

PALACKÝ UNIVERSITY OLMOUC  
FACULTY OF SCIENCE  
JOINT LABORATORY OF OPTICS

**BACHELOR THESIS**

Calibration and monitoring of astroparticle  
telescopes



Author:	<b>Daniel Staník</b>
Study program:	B0533A110007 Applied Physics
Field of study:	1702R001 Applied Physics (AFYZ)
Form of study:	Full-time
Supervisor:	Ing. Ladislav Chytka, Ph.D.
Deadline:	April 2022

## DECLARATION

I hereby declare that I elaborated this bachelor thesis independently under the supervision of Ing. Ladislav Chytka, Ph.D., using only information sources referred in the Literature chapter.

In Olomouc August 31, 2021

.....  
Daniel Staník

## Bibliographical identification

Autor's first name and surname	Daniel Staník
Title	Calibration and monitoring of astroparticle telescopes
Type of thesis	Bachelor
Department	Joint Laboratory of Optics
Supervisor	Ing. Ladislav Chytka, Ph.D.
The year of presentation	2022
Abstract	Lorem ipsum dolor sit amet, consectetur adipiscing elit. Curabitur et lectus sit amet lectus vestibulum dignissim. Cras sit amet enim vitae mi elementum blandit eget nec tortor. Curabitur eget eros vitae arcu luctus varius commodo vel mauris. Nam elementum convallis pretium. Nunc dignissim pulvinar urna, nec blandit ante fringilla at. Ut et magna purus, vel pellentesque massa. In tortor nisi, faucibus condimentum cursus ut, sollicitudin quis leo. Ut at purus nec arcu accumsan tincidunt id id massa. Nam id vehicula mi.
Keywords	keyword 1, keyword 2, ...
Number of pages	xx
Number of appendices	x
Language	english

# Bibliografická identifikace

Jméno a příjmení autora	Daniel Staník
Název práce	Kalibrace a monitorování astročásticových teleskopů
Typ práce	Bakalářská
Pracoviště	Společná Laboratoř Optiky
Vedoucí práce	Ing. Ladislav Chytka, Ph.D.
Rok obhajoby práce	2022
Abstrakt	Lorem ipsum dolor sit amet, consectetur adipiscing elit. Curabitur et lectus sit amet lectus vestibulum dignissim. Cras sit amet enim vitae mi elementum blandit eget nec tortor. Curabitur eget eros vitae arcu luctus varius commodo vel mauris. Nam elementum convallis pretium. Nunc dignissim pulvinar urna, nec blandit ante fringilla at. Ut et magna purus, vel pellentesque massa. In tortor nisi, faucibus condimentum cursus ut, sollicitudin quis leo. Ut at purus nec arcu accumsan tincidunt id id massa. Nam id vehicula mi.
Klíčová slova	klíčové slovo 1, klíčové slovo 2, ...
Počet stran	xx
Počet příloh	x
Jazyk	anglický

# Contents

<b>Introduction</b>	<b>7</b>
<b>1 Astroparticle detection</b>	<b>8</b>
1.1 Cosmic rays and particles . . . . .	8
1.2 Ultra-high energy cosmic rays (UHECRs) . . . . .	8
1.3 Detection principles . . . . .	8
<b>2 FAST telescope</b>	<b>9</b>
2.1 Principle of operation . . . . .	9
2.2 Remote control and monitoring . . . . .	9
2.3 . . . . .	9
<b>3 Instrumentalization and measurement preparation</b>	<b>10</b>
3.1 Integration sphere . . . . .	10
3.2 Photomultiplier tube . . . . .	11
3.2.1 Operating principle . . . . .	11
3.2.2 Gain and sensitivity . . . . .	12
3.2.3 Noises and Dark current . . . . .	12
3.2.4 Operating life and degradation . . . . .	12
3.2.5 FAST's PMTs . . . . .	13
3.2.6 Calibration . . . . .	13
3.3 Silicon PM . . . . .	13
3.4 Hardware for experiment control . . . . .	13
3.4.1 Raspberry Pi . . . . .	13
3.4.2 STM32 based microcontrollers . . . . .	13
3.5 Sensors and other electronics components . . . . .	13
3.5.1 MPU6050 . . . . .	13
3.5.2 servo motors . . . . .	13
3.5.3 Dallas DS18B20 thermometer . . . . .	13
<b>4 Calibration UV optical source</b>	<b>14</b>
4.1 Karlsruhe UV source . . . . .	14
4.2 Testing and measurement of UV source . . . . .	14
4.3 Adding optical feedback . . . . .	14
4.4 Modified UV source for drone mounting . . . . .	14
<b>5 FAST Calibration data analysis</b>	<b>15</b>
5.1 Photomultiplier relative calibration . . . . .	15
5.2 . . . . .	15
5.3 . . . . .	15



# Introduction

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Curabitur et lectus sit amet lectus vestibulum dignissim. Cras sit amet enim vitae mi elementum blandit eget nec tortor. Curabitur eget eros vitae arcu luctus varius commodo vel mauris. Nam elementum convallis pretium. Nunc dignissim pulvinar urna, nec blandit ante fringilla at. Ut et magna purus, vel pellentesque massa. In tortor nisi, faucibus condimentum cursus ut, sollicitudin quis leo. Ut at purus nec arcu accumsan tincidunt id id massa. Nam id vehicula mi.

<http://exfyz.upol.cz/didaktika/>

# Chapter 1

## Astroparticle detection

More than 100 years have passed since Victor Franz Hess first encountered cosmic radiation. Since those times the techniques and methods of detection have been strongly improved. We have moved up from elevating electroscopes by ballons to observe growing electric charge to specialized techniques, which allows us to measure particles' energies, trajectories, etc.

### 1.1 Cosmic rays and particles

### 1.2 Ultra-high energy cosmic rays (UHECRs)

### 1.3 Detection principles



# Chapter 2

## FAST telescope

The Fluorescence detector Array of Single-pixel Telescopes (FAST) is an international project of fluorescence telescope sensitive to UHERCs.

Until today there are four prototypes in active service. Three of them are situated in Black Rock Mesa site of the Telescope Array experiment in central Utah and one in Argentina near Pierre Auger Observatory.

### 2.1 Principle of operation

Main detection part of telescope consists of superreflective UV mirrors and photomultipliers.

The entire telescope along with monitoring systems and other instruments is situated in a hut with remote shutter, where it is protected from negative metrological phenomena, such as rain or fast wind, but also from dust and aerosols. Exposure of mirrors to any of this phenomena could lead to reduction of theirs reflectivity. It is also necessary to monitor and protect PMTs from unwanted light sources. Even a low-intensity sources could decrease PMT's service life.

### 2.2 Remote control and monitoring

### 2.3

# Chapter 3

## Instrumentalization and measurement preparation

To perform all of necessary measurements we need to use various types of optical and electronical equipment.

### 3.1 Integration sphere

The Integration sphere (IS) is a special optical equipment, which can be used either as extended uniform light source (EULS) or with spectrometer in determining the material reflectance. In our experiments we use general purpose Labsphere (Fig. 1).



Figure 1: General purpose Labsphere.

The IS inner surface consist of white optical diffusive material ( $\text{BaSO}_4$  and Poly-tetrafluoroethylene). The IS also contains several circular apertures, which are called input/output ports. They can be used to mount detectors or optical sources or left free to let light flux enter or exit IS.

The inner surface is part where light intergration happens. The effect which takes place here is known as Lambertian scattering. After one spot of inner surface is hit by a ray, the energy should be uniformly radially distributed. In output port this produces a homogenous light source. The homogeneity decreases with increasing number and sizes of input/output ports.

Using optical source with IS requires baffle to prevent source's light flux or its part to exit IS without integration.

More deeper explanation of IS working principles and characterization of optical properties of identical IS, which we use, can be found in [1].

For our pusrposes, in case of FAST calibration, we use IS as EULS in UV spectre. In case of testing optical calibration source, we don't even care about homegenity. The

reason why we use IS in this case is that it focuses the entire optical power of the source into output ports, where our detectors are mounted, and blocks any other external light source, which could affect our detectors.

## 3.2 Photomultiplier tube

Photomultiplier tube (PMT) is considered to be a high voltage optoelectronic part. It allows us to measure very low intensity optical signals. PMT is also characterized by high amplification, low noise and stability.

### 3.2.1 Operating principle

PMT consists of 6 main elements, which can be seen on scheme 2.



Figure 2: Photomultiplier tube scheme.

The input photon with sufficient energy, which strikes the PMT's photocathode, excites photocathode's electron. This electron then follows electrostatic field to the first dynode of the electron multiplier, where it induces secondary emission of more electrons. These electrons are then attracted by the next dynode, where the emission process repeats. After few times of multiplying electron number over dynodes, the electrons are then collected by the anode, which is situated on the end of the electron multiplier. The anode output current is then converted to voltage signal by appropriate load resistor or by operational amplifier current-to-voltage circuit.

As all other laboratory instruments, which are based on accelerating electrons, such as electron microscopes, the photomultiplier's main parts must be kept in vacuum. To maintain vacuum, the photomultiplier is surrounded by special glass envelope. To avoid mechanical damage of the glass envelope, the entire photomultiplier is situated in a plastic tube.

One of the basic adjustable characteristic of PMT is its gain. The gain is defined as:

$$G = \frac{I_a}{I_p} \quad (3.1)$$

### Window

The photocathode is superimposed by glass window, whose main purpose is to admit light of certain wavelengths. Glass materials are characterized by the spectral sensitivity to wavelengths. For transparency in UV spectre, it is advised to use borosilicate or fused silica glasses.

## Photocathode

The photocathode is the only light-sensitive part of PMT. It transfers the light flux into electric current.

One of its main parameters is quantum efficiency. It is referred as ratio of emitted photoelectrons to the number of incident photons expressed as a percentage. It is generally less than 35 %. For measurement, the more practical parameter is cathode radiant sensitivity. It is the ratio of photocathode current to an incident light power, which is expressed in mA/W.

Photocathode material must be sensitive to certain wavelengths, which we want to detect with the PMT, and must have sufficient quantum efficiency. Preferred materials are usually alkali antimonides.

## Electron multiplier

The electron multiplier consists of dynodes and one anode. Dynodes are electrodes, which produce more electrons through secondary emission. To maintain electrostatic field between dynodes, each of dynodes is held on different potential. This is achieved by using the voltage divider. Every resistor in the divider sets the potential of one diode according to its resistivity.

All of the photoelectrons emitted by photocathode should be ideally collected by the first dynode. However, many of them could be diverted from their path to dynode due to various effects. The parameter, which characterizes this, is the collection efficiency. The Collection efficiency is a probability that photoelectron will strike area of the first dynode.

There are few types of dynodes arrangements. On the fig. 2 is the classic linear-focusing multiplier.

## Voltage divider and voltage adjustment

Voltage divider could be a simple resistor serial network, which divide high input voltage between the dynodes.

It is necessary to consider, that the multiplier current density increases in direction to the anode, so it tends to lessen the voltage between last dynode and anode. This phenomena can shake the potential levels across the entire multiplier. One way to reduce the impact on PMT's behaviour is to choose the proper resistor values of the divider.

The resistor values could same for all the dynodes, but for some applications it is better to have progressive voltage distribution, which increases from cathode to anode, or intermediate distribution with highest values on the beginning of the multiplier.

In some applications, where high anode current peaks are expected, the divider can be filled with reservoir capacitors, which prevent the temporary charge exhaustion of the dynodes. In pulse mode, the unwanted oscillations on dynodes may occur, in that case, it is desirable to connect additional damping resistor to the divider.

### **3.2.2 Gain and sensitivity**

### **3.2.3 Noises and Dark current**

### **3.2.4 Operating life and degradation**

The operating life of PMT is defined as the time required for anode sensitivity to be halved.

### **3.2.5 FAST's PMTs**

### **3.2.6 Calibration**

## **3.3 Silicon PM**

## **3.4 Hardware for experiment control**

### **3.4.1 Raspberry Pi**

### **3.4.2 STM32 based microcontrollers**

## **3.5 Sensors and other electronics components**

### **3.5.1 MPU6050**

### **3.5.2 servo motors**

### **3.5.3 Dallas DS18B20 thermometer**

# Chapter 4

## Calibration UV optical source

Blah blah we need it.

### 4.1 Karlsruhe UV source

### 4.2 Testing and measurement of UV source

### 4.3 Adding optical feedback

### 4.4 Modified UV source for drone mounting

# Chapter 5

## FAST Calibration data analysis

### 5.1 Photomultiplier relative calibration

### 5.2

### 5.3

# Conclusion

We are completely f\*\*\*\*d.



# Bibliography

- [1] Martin Vacula, Pavel Horvath, Ladislav Chytka, Kai Daumiller, Ralph Engel, Miroslav Hrabovsky, Dusan Mandat, Hermann-Josef Mathes, Stanislav Michal, Miroslav Palatka, Miroslav Pech, Christoph M. Schäfer, and Petr Schovanek. Use of a general purpose integrating sphere as a low intensity near-uv extended uniform light source. *Optik*, 242:167169, 2021.
- [2] M. Malacari, J. Farmer, T. Fujii, J. Albury, J.A. Bellido, L. Chytka, P. Hamal, P. Horvath, M. Hrabovský, D. Mandat, J.N. Matthews, L. Nozka, M. Palatka, M. Pech, P. Privitera, P. Schovánek, R. Šmída, S.B. Thomas, and P. Travnicek. The first full-scale prototypes of the fluorescence detector array of single-pixel telescopes. *Astroparticle Physics*, 119:102430, 2020.
- [3] Lenka Tománková. *Optical Properties and Calibration of the Pierre Auger Fluorescence Detector*. PhD thesis, Karlsruher Institut für Technologie (KIT), 2016.
- [4] Photonis: Photomultiplier tube basics.

Preferované jsou citace podle norem ČSN ISO 690 a ISO 690-2, popř. styly APS (American Physical Society – u prací zaměřených fyzikálně) nebo APA (American Psychological Association – u prací zaměřených více didakticky a pedagogicky).