PMT.

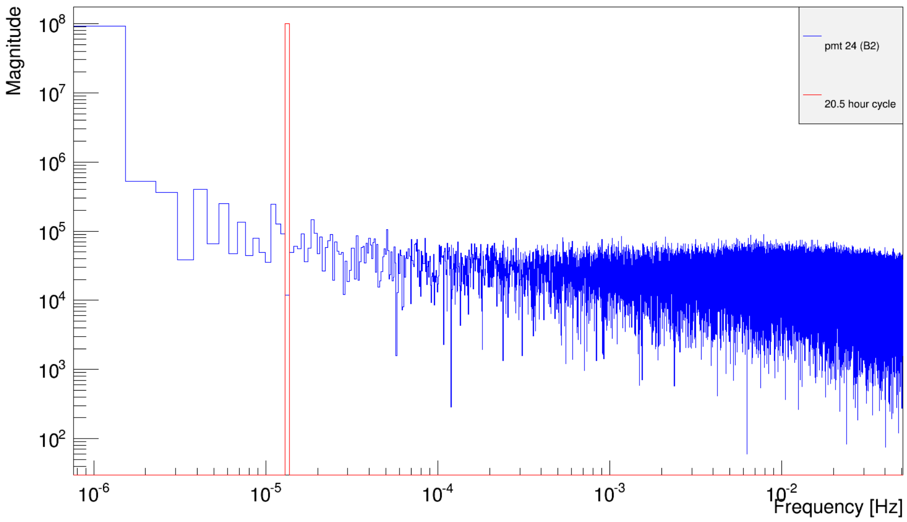


Figure 3.14: *The FFT of the timestream of PMT 24 (blue) and in green the bin where a peak of period 20.5 h would be*

Instead of the peak at exactly a period of 20.5 h (1.4×10^{-5} Hz) there is a peak close to it. This peak corresponds to a 25.1 h periodicity. The width of the bin of this peak is 1.6 h.

Concluding; this does not confirm the 20.5 h peak found in the other study, but it could be a hint to that periodicity. However this study only studied a period two weeks, in order to confirm or refute the 20.5 h periodicity more data has to be studied.

Chapter 4

Malfunctioning PMTs

By studying the characteristics of the bioluminescence a number of malfunctioning PMTs have been found. In this chapter more information is given about these malfunctioning PMTs.

The hit rate of the ^{40}K-decay should be constant and the distribution of the hit rates of a PMT should have one clear peak, an example of a well-working PMTs rate distribution and timestream is shown in figure 4.1. The baseline (mean ^{40}K-hit rate) depends on the efficiency of the PMT, so this can differ per PMT.

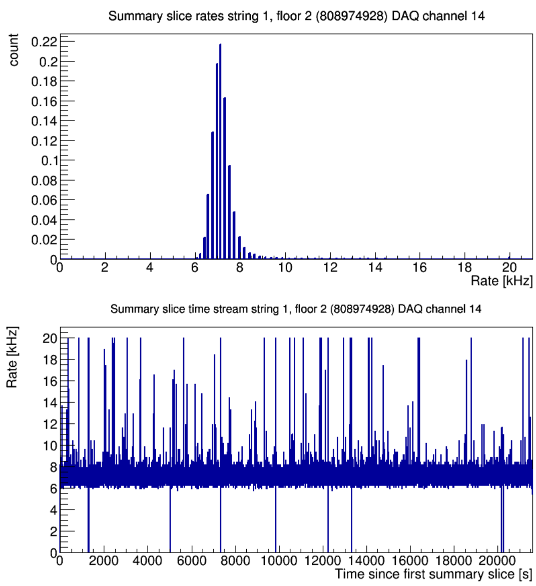


Figure 4.1: *The distribution of the hit rates (top) and the timestream (bottom) of a well-working PMT*

During analysis of the data there were some PMTs found with a anomalously high burst fraction, this turned out to be PMTs that have two peaks in their rate distribution histogram. A double peak is defined as a rate distribution histogram showing a second peak that has a maximum of 10% or more of the highest peak. These double peaks mean that the mean hit rate has shifted, but since the ^{40}K-decay in the sea water is constant, this has to be an effect of a PMT not functioning properly. The runs that have been searched for histograms with two peaks are run 5009 (23/12/2016) till run 5256 (08/02/2017).

There are different ways in which a PMT can malfunction, some typical examples are given below.

During the search for histograms with double peaks, it was found that, from run 5091 (11/01/2017) till the last run, PMT 20 in DOM 16 DU1 was showing unexplained behaviour like a mean hit rate of around 16 kHz, which is very high compared to other PMTs with a baseline of somewhere between 5 and 10 kHz. This PMT is not working properly at all (see figure 4.2).

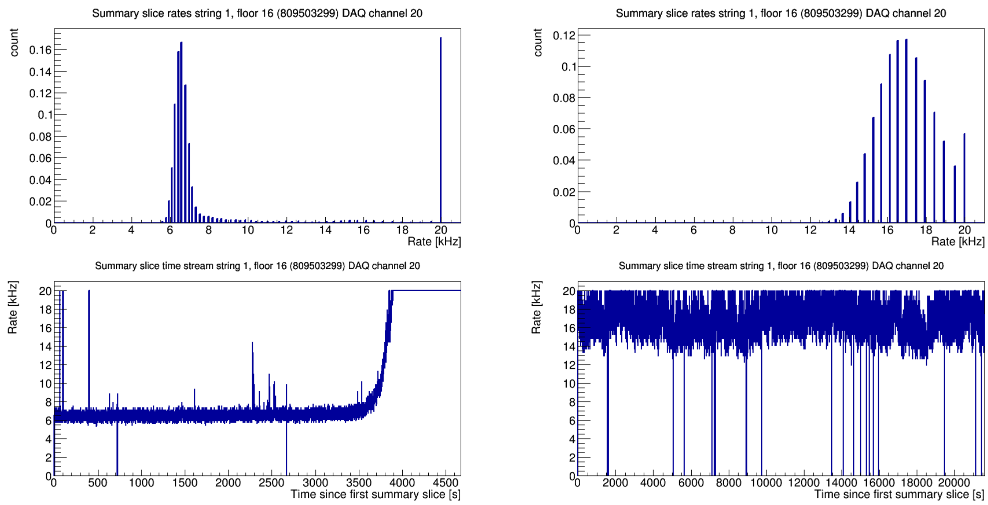
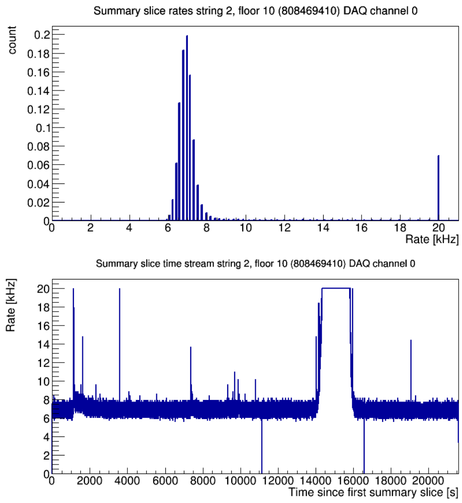
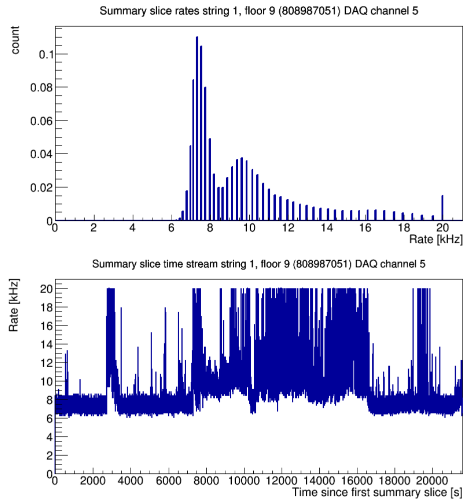


Figure 4.2: *The timestream histogram and rate distribution of PMT 16 of DOM 16, DU1. At the left of run 5091, where the PMT starts malfunctioning. On the right the histogram of run 5152, most histograms of this PMT after run 5091 look like this.*

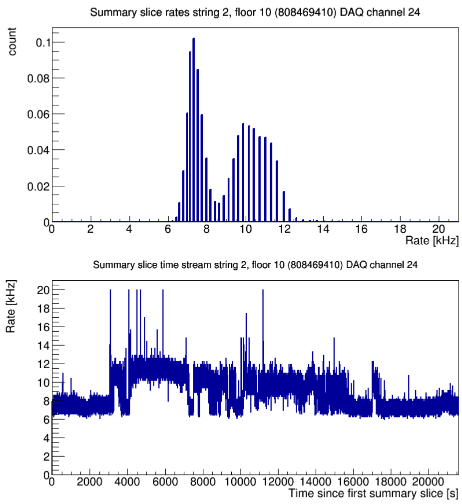
Furthermore in figure 4.3 there are some other examples of rate distributions and timestream histograms of PMTs that are malfunctioning in different ways. The malfunctioning of these PMTs mostly occur in only one run.



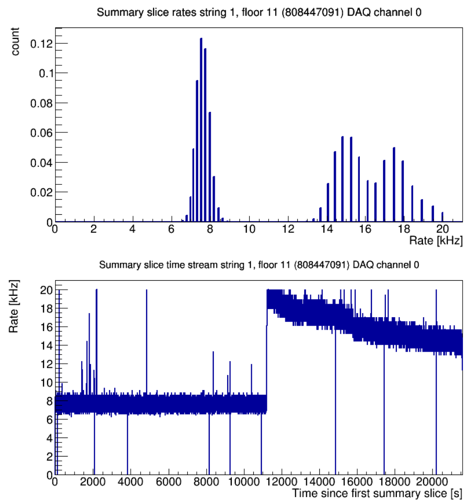
***(a)** run 5046, DU2, DOM 10, PMT 2*



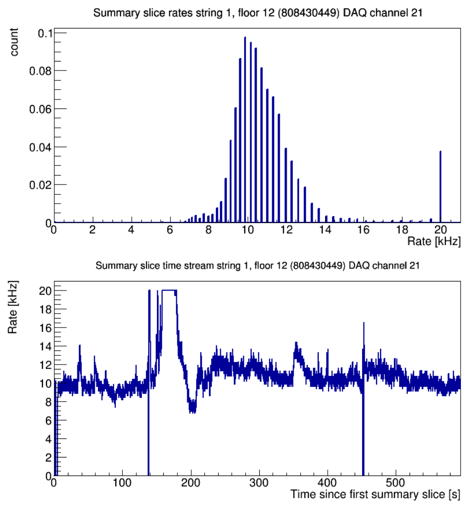
***(b)** run 5048, DU1, DOM 9, PMT 5*



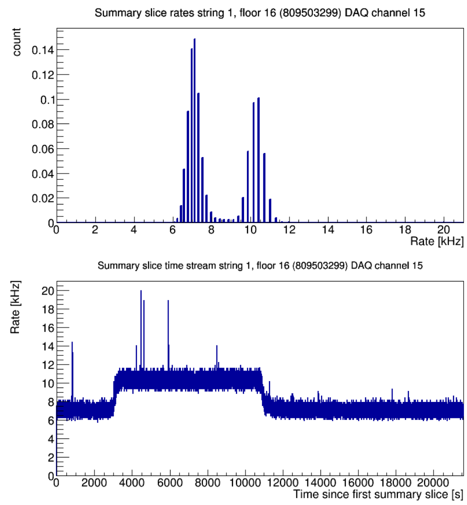
***(c)** run 5072, DU2, DOM 10, PMT 24*



***(d)** run 5142, DU1, DOM 11, PMT 0*



***(e)** run 5236, DU1, DOM 12, PMT 21*



***(f)** run 5047, DU1, DOM 16, PMT 15*

***Figure 4.3:** Examples of timestream histograms and rate distributions of malfunctioning PMTs*

The cause of these malfunctions is not known, but it is important to know that certain PMTs can show unexpected behaviour. This unexpected behaviour is not linked to one DOM or one PMT, but it appears to be random PMTs that suddenly start malfunctioning.

Chapter 5

Conclusions

The bioluminescence in the data that is taken for a period of approximately two months of two DUs on the KM3NeT-It site has been investigated. In the analysis of this data different characteristics have been found.

- The burst fraction (the contribution of bioluminescence to the signal) is well-defined as the fraction of the signal that has a hit rate of at least 120% of the mean ^{40}K-decay hit rate because it shows patterns that are independent of the ^{40}K hit rate.

- There is more bioluminescence detected in KM3NeT when there is a stream current or a change in current direction. There also is increased burst fraction detected on a few PMTs for an extended period of time, for example on the bottom of DOM 1 or on DOM 7. It is not certain what the cause of this is.

- Most of the time bioluminescent bursts are detected on only one PMT of a DOM. These are probably mostly random bursts.

- Bursts caused by bioluminescence have a duration of somewhere between 100 ms and 10 seconds. The chance that a detected burst is a burst of duration 1 to 10 seconds is biggest.

- An expected periodicity of 20.5 hours of the bioluminescence caused by the Coriolis force was not found in the data that was studied. There was an indication of a periodicity of 25 hours, which could possibly indicate a day-night pattern of 24 hours. More data has to be studied to confirm or refute the 20.5 hours or day-night periodicity.

- A number of PMTs are not working properly in KM3NeT; some PMTs display a shift in baseline during a run, which is caused by malfunctioning of the PMT. Most PMTs show this behavior in only one run and around 40 timestreams of all data that is investigated in this study have been found to show this behavior. There could however be other or more behavior that indicates malfunctioning PMTs, so further inverstigation is recommended.

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