MAHATMA GANDHI UNIVERSITY

PROJECT REPORT

EFFECTS OF SOLAR WIND TRANSIENTS IN OUR NEAR EARTH ENVIRONMENT

SUBMITTED BY

HARITHA D D

M.Sc.PHYSICS

REG NO. **AM21PHY010**

In partial fulfilment of the requirement of the award of
Master of Science Degree in Physics

DEPARTMENT OF PHYSICS AND
CENTRE FOR RESEARCH

ST. TERESAS'S COLLEGE (AUTONOMOUS)
ERNAKULAM,
2021-2023

MAHATMA GANDHI UNIVERSITY

PROJECT REPORT

EFFECTS OF SOLAR WIND TRANSIENTS IN OUR NEAR EARTH ENVIRONMENT

Year: 2021-2023

In partial fulfilment of the requirement of the award of

Master of Science Degree in Physics

BY

HARITHA D D

M.Sc.PHYSICS

REG NO. **AM21PHY010**

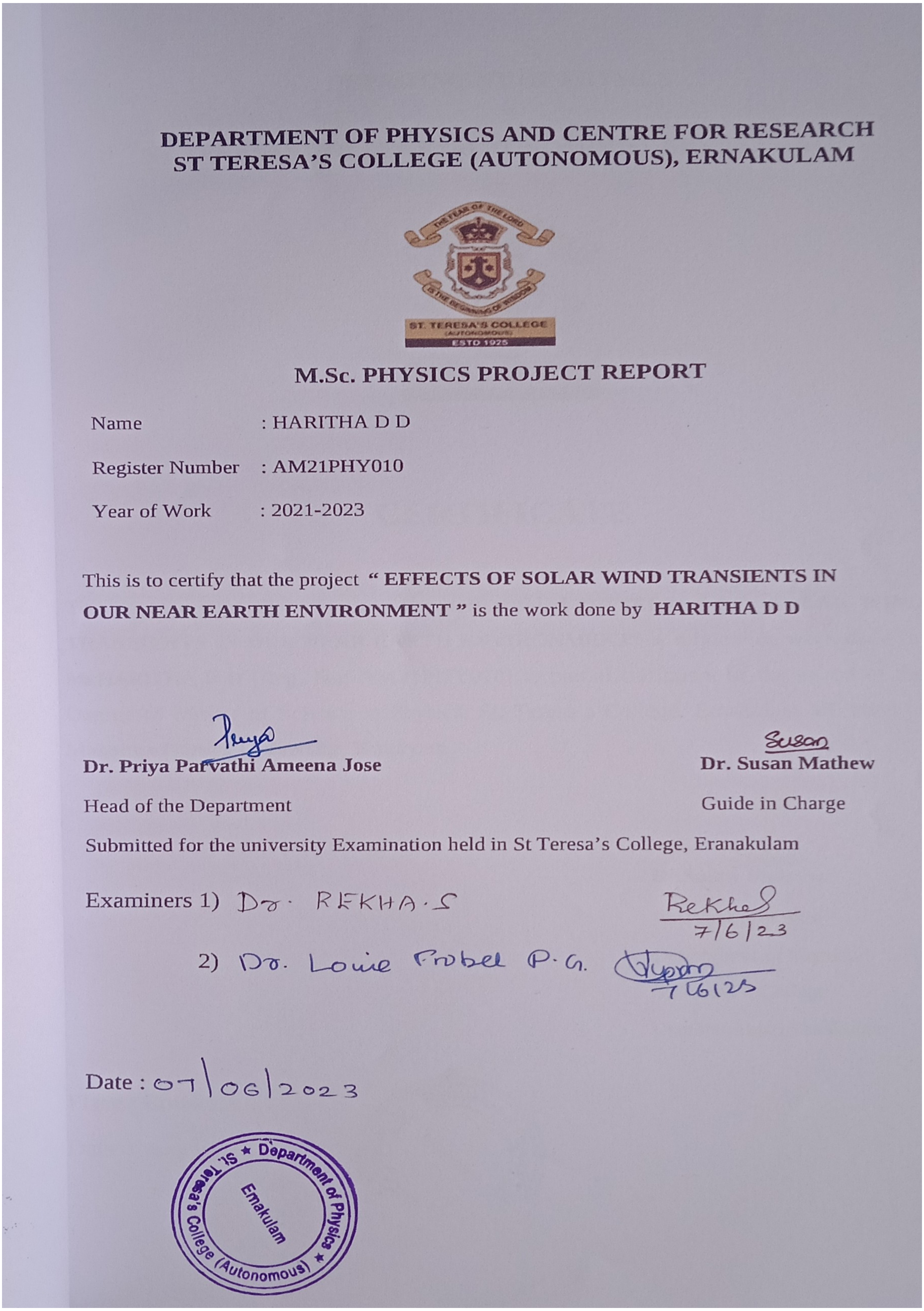
Under the supervision of

Dr. SUSAN MATHEW
Department of Physics
St. Teresa’s College, Ernakulam

and

Dr. K P ARUN BABU
Department of physics
St. Albert’s College, Ernakulam

ST. TERESAS’S COLLEGE (AUTONOMOUS)
ERNAKULAM, KOCHI-682011



DEPARTMENT OF PHYSICS AND CENTRE FOR RESEARCH
ST TERESA'S COLLEGE (AUTONOMOUS), ERNAKULAM

M.Sc. PHYSICS PROJECT REPORT

Name	: HARITHA D D
Register Number	: AM21PHY010
Year of Work	: 2021-2023

This is to certify that the project **" EFFECTS OF SOLAR WIND TRANSIENTS IN OUR NEAR EARTH ENVIRONMENT "** is the work done by **HARITHA D D**

Priya	Susan
Dr. Priya Parvathi Ameena Jose	**Dr. Susan Mathew**
Head of the Department	Guide in Charge

Submitted for the university Examination held in St Teresa's College, Eranakulam

Examiners 1) Dr. REKHA. S Rekha 7/6/23

2) Dr. Louie Frobel P. G. 7/6/23

Date : 07/06/2023

DEPARTMENT OF PHYSICS

ST TERESAS COLLEGE (AUTONOMOUS), ERNAKULAM

CERTIFICATE

This is to certify that the project report entitled **"EFFECTS OF SOLAR WIND TRANSIENTS IN OUR NEAR EARTH ENVIRONMENT"** is a bonafide work done by **Ms.HARITHA D D** (Reg. No: AM21PHY010) in partial fulfilment of the award of the Degree of Master of Science in Physics, St. Teresa's College, Ernakulam affiliated to Mahatma Gandhi University, Kottayam.

Susan
Dr.Susan Mathew
Assistant professor
Department of Physics
St.Teresa's College
(Autonomous),Ernakulam

Place : Ernakulam
Date : 07/06/2023

DEPARTMENT OF PHYSICS
ST.ALBERTS COLLEGE (AUTONOMOUS), ERNAKULAM

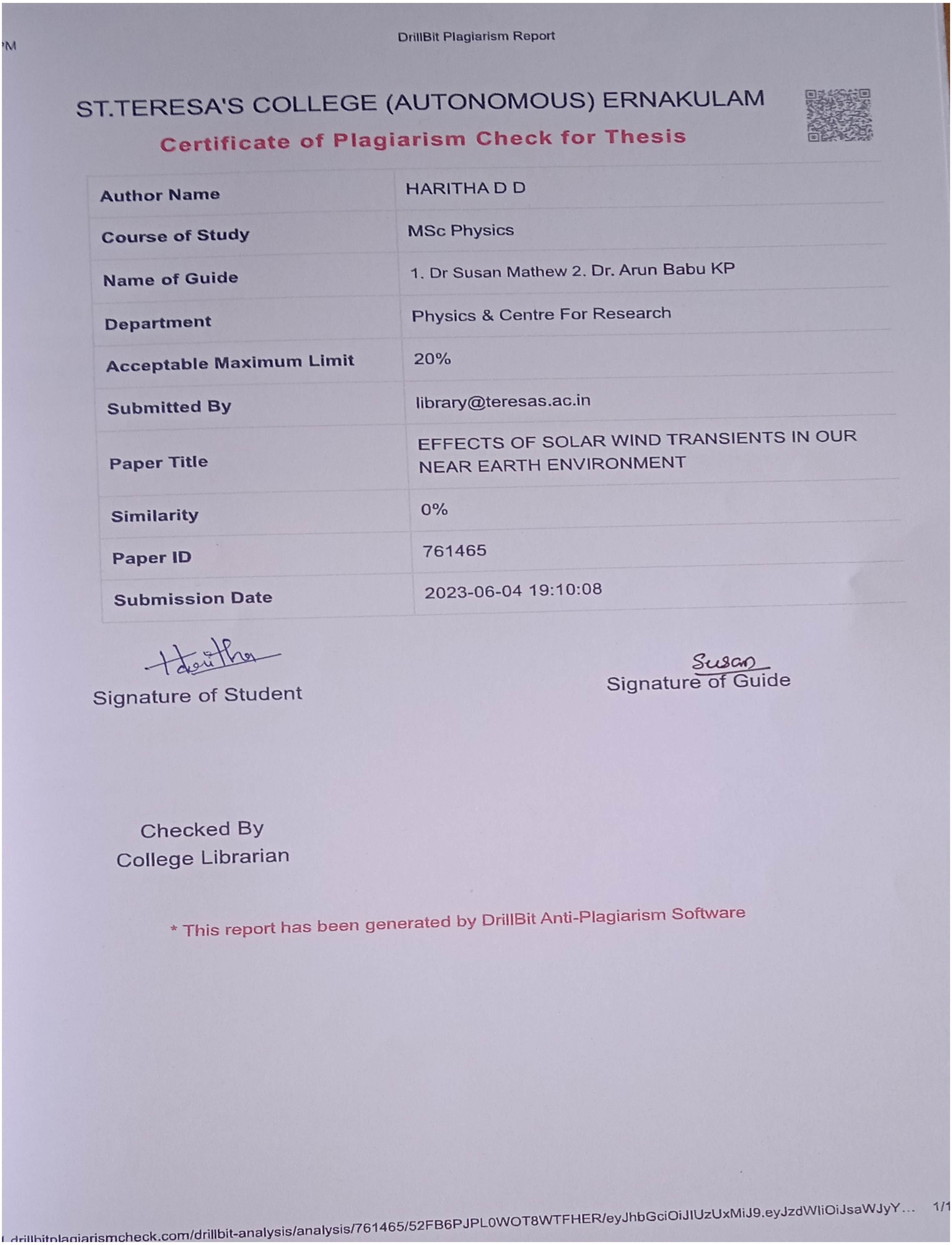
CERTIFICATE

This is to certify that the project report entitled **"EFFECTS OF SOLAR WIND TRANSIENTS IN OUR NEAR EARTH ENVIRONMENT "** is the bonafide work done by **Ms. HARITHA D D**(Reg. No: AM21PHY010) towards partial fulfilment of the the award of the Degree of Master of Science in Physics is a bonafide record of the work carried out by the candidate under my supervision .

Dr. Arun Babu K P
Asst. Professor
Department of Physics

Dr. ARUN BABU K.P.
Assistant Professor
Department of Physics
St. Alberts College (Autonomous)
Ernakulam - 682 011

Place : Eranakulam
Date : 07/6/2023



ST.TERESA'S COLLEGE (AUTONOMOUS) ERNAKULAM

Certificate of Plagiarism Check for Thesis

Author Name	HARITHA D D
Course of Study	MSc Physics
Name of Guide	1. Dr Susan Mathew 2. Dr. Arun Babu KP
Department	Physics & Centre For Research
Acceptable Maximum Limit	20%
Submitted By	library@teresas.ac.in
Paper Title	EFFECTS OF SOLAR WIND TRANSIENTS IN OUR NEAR EARTH ENVIRONMENT
Similarity	0%
Paper ID	761465
Submission Date	2023-06-04 19:10:08

Haritha

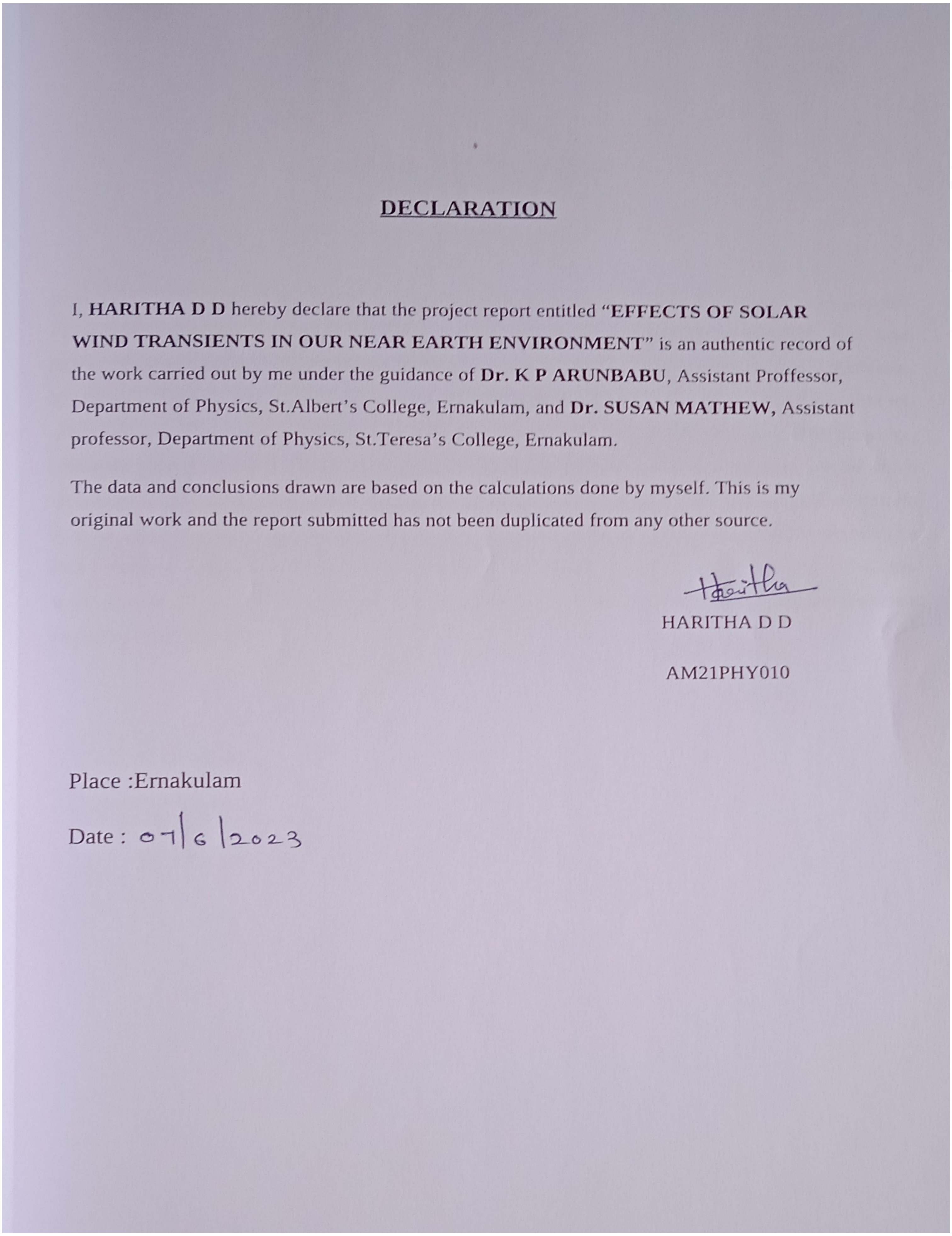
Signature of Student

Susan

Signature of Guide

Checked By
College Librarian

* This report has been generated by DrillBit Anti-Plagiarism Software



DECLARATION

I, **HARITHA D D** hereby declare that the project report entitled "**EFFECTS OF SOLAR WIND TRANSIENTS IN OUR NEAR EARTH ENVIRONMENT**" is an authentic record of the work carried out by me under the guidance of **Dr. K P ARUNBABU**, Assistant Proffessor, Department of Physics, St.Albert's College, Ernakulam, and **Dr. SUSAN MATHEW,** Assistant professor, Department of Physics, St.Teresa's College, Ernakulam.

The data and conclusions drawn are based on the calculations done by myself. This is my original work and the report submitted has not been duplicated from any other source.

Haritha

HARITHA D D

AM21PHY010

Place :Ernakulam

Date : 07/6/2023

ACKNOWLEDGEMENT

First of all, I would like to thank the Almighty God for being able to complete this project with success. I take this opportunity to express my profound gratitude and deep regards to my guide Dr. K P Arun Babu, Assistant Professor, St. Albert’s College, Ernakulam, and Dr. Susan Mathe, Assistant Professor, St. Teresa’s College, Ernakulam, for their exemplary guidance, monitoring, support and constant encouragement without which this project would not be able to exist in the present shape. The blessings, help and guidance given by them time to time shall carry us a long way in the journey of life on which we are about to embark. They have taken pain to go through the project and make necessary corrections as when needed. I am extremely thankful to all other faculties of the department of physics, for their constant support. I would like to express my thanks to all respondents and colleagues in developing the project. I’m grateful to my parents for their blessings and constant encouragement throughout the project.

ABSTRACT

A geomagnetic storm is a significant disruption of the Earth’s magnetosphere that happens when energy from the solar wind is exchanged very effectively with the space environment around Earth. High speed solar wind that continues for several hours and, most significantly, a southward-directed solar wind magnetic field are the main solar phenomena that cause geomagnetic storms. We considered 5 years to determine whether there is any correlation between solar wind parameters and geomagnetic storm events. Parameters of solar wind, which are magnetic field and dynamic pressure along with DST indices are analysed.

Key words: Magnetosphere, Geomagnetic storm, Solar wind, dynamic pressure.

CONTENTS

1. INTRODUCTION

Our Earth is experiencing a continuous stream of charged particles released from the upper atmosphere of the Sun known as the solar wind. The dynamic pressure and magnetic field of solar wind are compressing the magnetosphere in the day-side to bow-shock-nose. During a solar-transient event the solar wind cause a significant change in our magnetosphere known as geomagnetic storms.

We are analysing the solar transient events during the period from 2001 to 2020 .

1.1 SUN

The Sun is a luminous, gaseous star located at the center of our solar system. It is an enormous ball of hot plasma, primarily composed of hydrogen (about 74% by mass) and helium (about 24% by mass), with trace amounts of other elements. With a diameter of about 1.4 million kilometres (870,000 miles), the Sun is roughly 109 times the diameter of Earth. Its mass is approximately 330,000 times that of Earth, accounting for about 99.86% of the total mass of the solar system.

At the core of the Sun, temperatures reach extreme levels, reaching around 15 million degrees Celsius (27 million degrees Fahrenheit). These temperatures and pressures are so intense that they facilitate nuclear fusion, specifically the fusion of hydrogen atoms to form helium. This process releases an enormous amount of energy in the form of light and heat, which radiates outwards, eventually reaching the Sun's surface and escaping into space.

The Sun's surface, called the photosphere, has an average temperature of about 5,500 degrees Celsius (9,932 degrees Fahrenheit). It appears as a bright, yellowish disk when observed from Earth. The photosphere is characterized by the presence of dark spots called sunspots, which are regions of intense magnetic activity. Sunspots are cooler than the surrounding areas and can vary in size from a few hundred to tens of thousands of kilometres in diameter.

Above the photosphere lies the Sun's outer atmosphere, consisting of two distinct regions: the chromosphere and the corona. The chromosphere is a thin layer of hot, glowing gas with a reddish appearance. During a solar eclipse, it becomes visible as a narrow, pinkish ring around the darkened disk of the Sun. The outermost layer, the corona, is an extremely hot (over a million degrees Celsius) and tenuous plasma that extends several million kilometres into space. It is visible during total solar eclipses as a faint, pearly white halo surrounding the Sun.

The Sun is a dynamic and active star, exhibiting various phenomena driven by its magnetic field. Solar flares and coronal mass ejections (CMEs) are powerful eruptions of energy and matter from the Sun's surface into space. These events can release vast amounts of charged particles and electromagnetic radiation, including X-rays and ultraviolet light, which can impact Earth's magnetosphere and cause auroras, disrupt satellites, and affect communication and power systems.

The Sun also undergoes an approximately 11-year activity cycle known as the solar cycle or sunspot cycle. During the peak of this cycle, the number of sunspots and solar activity increases, resulting in more frequent solar flares and CMEs. This period is called solar maximum. Conversely, during solar minimum, the Sun is relatively calm, with fewer sunspots and reduced activity.

The energy radiated by the Sun is crucial for sustaining life on Earth. It provides heat and light necessary for various processes, including photosynthesis in plants, atmospheric circulation, and the water cycle. Additionally, sunlight is a primary source of energy for solar power generation and plays a fundamental role in weather and climate patterns.

Studying the Sun is essential for understanding the dynamics of stars, the formation of galaxies, and the overall structure of the universe. Scientists employ a range of instruments and telescopes, both ground-based and space-based, to observe the Sun across different wavelengths of light, including visible, ultraviolet, and X-ray. These observations contribute to our knowledge of solar physics, space weather forecasting, and ongoing research into renewable energy sources and fusion energy

1.1.1 SOLAR INTERIOR

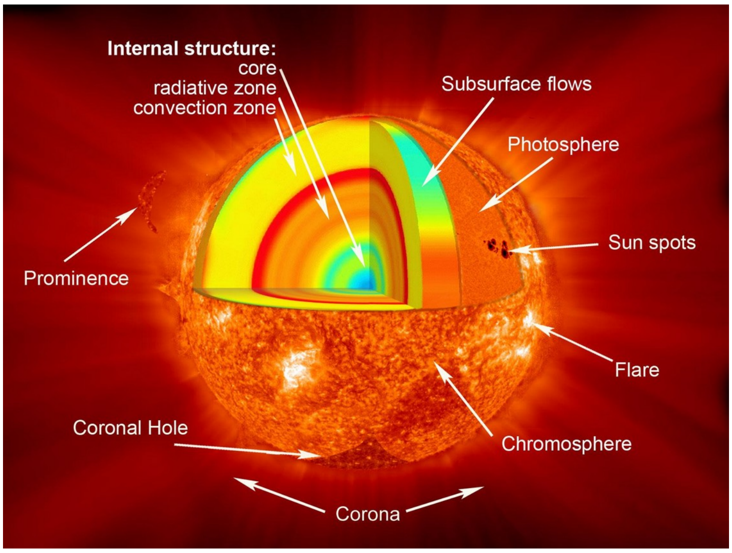


Fig1: shows the different layers of Sun. At the centre is the corona where fusion takes place. The energy generated at corona is transmitted to radiative zone where solar plasma is cool enough to form ionized atoms and becomes optically thick. Hence it is convectively unstable and energy is transported through mass motion in convection zone. (Image courtesy: Geyser landobservatory)

The solar interior refers to the internal structure and composition of the Sun. It can be divided into several distinct layers, each with its own unique properties and characteristics.

Core: At the very center of the Sun lies the core, which is the central region where nuclear fusion takes place. The core is incredibly hot, with temperatures reaching about 15 million degrees Celsius (27 million degrees Fahrenheit). In this extreme environment, hydrogen atoms are fused together to form helium, releasing a tremendous amount of energy in the process.

Radiative Zone: Surrounding the core is the radiative zone, which extends outward from the core to about 70% of the Sun's radius. In this region, energy generated in the core is transported through a process called radiation. Photons (particles of light) are continuously emitted and absorbed by the hot plasma present in the radiative zone, slowly diffusing outwards.

Convective Zone: Beyond the radiative zone lies the convective zone, which extends from about 70% of the Sun's radius to the surface. Unlike the radiative zone, where energy is transported by radiation, the convective zone transfers energy through convection. The material in this region becomes heated and rises in hot, buoyant bubbles, while cooler material sinks back down. This creates a cycle of rising and sinking plasma, akin to boiling water, which helps to transport energy to the Sun's surface.

Photosphere: The photosphere is the visible surface of the Sun that we observe from Earth. It is the layer from which most of the Sun's light and heat escape into space. The photosphere has an average temperature of about 5,500 degrees Celsius (9,932 degrees Fahrenheit) and appears as a bright, yellowish disk. Sunspots, which are cooler and darker areas, can also be observed on the photosphere's surface.

The detailed understanding of the Sun's interior structure has been primarily derived from theoretical models and observations of solar phenomena. Instruments such as helioseismographs, which detect solar oscillations or "sunquakes," have provided valuable insights into the Sun's internal structure by studying the propagation of seismic waves within the Sun.

Overall, the solar interior is a dynamic and complex region where intense heat, pressure, and nuclear reactions create the energy that powers the Sun and sustains life on Earth.

1.1.2 SOLAR ATMOSPHERE

The solar atmosphere refers to the outer layers of the Sun, which extend beyond the visible surface called the photosphere. It comprises three distinct regions: the chromosphere, the transition region, and the corona. Each of these regions has its own unique characteristics and plays a crucial role in the Sun's behavior and interactions with space.

Chromosphere: The chromosphere is the region located just above the photosphere. It is a thin layer of hot, glowing gas with a reddish appearance. During a total solar eclipse, the chromosphere becomes visible as a narrow ring around the darkened disk of the Sun. It has an average temperature of around 4,000 to 10,000 degrees Celsius (7,200 to 18,000 degrees Fahrenheit). Prominences, which are large, looping structures of gas held by magnetic fields, can be observed in the chromosphere.

Transition Region: The transition region is a narrow region that lies between the chromosphere and the corona. It is characterized by a rapid increase in temperature, transitioning from a few thousand degrees Celsius in the chromosphere to over a million degrees Celsius in the corona. The exact mechanism responsible for this temperature jump is still a subject of scientific research.

Corona: The corona is the outermost layer of the Sun's atmosphere. It extends millions of kilometers into space and is characterized by its extremely high temperature, reaching several million degrees Celsius. Despite its high temperature, the corona emits very little visible light, as it is much fainter than the photosphere. However, it becomes visible as a faint, pearly white halo surrounding the Sun during a total solar eclipse. The corona is also the source of the solar wind, a continuous stream of charged particles that flows outward from the Sun and affects the space environment around the solar system.

Heliosphere: The heliosphere is not part of the Sun's atmosphere but is an extended region of space influenced by the Sun's presence and solar wind.

The heliosphere is a vast region of space that encompasses the Sun and extends far beyond the outermost layers of its atmosphere. It is created by the continuous outflow of charged particles, known as the solar wind, emanating from the Sun. The solar wind consists of high-energy particles, mainly protons and electrons, that are constantly streaming outward in all directions.

As the solar wind propagates outward from the Sun, it encounters the surrounding interstellar medium, which consists of particles and magnetic fields originating from other stars and galaxies. The interaction between the solar wind and the interstellar medium shapes the heliosphere and influences its boundaries and dynamics.

The shape of the heliosphere is often compared to that of a comet, with the Sun located near the centre and the solar wind forming a long tail trailing behind it. This elongated structure is caused by the relative motion between the Sun and the interstellar medium. The boundary of the heliosphere is known as the heliopause, where the solar wind pressure balances with the pressure from the interstellar medium. The heliopause is located at a distance of about 120 astronomical units (AU) from the Sun, with one AU being the average distance between the Sun and Earth. Beyond the heliopause, the influence of the Sun's magnetic field and solar wind diminishes, and the interstellar medium dominates.

The heliosphere acts as a protective shield, deflecting many of the high-energy cosmic rays coming from outside the solar system. It also plays a crucial role in shaping the space weather environment around our solar system, including the modulation of cosmic rays and the interaction with interstellar magnetic fields.

Our understanding of the heliosphere and its boundaries comes from measurements obtained by various spacecraft, such as the Voyager missions and the Interstellar Boundary Explorer (IBEX). These missions have provided valuable data and insights into the structure and dynamics of the heliosphere.

In summary, the heliosphere is an extended region of space influenced by the solar wind emanating from the Sun. It acts as a protective bubble around our solar system, interacting with the interstellar medium and shaping the space weather environment in our vicinity.

1.1.3 CORONA

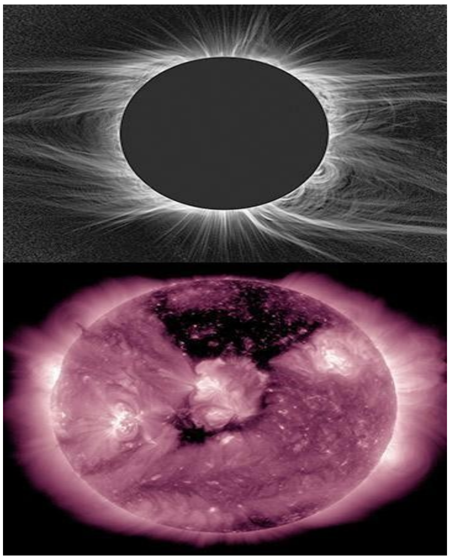


Fig 2: Two views of corona: during an eclipse (top)and ultraviolet light (bottom)(Credit: NASA)

The corona is the outermost layer of the Sun's atmosphere, extending millions of kilometres into space. It is a region of extremely hot and tenuous plasma, with temperatures reaching several million degrees Celsius. Despite its high temperature, the corona emits very little visible light and is much fainter than the photosphere, making it difficult to observe under normal circumstances.

The corona becomes visible during total solar eclipses when the Moon blocks the bright disk of the Sun, revealing the outer atmosphere. At this time, the corona appears as a faint, pearly white halo surrounding the darkened disk of the Sun. It exhibits a beautiful and intricate structure, consisting of streamers, loops, and plumes that extend outward from the Sun.

One of the remarkable features of the corona is its high temperature. While the surface of the Sun, called the photosphere, has an average temperature of about 5,500 degrees Celsius, the corona's temperature rises to several million degrees. This temperature inversion, where the outer atmosphere is hotter than the Sun's surface, remains a significant puzzle in solar physics, known as the coronal heating problem. Several mechanisms, such as magnetic reconnection and wave heating, are believed to contribute to the heating of the corona, but the exact process is still not fully understood.

The corona is also the source of the solar wind, a continuous stream of charged particles that flows outward from the Sun in all directions. The solar wind carries the Sun's magnetic field into space and interacts with the magnetospheres of planets, including Earth, influencing space weather conditions and the dynamics of planetary environments.

Scientists study the corona using specialized instruments and telescopes that observe the Sun in extreme ultraviolet (EUV) and X-ray wavelengths. These observations help reveal the intricate structures and dynamics of the corona, as well as phenomena like solar flares, coronal mass ejections (CMEs), and coronal holes—regions of reduced density and cooler temperatures.

Understanding the corona is essential for unraveling the mysteries of the Sun, such as its magnetic activity, energy transfer mechanisms, and the origin of solar storms that can impact our technological infrastructure. Space missions such as NASA's Solar Dynamics Observatory (SDO) and the European

Space Agency's Solar Orbiter are dedicated to studying the corona and advancing our knowledge of this fascinating and dynamic region of the Sun's atmosphere.

COMPONENTS OF CORONA

The terms K-corona, F-corona, E-corona, and T-corona are used to describe different components or aspects of the Sun's corona:

K-corona (Continuum Corona): The K-corona, or continuum corona, refers to the part of the corona that is responsible for the continuous spectrum of sunlight that is observed during a total solar eclipse. It is composed of sunlight scattered by free electrons in the corona. The K-corona is the most easily observed component and appears as a smooth, white, and relatively featureless halo around the darkened disk of the Moon during an eclipse.

F-corona (Fraunhofer Corona): The F-corona, or Fraunhofer corona, is the outermost part of the solar corona. It is named after the German physicist Joseph von Fraunhofer, who discovered dark absorption lines in the solar spectrum known as Fraunhofer lines. The F-corona is composed of sunlight that is scattered by dust particles or small debris in the interplanetary space around the Sun. These scattered photons result in the appearance of faint, whitish light that is observed as a halo around the Sun.

E-corona (Emission Corona): The E-corona, or emission corona, refers to the part of the corona that emits its own light, primarily in spectral lines. This emission is caused by the excitation and ionization of the coronal plasma by high temperatures and intense magnetic fields. The E-corona is typically observed using specialized instruments that can capture the emission spectra of specific elements or ions in the corona, such as hydrogen (H-alpha) or iron (Fe XIV).

T-corona (Thomson Corona): The T-corona, or Thomson corona, refers to the scattering of sunlight by free electrons in the corona. It is named after the British physicist J.J. Thomson, who explained the scattering of light by charged particles. The T-corona is responsible for the polarization of sunlight observed during a total solar eclipse. By analysing the polarization properties of sunlight, scientists can gather information about the density and distribution of electrons in the corona.

Cited from European Space Agency

1.2. SOLAR CYCLE

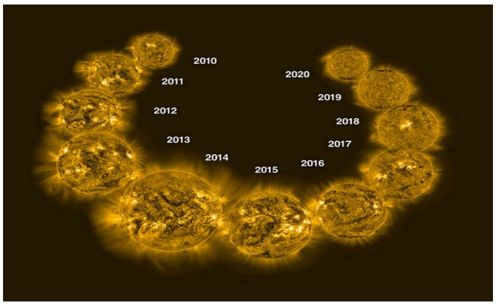


Fig:3 Evolution of the Sun in extreme ultraviolet light from 2010 through 2020, as seen from the telescope aboard Europe's PROBA2 spacecraft. (Credit: Dan Seaton/European Space Agency (Collage by NOAA/JPL-Caltech))

Image Credit: NASA/Goddard/Scientific Visualization Studio

The solar cycle, also known as the sunspot cycle or solar magnetic activity cycle, is a recurring pattern of changes that occur on the Sun over approximately an 11-year period. It is characterized by variations in the number of sunspots, solar flares, and other solar phenomena.

The solar cycle is driven by the Sun's magnetic field, which undergoes a complete reversal of polarity over the course of each cycle. The cycle can be divided into two main phases: the solar minimum and the solar maximum.

Solar Minimum: During the solar minimum, the Sun experiences a period of low magnetic activity and reduced sunspot numbers. The number of sunspots is relatively low, and those that do appear tend to be small and short-lived. Solar flares and other solar eruptions are infrequent during this phase. The solar minimum marks the end of one solar cycle and the beginning of the next.

Solar Maximum: The solar maximum represents the peak of solar activity within the cycle. During this phase, the Sun's magnetic field becomes more complex, and sunspots are more numerous, larger, and longer-lasting. Solar flares and coronal mass ejections (CMEs) are more frequent and powerful during the solar maximum, releasing vast amounts of energy and material into space. These solar eruptions can have implications for space weather, affecting Earth's magnetosphere and potentially disrupting satellite communications, power grids, and other technological systems.

The duration of the solar cycle is not fixed and can vary from cycle to cycle. The average length of a solar cycle is around 11 years, but it can range from approximately 9 to 14 years. Additionally, the intensity of solar activity can also vary from one cycle to another. Some cycles exhibit higher levels of solar activity with more sunspots and stronger solar flares, while others may be relatively subdued.

The solar cycle is closely tied to the Sun's magnetic dynamo, a process involving the generation and amplification of magnetic fields within the Sun. It is driven by the interplay of magnetic fields generated by differential rotation in the solar interior. The precise mechanisms underlying the solar cycle and its variations are still an active area of research and study in solar physics.

The solar cycle has significant implications for space weather, satellite operations, telecommunications, and other technological systems that can be affected by solar activity. Scientists monitor and study the solar cycle using various instruments and spacecraft to gain a better understanding of the Sun's behavior and its impact on Earth and our space environment.

Cited from https://scijinks.gov/solar cycle/

1.3. SOLAR WIND

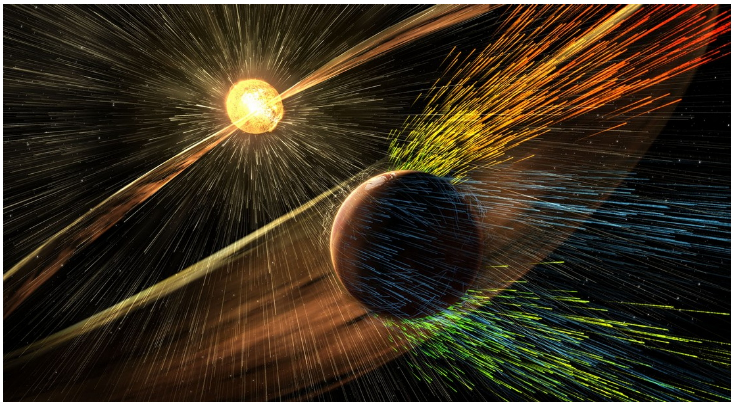


Fig:4 solar wind :Image Credit:NASA

Solar wind is a continuous stream of charged particles that flows outward from the Sun in all directions. It is primarily composed of electrons and protons, with a small percentage of heavier ions.

The solar wind originates from the outermost layer of the Sun's atmosphere, called the corona. The high temperature of the corona, reaching several million degrees Celsius, causes the gas particles to move at high speeds and escape the Sun's gravitational pull.

The solar wind is driven by several factors, including the Sun's intense heat, the expansion of the corona, and the Sun's magnetic field. The corona's high temperature is a result of the energy released by nuclear fusion reactions in the Sun's core. The expansion of the corona creates a pressure gradient that propels the particles outward. Additionally, the Sun's magnetic field, which extends into space, plays a role in accelerating and shaping the solar wind.

The solar wind is not uniform but consists of different types of flows. The fast solar wind originates from coronal holes, which are regions on the Sun's surface where the magnetic field lines are open, allowing the solar wind to escape more easily. The slow solar wind, on the other hand, originates from other areas of the Sun's corona.

The solar wind carries with it the Sun's magnetic field, known as the interplanetary magnetic field (IMF). As the solar wind travels through space, the IMF gets stretched into a spiral shape due to the Sun's rotation. This spiral pattern is known as the Parker spiral.

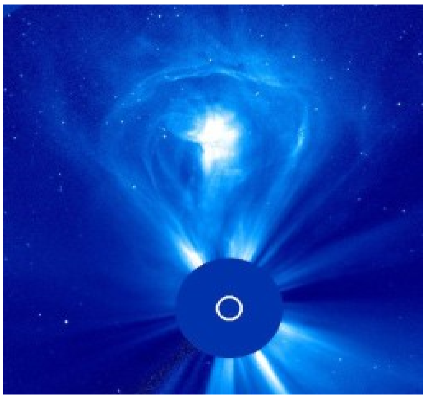
The solar wind has a significant impact on the space environment around the Sun, including the heliosphere, planets, and other celestial bodies. When the solar wind interacts with a planet's magnetic field, it can cause various phenomena such as auroras and magnetospheric disturbances. On Earth, the solar wind interaction with the magnetosphere is responsible for the creation of the auroras in the polar regions.

The solar wind also plays a crucial role in space weather. Disturbances in the solar wind, such as coronal mass ejections (CMEs) and high-speed solar wind streams, can reach Earth and interact with its magnetosphere, potentially causing geomagnetic storms and impacting satellite operations, power grids, and communication systems.

Scientists study the solar wind using spacecraft such as the Solar and Heliospheric Observatory (SOHO), the Solar Dynamics Observatory (SDO), and the Parker Solar Probe. These missions provide valuable data and insights into the properties, dynamics, and effects of the solar wind, contributing to our understanding of the Sun and its influence on the space environment.

Cited from https://www.jpl.nasa.gov/nmp/st5/SCIENCE/solarwind.html/

1.4. CORONAL MASS EJECTION (CME)



Large_coronal_mass_ejection_on_2000-02-27_from_SOHO_LASCO_C3_coronagraph,wikipedia

A coronal mass ejection (CME) is a significant and powerful event that occurs on the Sun, involving the ejection of a massive amount of plasma and magnetic field into space. It is one of the most energetic phenomena observed in the solar system.

A CME typically starts with a sudden release of energy in the Sun's corona, often associated with the destabilization and reconfiguration of the Sun's magnetic field. This can be triggered by various processes, including magnetic reconnection, where magnetic field lines with different orientations collide and realign, releasing a vast amount of stored magnetic energy.

During a CME, a large bubble or "cloud" of magnetized plasma, consisting of charged particles such as electrons and protons, is expelled from the Sun. This cloud can contain billions of tons of material and can travel at speeds ranging from a few hundred to several thousand kilometers per second.

The exact shape and trajectory of a CME depend on the initial conditions of the erupting magnetic structure and the surrounding coronal environment. Some CMEs are relatively symmetrical and expand uniformly, while others may exhibit complex shapes and asymmetric behavior.

The primary driver behind the acceleration and propagation of a CME is the magnetic pressure within the plasma bubble. The magnetic field lines embedded in the CME interact with the ambient magnetic field in the interplanetary medium, causing the CME to expand and push against the solar wind.

When a CME reaches Earth, it interacts with the planet's magnetosphere. The magnetic field carried by the CME can cause disturbances in Earth's magnetosphere, resulting in various space weather effects. These effects include geomagnetic storms, enhanced auroral displays, and potential disruptions to satellite operations, power grids, and communication systems.CMEs are often associated with other solar phenomena, such as solar flares. While flares and CMEs are distinct events, they can occur together as they are both driven by the Sun's magnetic activity. The energy released during a solar flare can contribute to the initiation or intensification of a CME.Scientists study CMEs using a combination of ground-based observatories and space-based missions dedicated to solar and heliospheric research. These include spacecraft like the Solar and Heliospheric Observatory (SOHO), the Solar Dynamics Observatory (SDO), and the Parker Solar Probe. These missions provide valuable data on the properties, structure, and dynamics of CMEs, enabling a better understanding of their origins, evolution, and potential impacts on Earth and the space environment.

Cited from https://www.swpc.noaa.gov/phenomena/coronal-mass-ejections

1.5 SUN EARTH CONNECTIONS

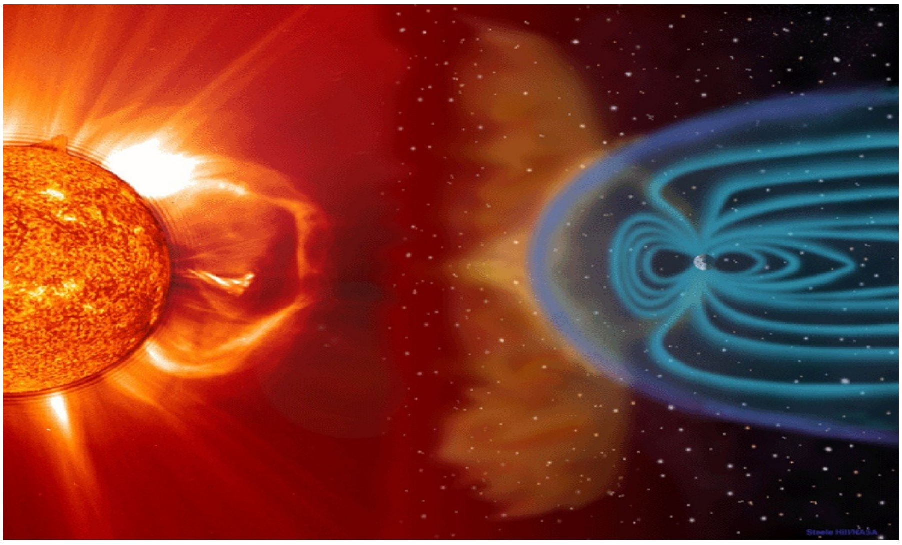


Fig.6 :Credit: European Space Agency

Living on Earth requires energy from the Sun. The Sun is the closest star to us. It is a hot ball of gas primarily composed of hydrogen, as are all stars. Due to the Sun's extreme heat, plasma, the fourth state of matter, makes up the majority of the gas.

The first state of matter is a solid, and it is the coldest. A solid turns into a liquid when it is heated. The second state of matter is liquid. The conversion of liquid to gas occurs when it is heated. The third state of matter is gas. Atoms in the gas disintegrate into charged particles as it is heated, transforming it into plasma. Same term, different substance—this is not the same kind of plasma that may be found in your blood. The plasma of the Sun is so hot that even the most powerful charged particles can fly away into space and escape the Sun's gravitational pull. Because it rushes past the planets and the Sun, interacting with their magnetic fields and/or atmospheres, we refer to this plasma as the solar wind. The magnetic field of the Sun, which extends past Pluto and Neptune from the Sun, is present together with the solar wind.

Magnetic fields and charged particles interact with one another. As a result, the dipole magnetic field, which is depicted on the Earth's Magnetosphere page, is replaced by a plasma-swept magnetosphere that resembles someone's blow-dried hair when the solar wind, which is composed of charged particles, blows by Earth's magnetosphere. The Sun-Earth Connection refers to this interaction between the plasma wind from the Sun and the magnetosphere of Earth. The "dayside magnetosphere" refers to the side of the magnetosphere facing the Sun that is being struck by the solar wind. The magnetotail is the region of the magnetosphere that extends back as though it were streaming with solar wind.

Cited from https://www.nasa.gov/mission_pages/themis/auroras/sun_earth_connect.html

2. DATA ANALYSIS AND INTERPRETATION

In this project we have analysed the effects of solar wind transients on our Earth. The program codes were writted in Root software, which enables statistically sound scientific analysis and visualisation of large amount of data. We are analysing parameters such as dynamic pressure, scalar magnetic field and magnetic field components along with DST index data for a period from 2001 to 2020. We considered the years 2004,2005,2010,2011 and 2016. The one minute resolution solar wind parameters were obtained from the OMNIWeb Service (https://omniweb.gsfc.nasa.gov/)developed and supported by NASA.

We observed the events of dynamic pressure. Corresponding values of magnetic field and the DST values corresponding to each onset and offset time for all the above mentioned years were noted. Then graphs were plotted with maximum values of pressure, maximum value of magnetic field and integrated values of product of dynamic pressure and magnetic field with corresponding DST values.

Tprofile

All the histograms used for data analysis were made using Tprofile function provided in Root. Profile histograms are used to display the mean value of Y and its error for each bin in X. The displayed error is by default the standard error on the mean. Profile histograms are elegant replacements of two dimensional histograms. The inter-relation of two measured quantities X and Y can always be visualised by a two dimensional histogram or scatter plot, but if Y is an unknown, but single valued, approximate function of X, this function is displayed by a profile histogram with much better precision than by a scatter plot.

2.1 SOLAR WIND PARAMETERS

1. Magnetic Field : The magnetic field in the solar wind is relatively weak and is carried along by the solar wind. The rotation of the Sun results in the lines of magnetic flux in the solar wind being drawn into Archimedean Spirals. This occurs because the Sun rotates on its axis every ~25.5 days, while it takes the solar wind around 4.34 days for the Solar Wind particles to reach 1 AU. During the same time, the Sun will have revolved through about 60°, or about of a full rotation. The magnetic field in the Solar Wind, or the interplanetary magnetic field, is attached to the point where the solar wind began. Thus the point on the field line attached to the Sun is turned through an angle of 60° to the point on the magnetic field line that is at 1 AU. It gives one minute resolution.(Cited from Sciencedirect.com

2. Dynamic Pressure : The variation of solar wind dynamic pressure are known to affect the energy and momentum transfer from the solar wind to the magnetosphere ionosphere system. The two important reasons are the duration and rise time of the pressure perturbation. Strong transient perturbations are observed for short rise times both in the magnetosphere and in the ionosphere until a new location of magnetopause boundary is established. The solar wind dynamic pressure Psw could be regarded as a function of solar wind particle density, its expression is

$$P_{sw} = Nm_p v^2$$

where N is the solar wind particle density, mp the proton mass and V, the flow speed of solar wind velocity. It gives one minute resolution.

Cited from Solar wind dynamic pressure dependency on the plasma flow speed and IMF Bz during different geomagnetic activities.

3. Wind Velocity : Solar wind of different densities and speeds are produced by different regions of Sun. High speed solar winds, ranging from 500 to 800 kilometres per second produced by coronal holes. Large and persistent coronal holes can be seen at the poles of the Sun and therefore high latitudes are filled with fast solar wind. In the equatorial plane, where the Earth and the other planets orbit, the most common state of the solar wind is the slow speed wind, with speeds of about 400 kilometres per second. This portion of the solar wind forms the equatorial current sheet. It gives one minute resolution.(Cited from Solar wind|NOAA/NWS Space Weather Prediction Center)

4. Disturbance Storm Time Index (DST) : Disturbance Storm Time index measures the variation of magnetic field associated with magnetosphere. It is used to analyse the strength and duration of geomagnetic storms. DST is a measure of the decrease in the horizontal component of the Earth's magnetic field near the magnetic equator due to increases in the magnetospheric ring current. Values less than -50 nanotesla indicate high geomagnetic activity. It gives one hour resolution.

2.2 VARIATION OF PRESSURE, MAGNETIC FIELD AND VELOCITY WITH DST

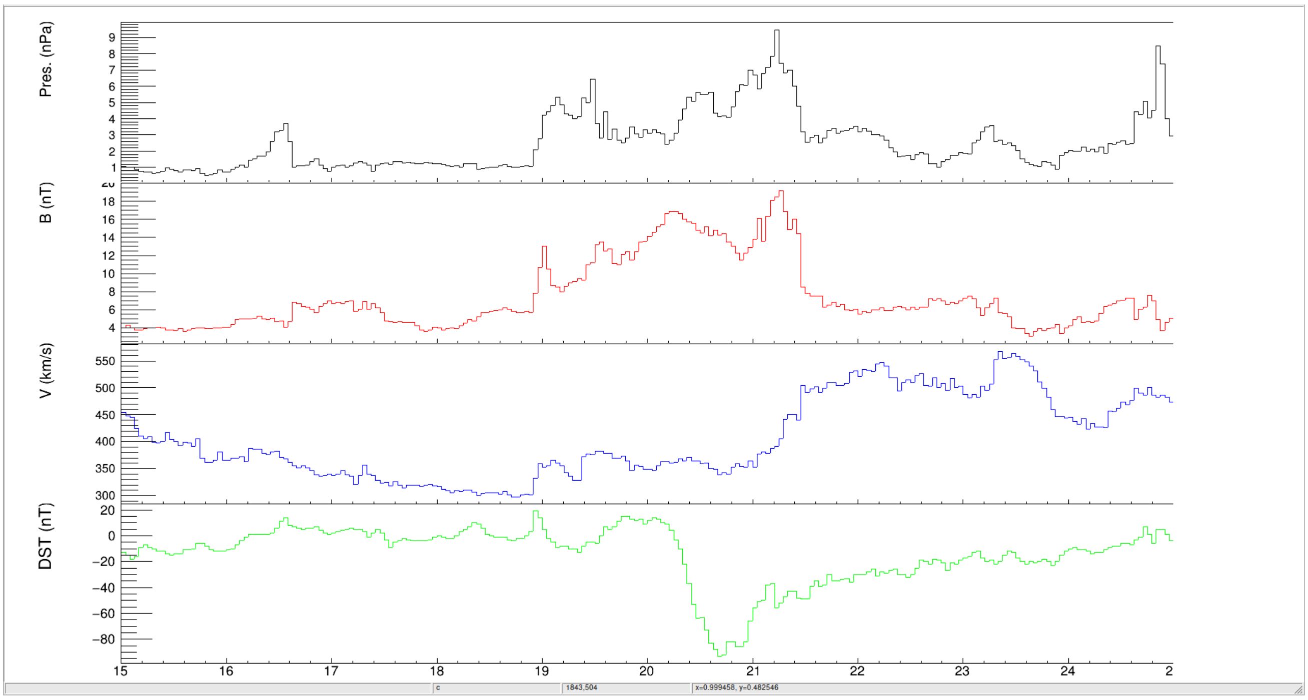


Fig. 7 The first panel shows the variation of pressure, the second panel shows the variation of magnetic field, the third shows the variation of velocity and the fourth panel shows the DST index during a 10 day interval

In the figure above, the Y-axis shows the values of the respective parameters and the X-axis represents the time in days. Here, we observe an increase in pressure and a corresponding increase in magnetic field, velocity and also a peak in the DST index. Both the pressure and magnetic field increases are short lived. The increase in velocity takes a longer time to recover back to its initial value. The peak in the DST is called an SSC (Sudden Storm Commencement), which is a small and sudden increment followed by a sudden drop and a slow recovery. This constitutes a geomagnetic storm event.

3. RESULT

A change in magnetic field and DST is observed relative to an enhancement in the dynamic pressure. We have analysed the dependency of dynamic pressure and magnetic field on DST. The events from 2001-2020 are analysed. Data for plotting graphs are taken using Tprofile histograms. The pressure is in the units of nano Pascal while DST and Magnetic field are in nano Tesla.

A geomagnetic storm is a disturbance in the Earth's magnetic field that occurs in response to changes in the solar wind. When the pressure of the solar wind increases in response to Solar phenomena like CMEs (Coronal Mass Ejections), the arrival of the solar wind at the bow of the magnetosphere leads to a compression of the magnetopause and a resulting sudden increase in the magnetic field on the day-side of the Earth. This event is known as the sudden storm commencement (SSC) and is typically of short duration (minutes).

This can be seen as a short increase in DST increase value which decreases almost immediately. This sudden increase is due to the magnetic field lines gets compressed together and thus, the flux density of the magnetic field of the Earth on the side facing the sun increases. Immediately following an SSC is an onset which can be seen as a short and sudden drop in the DST index value to a minimum. Following this onset is the recovery which begins from the point of minimum. The recovery phase is comparatively longer than the onset phase.

SSC is fitted with a gaussian function and its constant and sigma values are taken. Along with these values slope of onset and slope of recovery also taken as fit parameters. The plots between the observed parameters and the fitted parameters gives us the relationship between solar wind parameters and geomagnetic storm events. One of the fitted curve is given in the figure below.

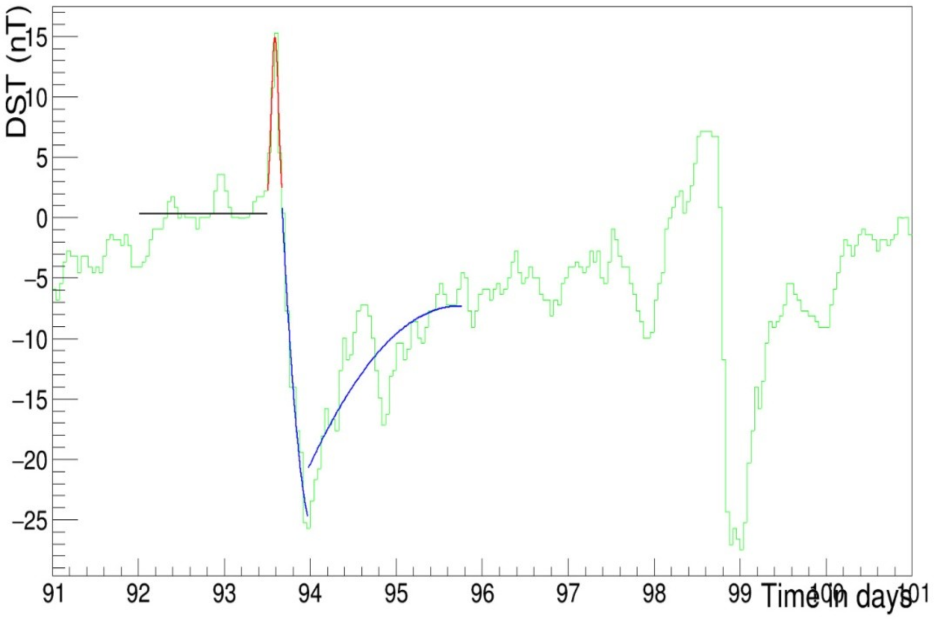


Figure 8

A geomagnetic storm event after performing curve fitting

On performing the fit, we obtained the fit parameters from it. The graph of a Gaussian is represented by a characteristic bell shaped curve. The parameter constant is the height of the curve's peak and the width of the curve . Sigma is the standard deviation which is the Gaussian RMS width . The constant indicates the strength of the event.

Larger sigma value indicates a wider SSC. SSC with larger sigma value will come to the onset portion slowly. A narrow SSC has a lower sigma value.

Relationship between maximum value of pressure and Constant value of Gaussian fit

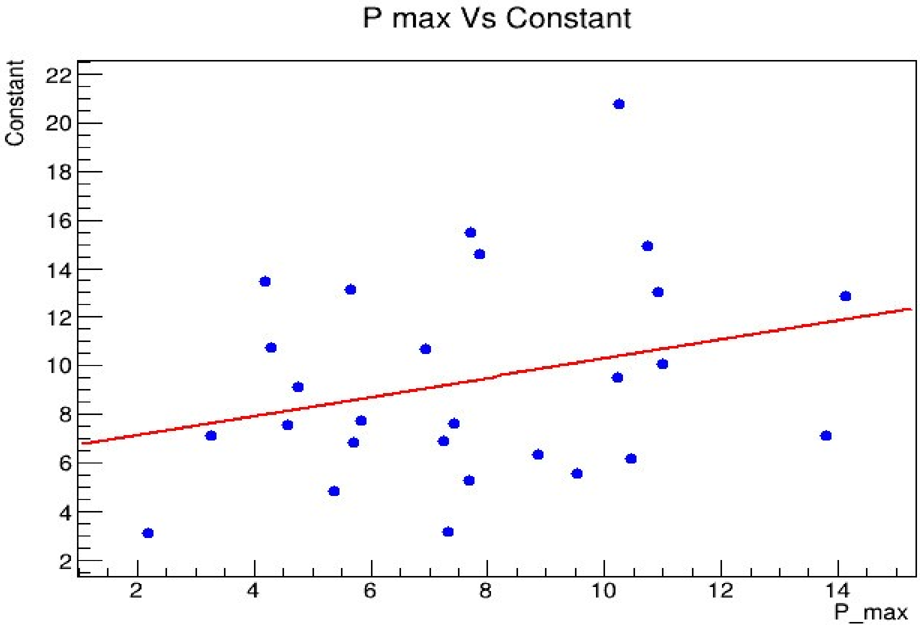


Figure 9: Plot between maximum value of pressure(X-axis) and the constant of the Gaussian fit(Y-axis)

The curve shows that the maximum value of pressure is directly proportional to strength of SSC.

As shown above in figure 9, we see that the maximum value of pressure is directly correlated to the constant of the Gaussian Fit. We can see this with the help of the trend line in red. We understand from this that higher the maximum pressure value, higher will be the peak of the SSC.

Relationship between maximum value of magnetic field and the constant of gaussian fit.

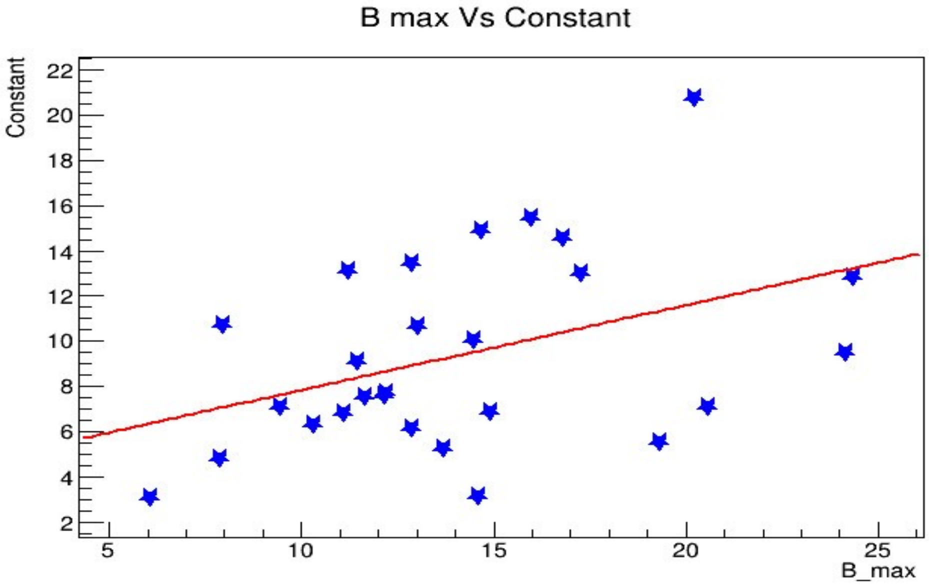


Figure 10: Plot between maximum value of magnetic field (X-axis) and the constant of Gaussian fit (Y-axis)

From the red curve in graph it is evident that higher the peak in magnetic field, higher will be the peak in SSC. ie, strength of SSC increases with an increase in maximum value of magnetic field.

Relationship between maximum value of Pressure and the sigma of the gaussian fit

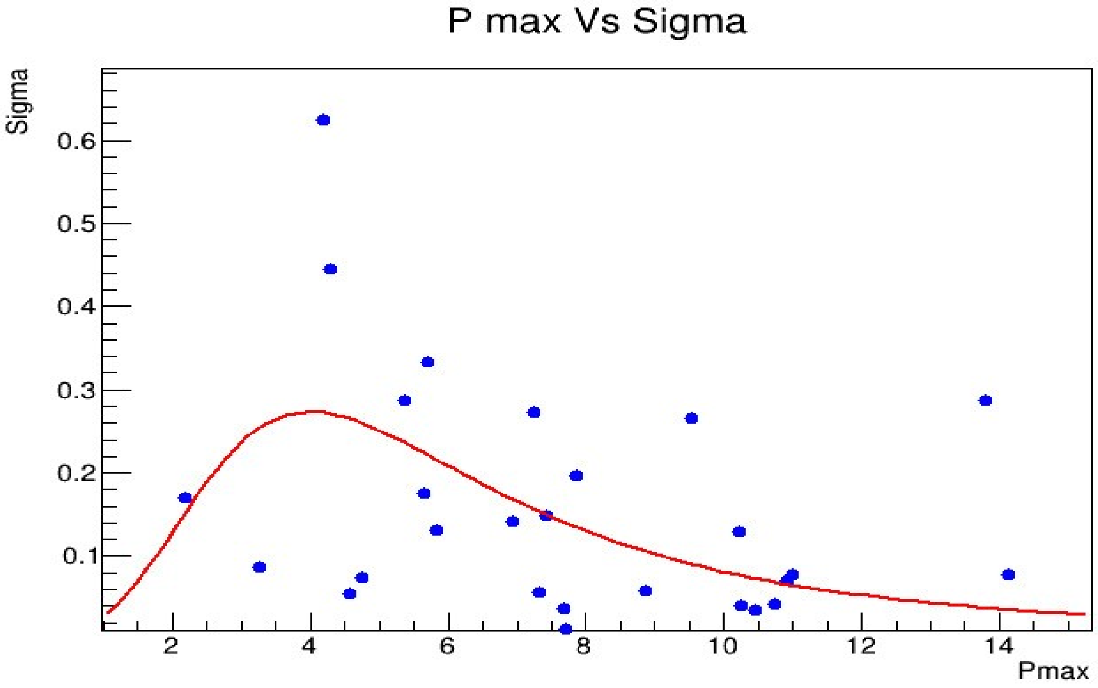


Figure 11: Plot between maximum value of pressure (X-axis) and the sigma of the Gaussian Fit (Y-axis)

A sudden increase of sigma value to a large threshold value can be seen from the graph, The sigma value decrease from this higher threshold value with increase in pressure. It indicates that as pressure increases the onset events start quickly.

The landau fit were used because a minimum threshold of pressure is required to have SSC, as pressure value increases compression start, low value cause compression slowly with large sigma, where as strong pressure make sudden compression with narrow peaks.

Relationship between maximum value of magnetic field and the sigma of the gaussian fit

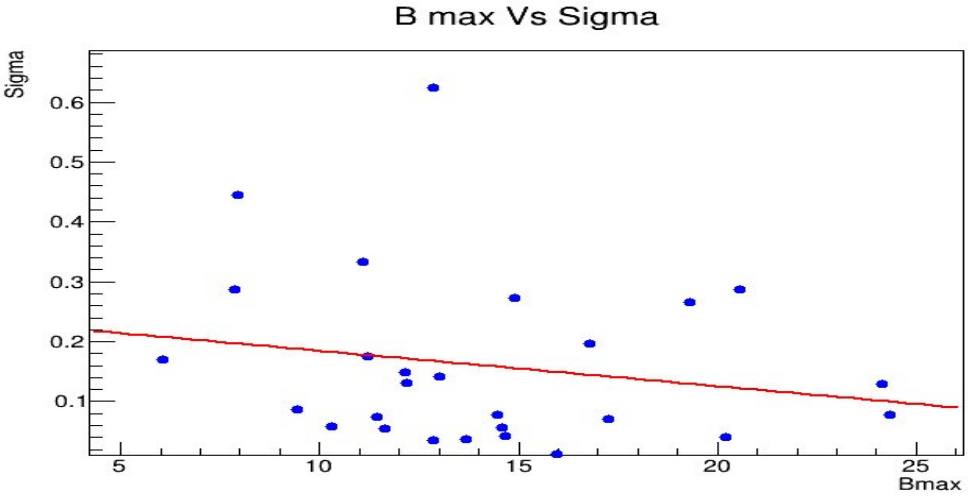


Figure 12: Plot between the maximum value of magnetic field and the sigma of the polynomial fit.

Here the points representing events are fitted with a first order polynomial function. It can be seen from the graph that as the maximum value of magnetic field increases, sigma value reduces. ie, a higher peak value of magnetic field leads to a smaller SSC. For a high value of magnetic field , sigma value will be lower, ie, SSC will return to its initial position faster.

Relationship between Dynamic pressure and constant of gaussian fit

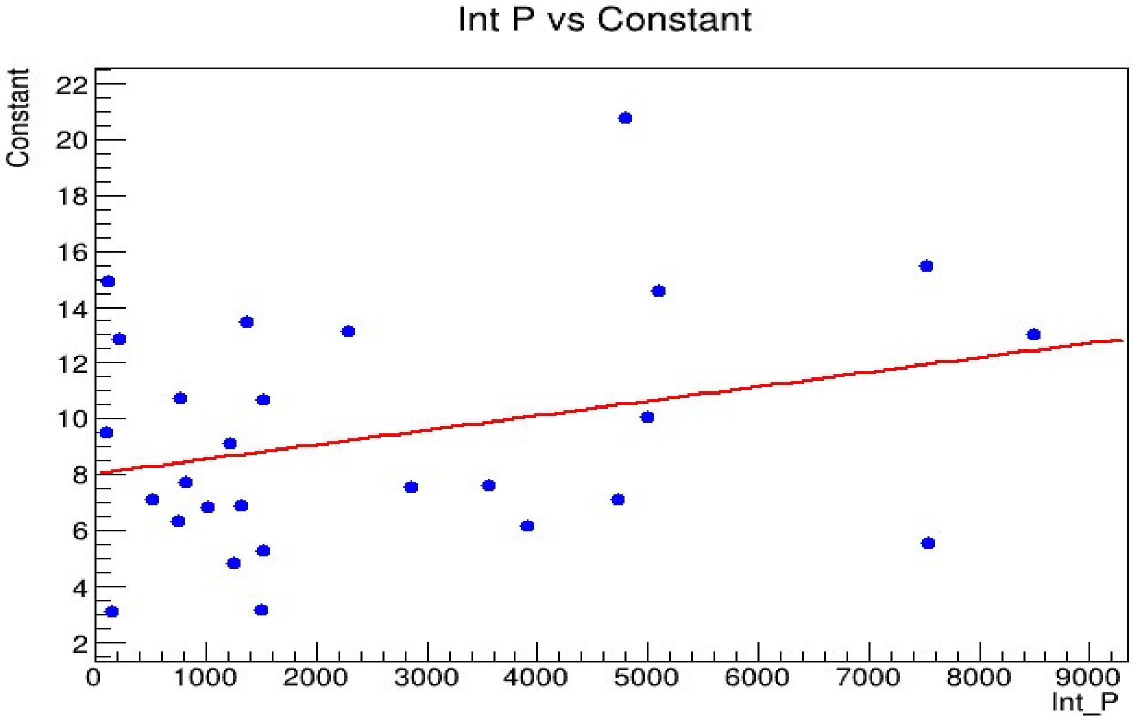


Figure 13: Plot between the integral value of pressure and the constant of gaussian fit.

Total influence of pressure energy with the parameter constant of SSC of Geomagnetic storm shows a direct correlation. As the total pressure energy increases the strength of SSC also increases. Most of the points are lied at the initial position of the graph.

Relationship between integral value of product of pressure and magnetic field and constant of gaussian fit

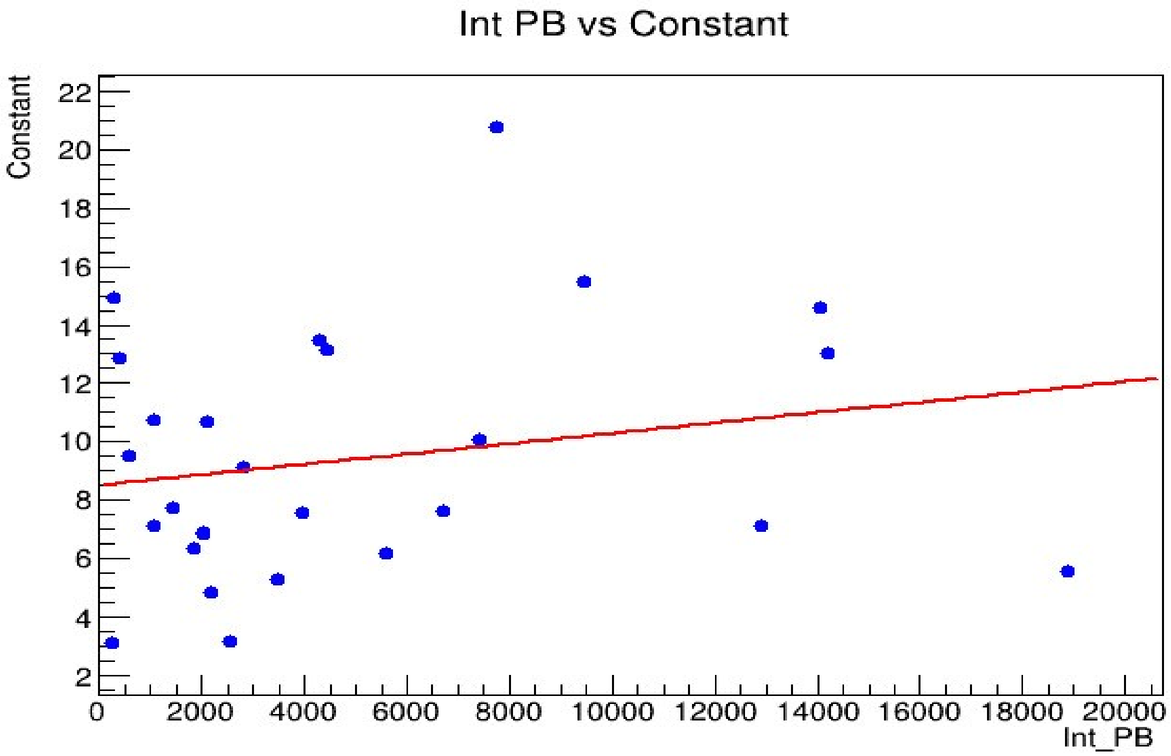


Figure 14: Plot between the Integral value of product of pressure and magnetic field and Constant parameter of Gaussian fit

The combined energy of pressure and magnetic field affects geomagnetic storm. As the energy of solar wind parameters increases, the constant value ie, strength of SSC is also increases.

4.CONCLUSION

The data shows some trends and we analysed it by plotting graphs by taking solar wind parameters along X-axis and DST changes along Y-axis and we obtain a good correlation between certain parameters.

The maximum value of pressure and magnetic field affects the DST. Strength of SSC increases with the maximum values of both pressure and magnetic field.

As higher as the peak value of magnetic field and pressure, quicker will be the events. Width of the gaussian fit is lower at higher pressure values. Initially sigma reaches a higher value at a particular low pressure value and after that it starts decreasing.

The integrated value of the parameters indicates the total influence of the parameters and the integrated value of product of pressure and magnetic field indicates that of combined energy with geomagnetic storm. Here the total dynamic pressure applied on the Earth’s magnetosphere gives a direct correlation with constant of gaussian fit and therefore strength of SSC increases. For a higher value of combined dynamic pressure and energy, the strength of SSC will be higher.

Any other trends are not seen. Using these findings we can understand about some of the parameters that affect Earth’s magnetosphere.

5.BIBLIOGRAPHY

REFERENCES

1. KP Arun babu et al. Astronomy and Astrophysics, Babu, A.V. (2014). Coronal Mass Ejections from the Sun - Propagation and Near-Earth Effects. arXiv: Solar and Stellar Astrophysics
2. https://doi.org/10.3847/1538-4357/abc344
3. https://link.aps.org/doi/10.1103/PhysRevLett.117.171101
4. https://spaceplace.nasa.gov/solar-cycles/en/
5. https://www.coursehero.com/study-guides/astronomy/the-structure and composition-of-the-sun/
6. https://www.britannica.com/science/solar-cycle
7. https://en.wikipedia.org/wiki/Geomagnetic_storm
8. http://cse.ssl.berkeley.edu/exploringmagnetism/space_weather/presentation.html
9. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/solarmagnetic-field
10. https://www.aer.com/science-research/space/space-weather/spaceweather-index/