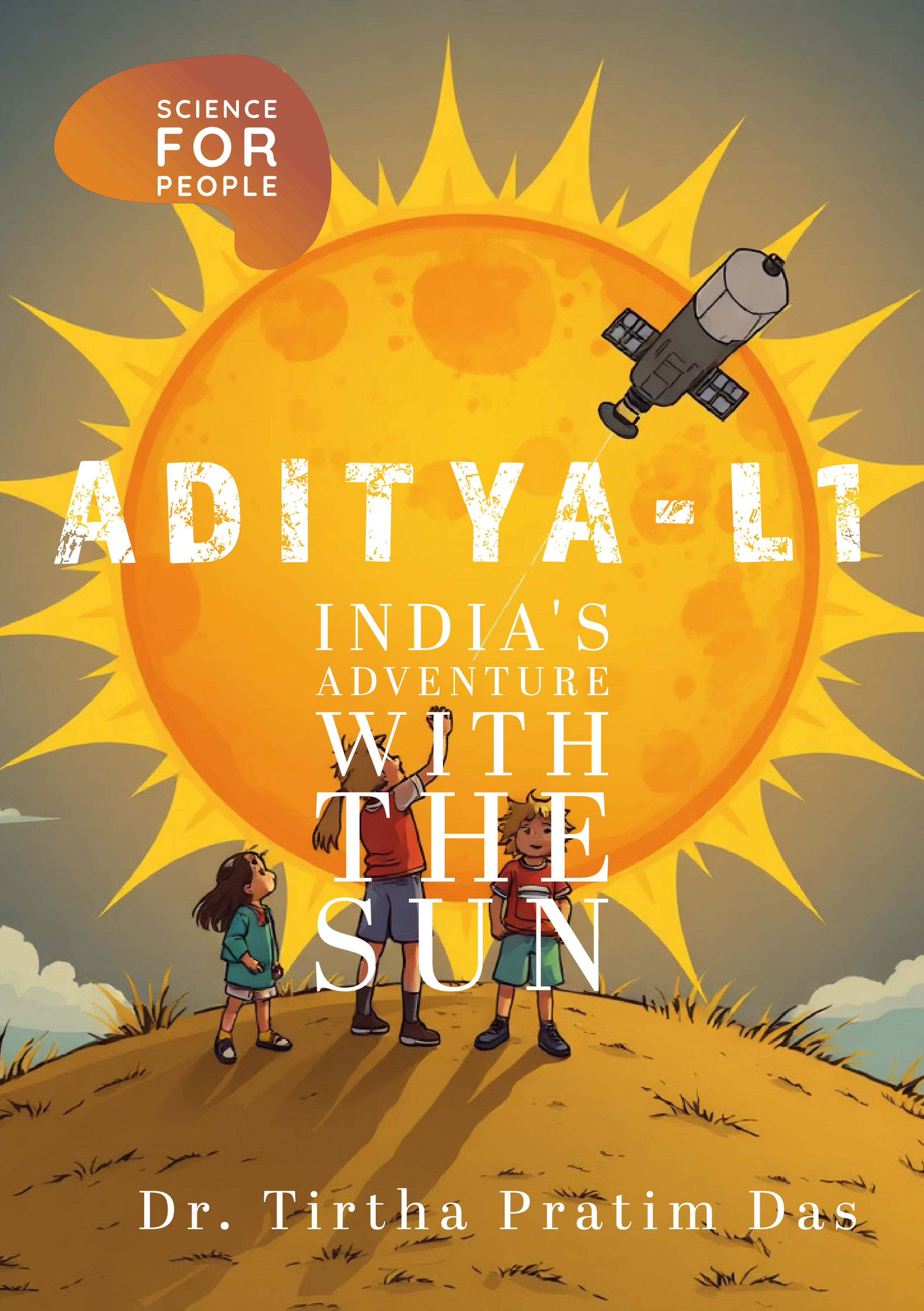

SCIENCE FOR PEOPLE

ADITYA-L1

INDIA'S ADVENTURE WITH THE SUN

Dr. Tirtha Pratim Das

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Edition-1

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Preface

This book is written keeping those enthusiastic people (especially the students) in mind, who will be happy to know about India's Aditya-L1 mission to study the Sun. Aditya-L1 happens to be India's first dedicated space-based solar observatory. People without hard core scientific background often find it difficult to identify easy-to-comprehend study material that would quench their thirst for knowledge. This book is dedicated to them.

India, as we know, has a long legacy of pursuing Astronomy and solar science. During the era of ~505 CE, *Surya Siddhanta* was written in India by Latadeva, who was a student of the great Indian scholar Aryabhatta. The text elaborated on the importance and influence of the Sun on our lives. There have been several ground-based observatories in India that contribute immensely to study the Sun.

Thus, in a country like India, where the legacy of solar science dates back well before the space age, Aditya-L1 takes it forward with a leap-frog progress by conducting continuous solar observation covering practically all the facets of the solar forcing. In this context, Aditya-L1 not only facilitates solar science research, but also provides insight to heliophysics, Sun-Earth connection, and would eventually foster scientific research on space weather. In this book, these concepts will be presented as lucidly as possible.

This book is a sincere attempt to introduce a few basic concepts of physics and solar science, and then to tell about the Aditya-L1 mission, and the scientific insights gained so far.

This book is a work to quench academic thirst, and to convey the scientific achievements of the Aditya-L1 mission. This book does not contain any privileged or confidential information. This book is not meant for any commercial activity; its use should be solely limited to academic and scientific outreach purpose.

I profusely thank Chairman, ISRO / Secretary, DOS for sustained encouragement, as well as the Principle Investigators, Principal Scientist, Project Director of this mission, and the teams for the information provided, that helped creating this book.

How to use this book:

- **If you have only a minute** to know the scientific greatness of this mission, just read the back cover page.
- **If you have three minutes**, read the blue-font text for more details of the scientific outcomes, and look at the pictures as well.
- If you have sufficient time, read the whole book. Initially you may like to skip the footnotes, but reading them will provide more insight.

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Table of Contents

Introduction

Aditya-L1 mission is India's first space mission to study the Sun **[1]**. The spacecraft did not go close to the Sun (forget about touching the Sun), but it was placed at a region between the Sun and the Earth, where their gravitational forces cancel each other. That place is called the first Sun-Earth Lagrange point (hence the term L1 came; L stands for Lagrangian). For Sun and Earth, there are four more Lagrange points (that's why this one is called the *first*), but we will not go to the depth of that discussion[1]. Here, while we venture to know about the Aditya-L1 mission, it is important to note that the first Sun-earth

[1] In space, the dynamics of a two-body system (like the Sun and the Earth) depends on the interplay of gravitational forces and orbital mechanics. As a result, there are five points around the two bodies, called the five Lagrange points, designated as L1, L2, L3, L4 and L5 points. Among these five points, L1, L2, and L3 lie along the line connecting the two bodies, which are gravitationally unstable. L4 and L5 are located at the vertices of equilateral triangles formed with the two bodies, which are gravitationally stable. In the context of the Sun-Earth system, L1, located between the Earth and Sun, offers an uninterrupted view of the Sun, crucial for solar observatories like Aditya-L1. L2, behind Earth, provides a stable, deep-space environment shielded from solar radiation, ideal for telescopes like JWST to observe distant galaxies. L3, opposite Earth from the Sun, is less explored due to its distance. L4 and L5 are gravitationally stable points where asteroids and potentially future space habitats could reside, and are important for studying interplanetary dust and space weather (space weather will be discussed in a following section).

Lagrange point (L1 point in short) is located about 1.5 million kilometers from the Earth, along a hypothetical line joining the centres of the Sun and the Earth, while the total distance between the Sun and the Earth is approximately 149.6 million kilometers. A schematic picture depicting the Sun-Earth Lagrange points and the approximate location of the Aditya-L1 spacecraft are depicted in Figure-1.

So, the L1 point is closer to the Earth, than to the Sun. Around the L1 point, we have considered a peculiar type of an orbit, which resembles more like a twisted rubber band, along which the Aditya-L1 spacecraft is made to revolve around the L1 point, which takes about 178 days.

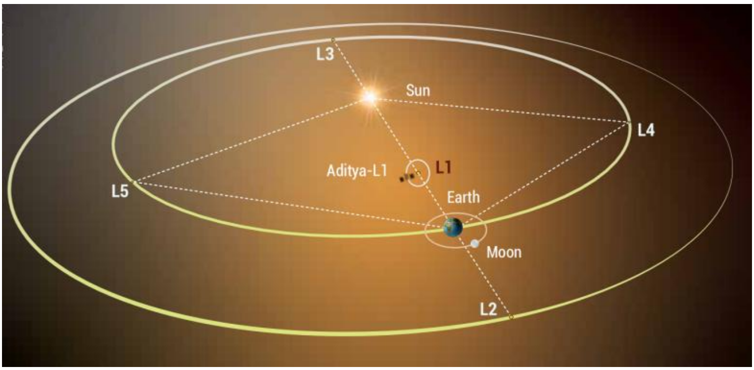

Figure 1: Depiction of the Sun-Earth Lagrange points, and the approximate location of the Aditya-L1 spacecraft. Image courtesy: ISRO

This peculiar, twisted orbit (peculiar because it is twisted, unlike the planar orbit that you must have studied while learning Kepler's laws) is called a halo orbit around the L1 point. Had the Aditya-L1 spacecraft not been made to follow this peculiar-shaped orbit, and asked to simply balance itself between the Sun and the Earth, it would definitely have ended up being pulled by the Sun's or the Earth's gravity. Figure 2 presents the trajectory of the Aditya-L1 and the approximate shape of the halo orbit around the Sun-Earth L1 point, where it stabilised.

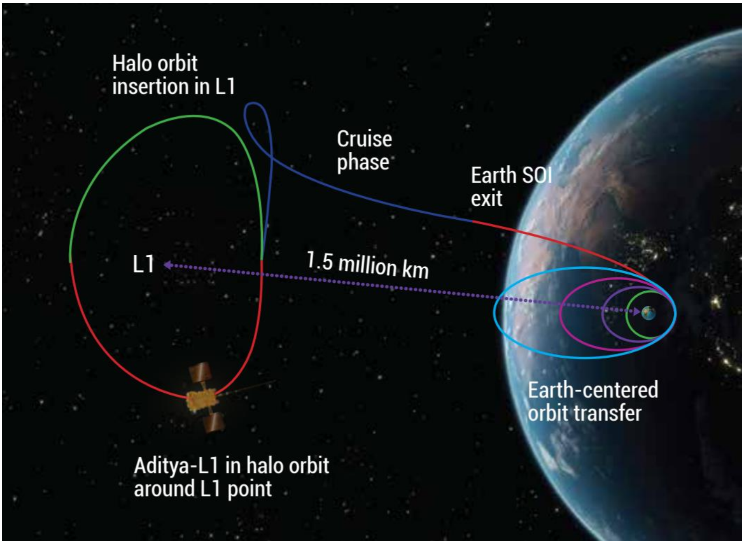

Figure 2: Trajectory of the Aditya-L1spacecraft, as it was inserted to the halo orbit. The picture also depicts the approximate shape of the halo orbit. Note that how it differs from the Keplerian orbit. In the picture, the term SOI represents 'Sphere of Influence' which means the distance of gravitational influence Image courtesy: ISRO

Now, the question is, what is Aditya-L1 doing around the Sun-Earth L1 point? A simple and obvious answer to that is, it is studying the Sun. An obvious question would follow then: why do we need to launch a spacecraft to such a complicated orbit; are the ground observatories studying the Sun not enough? The answer is 'no'. Ground observatories that study the Sun are limited by the intervention of the atmosphere around the Earth, as well as the Earth's magnetic field. Ideally speaking, one needs to study the Sun from a location where there is no atmosphere, no influence of the Earth's magnetic field, as well as continuous (we often call twenty-four by seven) view of the Sun without being blocked by anything else. The Sun-Earth L1 point satisfies all three of these conditions.

The following table provides a few key information about the Aditya-L1 mission.

Launch Date:	September 2, 2023
Launcher:	PSLV-C57
Date of Insertion to L1 point:	January 6, 2024
Broad Scientific Objective:	To study the radiation, particles and magnetic field from the Sun

The States of Matter

In order to appreciate why Aditya-L1 was sent to space for solar observation, it is necessary to understand Sun a bit. In this context, it is also necessary to start from the very basics; the states of matter, which most of us have studied in school. This will help us understand several facts about the Sun, and help introducing the context of the Aditya-L1 mission.

Atoms are considered as the building blocks of matter. A group of atoms constitute molecules. The atoms and molecules in any material feel the forces from the surrounding atoms and molecules. We refer this force as interatomic or intermolecular forces. These forces determine whether a material is a solid, liquid, or gas. These are the three states of matter we notice daily around us.

In solids, the atoms or molecules are packed very tightly together. They have very strong interatomic or intermolecular forces between one another. It is because of these strong nature of the forces between the atoms and molecules, solids have a definite shape and volume. The atoms and molecules in a solid, once supplied with energy, vibrate in their respective places, but do not move around.

On the other hand, in liquids, the atoms or molecules may still be close together, but they have a little more freedom for movement, as their intermolecular forces are weaker than in solids. This feature helps liquids to flow and assume the shape of the container. They have a definite volume, but no definite shape. Upon supply of some energy, the molecules of a liquid may move past one another faster.

Coming to the gases, the atoms or molecules are far apart, and hence, their interatomic / intermolecular forces are very weak, almost non-existent. That’s why they move around very quickly and freely, colliding with one another and the walls of their container. Thus, gases have no definite shape or volume. They spread out to fill whatever space is available.

Apart from these three states, matter also has a fourth state. That state is called ‘plasma’.

In all the previously-discussed states of matter (solid, liquid and gas), we have spoken about how are the abilities of atoms and molecules to move past one another. We have not spoken about disturbing the atoms by the removal of one or more electrons from them, making them ionized. When enough energy is supplied, it is possible to remove one or more electrons from the atoms. As a result, the atoms become positive ions (because of the difference in number between the positive and negative charges due to the removal of electrons), while the electrons removed from the atoms move around freely, no longer bounded to any atom. The material, therefore, can be compared with a ‘soup’ of positive ions and electrons. The overall charge of the whole ‘soup’ is almost zero (ideally zero), but the ions and electrons coexist in the ‘soup’ without neutralizing one another. That ‘soup’ is called ‘plasma’, which is the fourth state of matter.

As plasma comprises charged particles (ions and electrons), they can be disturbed using a magnet; at the same time, the motion of the charged particles creates magnetic fields. If you have studied about electric and magnetic fields, you must have been told that a charged particle, while at rest, gives rise to an electric field; while a charged particle at motion gives rise to a magnetic field. If you also remember an experiment you performed where iron filings used to create beautiful, symmetrical patterns of lines around a piece of magnet, you will also recall the concept of the magnetic field lines. Those beautiful patterns of the iron fillings you saw around the magnet were the traces of the magnetic field lines, which are otherwise invisible to our eyes. Thus, the charged particles comprising the plasma give rise to complicated structures of magnetic field lines.[2]

The Sun as a Ball of Plasma

You can find plasma almost everywhere in nature, although you might not have thought deeper about them. Think of lightning, the sun, and neon signs. They all contain plasma, the fourth state of matter. In fact, plasma is the most common form of matter in the universe. Stars are made of plasma, and our Sun is also a giant ball of plasma.

Anatomy of Sun

Sun, the giant ball of plasma, has a layered structure. The figure 3 presents a view of the anatomy of the

[2] Beyond the well-known solid, liquid, gas, and plasma, there are additional states of matter. One such state is the Bose-Einstein condensate (BEC), formed when specific atoms are cooled to temperatures extremely close to -273.15 °C, where all the motions of a molecule 'almost' get frozen (we call this 'absolute zero' temperature). This extreme cooling causes the atoms to merge, lose their individual properties, and act as a single atom. Additionally, other states, such as Fermionic condensates exist, which represent a state where fermions (like electrons), which normally avoid each other, are coaxed into pairing up and behaving as a unified whole. However, these concepts will not be required for our present discussion.

Sun, as if, the Sun is dissected so that its inner layers are visible.

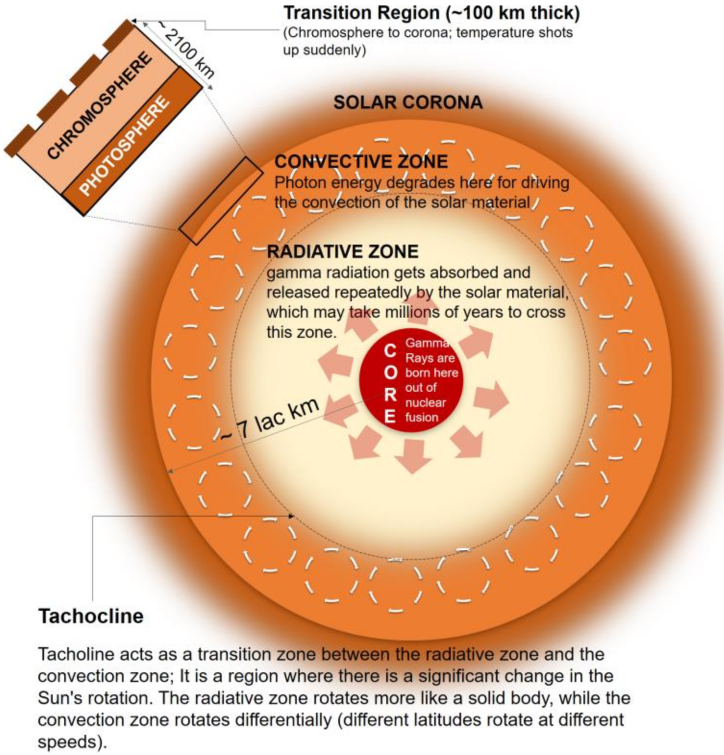

Figure 3: Anatomy of the Sun, depicting its layers. Picture drawn by: Tirtha Pratim Das

The core, its innermost region, is a site of intense heat and density, where nuclear fusion converts Hydrogen into Helium, generating immense energy. This energy travels outward through a layer called the radiative zone, where energy moves outward as radiation. The photons created by the core's fusion reactions, take a very long and indirect path through this zone. They get absorbed and released over and over by the dense material there, making this a very slow way for energy to travel. It can take millions of years for the energy to get through this layer. Above the radiative zone, there is convective zone, where energy is moved by circulation (we call this process ‘convection’) of plasma materials, with hot plasma rising and cooler plasma descending. The photosphere, the Sun's visible surface, releases the majority of the light we see, and has a grainy appearance due to these convection circulation process. The chromosphere, a thinner, hotter layer above the photosphere, is characterized by jets of hot gas. Finally, the corona, which is the Sun's outermost layer, extends far into the space. Corona is extremely hot but of low density, and emits extreme UV rays (Extreme UVs, or EUVs are even more energetic in the range of UV rays), X-rays and the solar wind.

Thus, the core of the Sun, due to the nuclear fusion, is the foster house of the gamma rays (very high energy photons, not visible to human eyes). However, the gamma rays produced in the core do not travel directly to the Sun's surface. They undergo a series of processes. As they move outward through the radiative zone, they are repeatedly absorbed and re-emitted by the dense plasma, thereby losing energy. Thus they gradually transform into lower-energy photons, such as X-rays, ultraviolet light, and eventually, visible light (which we can see). By the time the energy reaches the Sun's surface (photosphere), it is primarily the visible light, which is what we see, although there are lights of higher (UV, X-Rays) and lower (Radio waves) energies.

The following table summarises the anatomy of the Sun. It starts from the Sun’s core in the topmost row, while the subsequent rows tell about the outer layers.

Regions		**Extension (approximate)**	**More information**
Inner Layers (up to 7 lac km from the Sun’s centre)	Core	Till around 140,000 km (1.4 lac km) from the Sun’s centre	Nuclear fusion takes place here. Gamma ray photons are released in this process.
	Radiative zone	From 1.4 lac km to 5 lac km (distances measured from the Sun’s centre)	Energy of the gamma rays moves outward as radiation by getting absorbed and released repeatedly by the dense material there, which may take millions of years to cross this zone. Temperatures decrease with distance outwards, ranging from

Regions		Extension (approximate)	More information
			approximately 7 million deg C at the inner boundary to about 2 million deg C at the outer edge
	Convection zone	From 5 lac km to 7 lac km (distances measured from the Sun's centre)	Temperatures continue to decrease with distance from the core, dropping from about 2 million deg Celsius at the base to approximately 6000 degrees Celsius at the visible surface, the photosphere
Outer layers (start at about 7 lac km from the Sun's centre; leaving aside the corona, this layer has a thickness of only	Photosphere	About 400 km thick above the convection zone	The deepest directly visible layer of the Sun; releases the majority of the visible light; has a grainy appearance due to convection circulation; the temperature varies between about 6000 deg C at the bottom and 3700 deg C at the top.

Regions		Extension (approximate)	More information
about 2100 km)	Chromosphere	About 1700 km thick, above the photosphere	Characterized by jets of hot gas; Temperature in the chromosphere varies between about 3700 deg C at the bottom and 7700 deg C at the top
	Transition Region	About 100 km thick, above the photosphere, which leads to the solar corona	Temperature rises abruptly from about 7700 to about 500,000 deg C
	Corona	Starts above the transition region, extends to the heliosphere (practically no upper limit of its extension)	Also called the 'solar atmosphere'; very thin in density but very high temperature (high energy); temperature may rise to up to a few million deg C

The Sun-Earth Connection

Sun generates complicated magnetic field lines around itself, most of which originate and terminate on the Sun forming loop-like structures called arcades, but some of them open up, releasing gush of charged particles to space, along them. Some of them may even be directed to the Earth.

Without venturing into the details, we may recall that the source of solar energy is the nuclear fusion reaction persistently occurring in the core of the Sun. As a result of the fusion process, tremendous amount of energy is released, which is transported from the core of the Sun to its outer atmosphere (called solar corona). The fusion reaction itself, and its effects on the solar plasma, cause release of charged particles from the Sun to the space. The charged particles emitted by the Sun are mostly (~95%) Hydrogen ions and, to a certain quantity (~ less than 5%) doubly ionized Helium (i.e. two electrons are stripped off from the Helium atom), as well as trace quantities (less than 1 %) of heavier ions. The stripped off electrons are also emitted from the Sun. Thus, around the Sun, there are outward flow of charged particles, which are collectively referred to as the 'solar wind', as if, a wind is blowing out from the Sun. However, the number of solar wind ions in the space near the Earth is only about 5 to 10 per centimeter cube. Despite their small number, they travel at a very fast speed, typically, a few hundreds of kilometers per second. If you assume the speed of the solar wind to be about 400 km/s, it would take about 103.89 hours to reach the Earth from the Sun (the distance between the Earth and Sun is about 149.6 million km). If that does not excite you, let me tell you further that, at that speed you can travel from Bengaluru to Delhi in about 4.35 seconds.

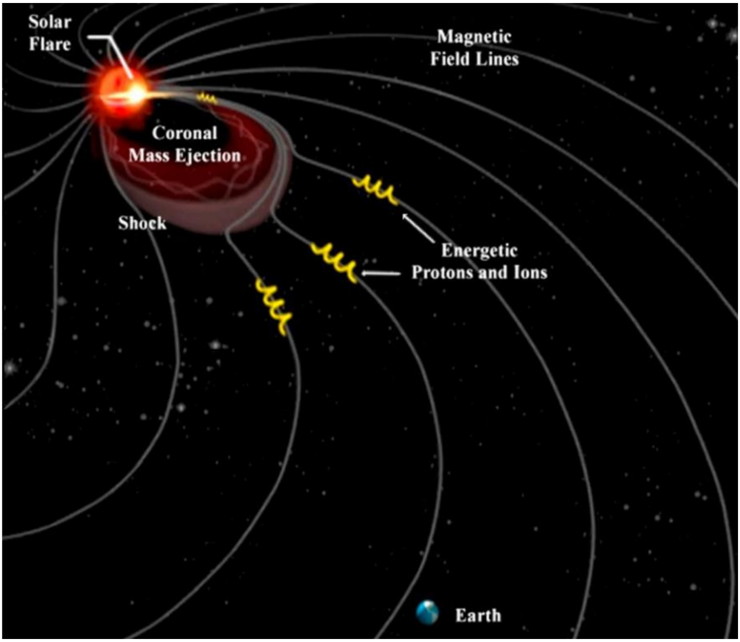

Figure 4: Cartoon depicting solar flare, Coronal Mass Ejection, and the spiral shaped Magnetic Field Lines of the IMF. The charged particles follow along the IMF lines in helical paths, as shown in yellow colour. Image courtesy: Nunez et al, 2016

Figure 4 depicts a cartoon style picture (we call these types of pictures ‘schematic pictures’) of the Sun and how it influences the Earth. In the image, the artist has shown solar flares, CMEs, the spiral shaped magnetic field lines of the IMF (these are called ‘Parker Spirals’) and the trajectory of the charged particles. We will soon discuss the concept of IMF, which is the magnetic field lines emitted from the Sun, associated with the motion of the charged particles along them. Aditya-L1 has two magnetic field measurement instruments, called magnetometer, to measure the IMF at the first Sun-Earth L1 point.

In contrast to the steady stream of lower-energy charged particles in the solar wind, Solar Energetic Particles (SEPs) are highly energetic charged particles (such as protons and ions), propelled to nearly the speed of light by solar flares and coronal mass ejections (CMEs). Unlike the consistent solar wind, SEPs arrive in sudden bursts, creating a serious radiation threat to spacecraft, astronauts, and potentially even affecting Earth's upper atmosphere. These fast-moving particles can damage electronics and cause radiation storms, making the study and prediction of SEP events vital for space weather forecasting and protecting technology in space. Aditya-L1 is equipped with particle measurement devices as well.

UV light's effects on Earth

Let me tell you, the UV light from the Sun has a lot to do with the chemistry of the Earth's upper atmosphere. It has some more effects on the Earth. Before venturing into the science questions addressed by Aditya-L1, it is important to look into this aspect.

The subject Chemistry sheds light on how substances interact and change. When the reactants participate in a chemical reaction, their atoms are rearranged, leading to the creation of completely new substances with distinct properties. Often, energy is required to start or speed up this transformation. In chemical reactions, the Ultra Violet (UV) light can serve as a catalyst (a catalyst is an agent that affects the speed of a chemical reaction), supplying the energy needed for the chemical reaction to take place. UV light works as a good catalyst in several chemical reactions, which can break the chemical bonds within the reactant molecules, increasing their reactivity and allowing them to form new products. This is especially significant in several of the chemical reactions that take place in the atmosphere of any planet. In the case of the Earth's atmosphere, UV radiation from the Sun helps the chemical reactions that generate and deplete (destroy) ozone, thereby affecting the makeup and protective functions of Earth's atmosphere. The process of a chemical reaction being affected by photons (in our present discussion, the UV light) is referred to as 'photochemistry'.

Solar UV radiation, specifically wavelengths between 200 and 400 nanometers, is a key factor in determining the chemical makeup of Earth's higher atmospheric layers. This type of radiation possesses enough energy to disrupt molecular bonds, triggering photochemical reactions that control the creation and destruction of various atmospheric components. A substantial portion of this UV energy is absorbed by the ozone layer within the stratosphere. This absorption drives the breakdown of oxygen molecules (O_2) and the subsequent formation of ozone (O_3). This ongoing cycle is essential for protecting Earth's surface from damaging UV radiation.

Beyond the ozone layer, this UV radiation also impacts the levels of other atmospheric substances. For instance, nitrogen oxides, which contribute to ozone depletion and other chemical processes, are affected by UV-induced reactions. The specific interactions of UV-C (100-280 nm), UV-B (280-315 nm), and UV-A (315-400 nm) radiation, all within the 200-400 nm range, contribute to the intricate dynamics and chemical processes of Earth's atmosphere. Comprehending these interactions is critical for understanding how solar radiation influences our planet's protective layers and for tracking and forecasting changes in atmospheric composition.

Thus, solar UV light has a notable influence on Earth's weather and climate. Additionally, UV light contributes to the creation of certain tiny particles that can help form clouds, influencing rainfall patterns. Even though the direct warming effect on the lower atmosphere is less than that of visible and infrared light, the UV range is vital in the complex interaction of atmospheric processes that ultimately determine Earth's weather and climate.

So, if you wish to study these major aspects of the Earth’s atmosphere and their effects on the weather and the climate, you need to study, apart from other aspects of the Sun-Earth system, the strength of fluctuations of the UV light from the Sun as well.

That is all what the Sun’s UV light causes to the Earth. For scientific studies of these aspects, one needs to trace back the UV radiation (200-400 nanometer range) to the Sun. While doing so, a few very interesting aspects of the Sun emerge.

UV light as a tool to study the Sun

The Sun's ultraviolet (UV) light, particularly within the 200-400 nanometer range, is essential for examining various features of the Sun, providing valueable information on the photosphere, chromosphere, filaments, sunspots, plages, and limb darkening. The photosphere, which is the Sun's visible surface, emits UV radiation that reveals its temperature and elemental constitution. Analyzing specific UV wavelengths allows researchers to identify specific elements and their ionization states. The chromosphere, which is the hotter layer above the photosphere, strongly emits UV light. UV observations are critical for mapping its structure and dynamics, showcasing features like spicules.

Filaments, dark, thread-like features seen on the solar disk, are cooler, denser plasma regions in the chromosphere. Observing the Sun in UV helps to ‘see’ their structure and evolution, as they absorb and re-emit UV radiation. Sunspots, the dark patches often seen on the Sun, which are basically the relatively cooler photospheric regions, emit UV radiation despite appearing dark in visible light. This radiation provides information on the temperature and the strength of the magnetic field. Plages, which are the bright chromospheric regions linked to the sunspots, show increased UV emission, indicating enhanced magnetic activity and heating. These regions are most clearly seen in the UV spectrum. Limb darkening, the Sun's dimming at its edges, is also observed in UV wavelengths. Analyzing the extent of limb darkening at different UV wavelengths allows scientists to calculate the Sun's atmospheric temperature and understand how the solar material gets sparser (thinner) with the distance from the Sun. Therefore, UV radiation in this range is crucial for comprehending the complex processes in the Sun, which also affect the Earth’s atmosphere, as discussed earlier.

Figure 5 shows the Sun photographed at UV wavelength of 280 nm, with the SUIT instrument flown in the Aditya-L1 mission. At that wavelength, it reveals many features of Sun’s Chromosphere, Sunspots, Plages, Quiet Sun features, as well as filaments. The Sun's visible surface reveals a variety of features caused by its magnetic activity. Sunspots, dark and cooler areas, are formed by strong magnetic fields that block heat. Brighter regions, called plages, often appear near sunspots, showing localized heating in the Sun's atmosphere. When the Sun is less active, the "quiet Sun" looks relatively even, as you can see the marked region in the figure. Dark, thread-like filaments are seen on the Sun's surface and are actually cooler plasma held up by magnetic fields. When viewed at the edge of the Sun against space, these filaments appear bright and are called prominences. These features all demonstrate the Sun's intricate magnetic behaviour.

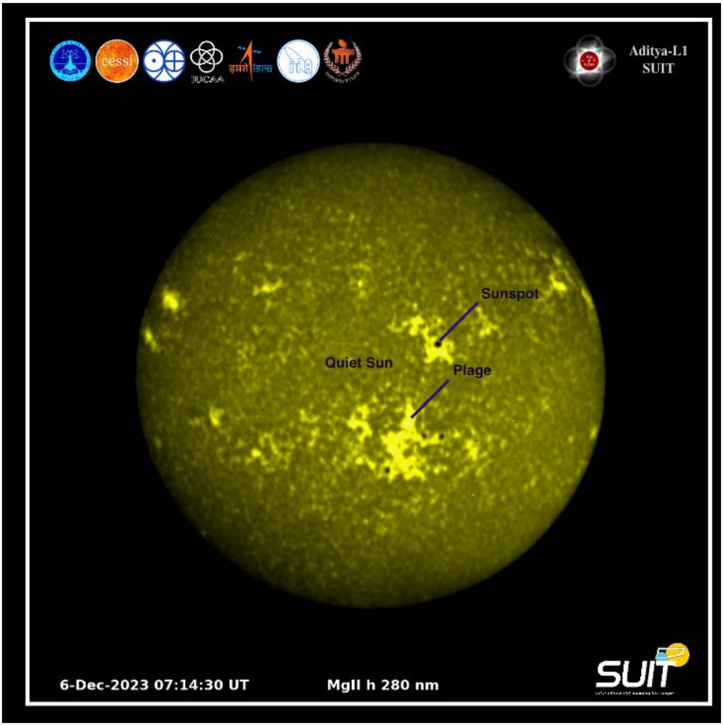

Figure 5: The Solar plasma ball, when photographed using its UltraViolet (UV) light (at 280 nm wavelength to be specific), looks like this, depicting different features of the Sun. Image courtesy: SUIT team, IUCAA

The Interplanetary Magnetic Field (IMF)

As moving charged particles carry a magnetic field along them, the solar wind ions also carry magnetic field, which is called the Interplanetary Magnetic Field (IMF). These are called 'interplanetary', because, as the solar wind ions travel long distances crossing the planets, the magnetic field lines also move along with them. However, as the IMF travels further away from the Sun, its strength (called 'intensity of the magnetic field') decreases. Do you know, how much strong is the IMF close to the Earth? It may vary between approximately 1 nano Tesla (abbreviated as nT ; nano means 10^{-9} , and Tesla is a unit of the magnetic field strength) to 30 nano Tesla, while 5 nano Tesla may be a good representative average. You may compare this value with that of the Earth's magnetic field near its surface, which is often approximated as 40,000 nT (although the Earth's magnetic field may vary from place to place, and with time; a range of ~ 25,000 nT to 70,000 nT is a good representative of the Earth's magnetic field). While around 40,000 nT is the value of the Earth's magnetic field near the Earth's surface, it is weakened at higher altitudes, as well as towards the polar regions. At higher altitudes (about to 10 times the Earth's radius; Earth's equatorial radius is ~ 6378 km), where the Earth's magnetic field is weak and comparable with the IMF near the Earth, often there is a 'hand-wrestling' between these two. As a result, the boundary of the Earth's magnetic field experiences fluctuations in the day-side. In the night side, the shape of the Earth's magnetic field is elongated; this is due to the lesser influence of the IMF in the night side. Now, you can compare both these numbers (i.e. IMF near the Earth, which is ~ 6 nT, and the Earth's magnetic field at the surface, which is ~ 40,000 nT) with that of a fridge magnet. A typical fridge magnet has a strength of approximately 10,000,000 nT. Thus, a typical fridge magnet is about a few hundred times stronger than the Earth's magnetic field (at its surface), and about ten lacs times stronger than the IMF near the Earth.

Here, remember that the solar wind and the IMF are not two independent entities, but quite interdependent. As you cannot separate a perfume from its fragrance, or a flame from its light, you cannot isolate the solar wind particles from the IMF. That's why we use the term 'associated with' when we refer to the solar wind particles and the IMF.

Apart from the solar wind ions and the IMF associated, Sun also emits light. We all are familiar with the importance of sunlight in our daily life. All the forms of life owe their energy to the sunlight. Sunlight allows us to see the world. However, as you are aware, there are light-waves that our eyes cannot sense. If you consider light as a wave, human eyes can typically sense light waves with wavelengths ranging approximately between 380 nm (violet) to 700 nm (red) [nm means nano meter]. Beyond this range, on the shorter wavelength side, there are Ultra Violet (UV) light, X-Rays, Gamma rays, which are invisible to the human eyes. On the longer wavelength side, we have Infra Red (IR) light and Radio waves, which we cannot see either. Sun emits light covering all these wavelengths. Thanks to the temperature of the Sun, which ensures that the Sun emits most of its light in the range of wavelength that our eyes can see. Otherwise, our eyes would have adapted for either different range of wavelengths, or for darker conditions.

Needless to say, apart from the Solar Wind, IMF and Sunlight (we will, now onwards, start calling sunlight as solar radiation, as radiation is a more general term), Sun's gravity also influences us. In his discussion, we need not delve into that topic. For a detailed tutorial on this topic, watch this video **[2]**.

So, next time when someone asks you about how Sun influences the Earth, don't forget to mention all the four of them, i.e. (i) gravitation, (ii) solar radiation, (iii) solar wind, and (iv) interplanetary magnetic field.

How Important Are These Effects on Earth?

If you ask me to arrange these four influences from the Sun in a descending order, I (as somebody residing on the surface of the Earth) will still follow the above-mentioned sequence, i.e. (i) gravitation, (ii) solar radiation, (iii) solar wind, and (iv) interplanetary magnetic field. Let me explain, why.

Sun's gravitational effects on Earth cause the year; also to a certain extent the dynamics of the fluids on Earth, to name a few. It is felt by us regardless of whether it is day or night. The solar radiation, on the other hand, directly and prominently affects the day-side of the Earth, although there are a few indirect effects on the night side. This is because the solar radiation does not reach the night side of the Earth. However, both the day and night sides of the Earth's surface remain fundamentally unaffected by the solar wind (thanks to the Earth's magnetic field) except for the polar regions (higher latitudes around 60 degree, to polewards). Lastly, the IMF is too feeble to be felt on the surface of the Earth, as the Earth's own magnetic field is several times stronger than the IMF at the Earth's surface.

Space Weather and Its Impact

However, in space, say, a few hundreds or thousands of kilometres above the Earth's surface, the situation is different. At those altitudes, the Earth's magnetic field has lesser strength as compared to the Earth's surface; hence, the solar wind particles can reach those regions. Associated with the solar wind particles, the IMF also penetrates those regions. These effects are more prominent at still higher latitudes, where the Earth's magnetic field may become too feeble to retain its importance as compared with the IMF.

This means that sitting at the surface of the Earth we remain more protected from the emissions from the Sun. Thanks to the collective effects of the Earth's atmosphere (which helps absorbing a few types of solar radiation that would have been harmful to the life forms) and the magnetosphere (which deflects the solar wind particles), that the Earth is capable of sustaining life. The moment you come out of the Earth's protective shield (atmosphere and magnetosphere) you are exposed to the harsh effects of the solar radiation and the solar wind. We say that we are exposed to what is called the ‘space weather'.

The term ‘space weather’ should not be confused with ‘weather’, as we are familiar with weather reports based on atmospheric pressure, temperature, wind, humidity, etc.. Earth's atmospheric weather and "space weather" are both about changes in their surroundings, but they're caused by different factors and have different kinds of effects. Space weather is driven by the Sun, and it disturbs the Earth's magnetic field. So, while atmospheric weather affects our daily lives, space weather mainly affects our technology, like satellites and power grids.

Space weather, to have a detailed understanding, is not only about the exposure to the solar radiation and solar wind (and the IMF associated), but also the wrath of something called solar flare and Coronal Mass Ejection (CME). Solar flares may be intuitively understood as sudden emissions of very bright, high energy radiation (often at X-ray wavelengths). You may call them ‘glaring’ of the Sun. This is not apparent to the bare eyes (not that you are supposed to stare at the Sun); you need certain types of instruments that are sensitive to high energy radiation. The CMEs may be looked upon as though chunks of solar pieces are erupted out of the bulk solar sphere. You may compare with the volcanic eruption of magmatic materials from the Earth's interior. As the Sun is a plasma ball, and plasma motion is, in general unstable, there is always a tendency of the plasma fluid to break free even the gravitational pull that holds them together. That is why although the Sun remains a sphere due to its self-gravity, chunks of plasma material may occasionally erupt from the Sun's surface. Those chunks of CME contain huge mass of particles (ions of Hydrogen, Helium and heavier ions, along with electrons). That's why is is called ‘Mass Ejection’. The adjective ‘Coronal’ is prefixed to indicate that this mass ejection takes place following the line of the solar corona, which is also known as the solar atmosphere. A typical CME may release billions of tons (one ton is one thousand kilogram) of solar material to space. If those are directed towards the Earth, there are possibilities of the Earth's magnetosphere and upper atmosphere getting severely affected. We call these effects ‘Space Weather Impacts’.

When powerful solar events, like CMEs and solar flares, send out a surge of solar wind, it can collide with Earth's magnetic shield, the magnetosphere. This collision disrupts the Earth's magnetic field, creating what we call a geomagnetic storm, which is a space weather impact. Essentially, a geomagnetic storm is named a "storm" because it mirrors the disruptive nature of regular weather storms. Both involve a sudden burst of energy that throws a normally stable system into chaos. Weather storms disrupt the atmosphere with wind and rain, while geomagnetic storms disrupt Earth's magnetic field with solar energy. Just like we talk about the intensity of a weather storm, we measure the strength of a geomagnetic storm. Both types of storms have a period of intense activity and then a return to normal.

Scientists gauge the strength of the geomagnetic storms using two main tools: the Kp-index and the Dst-index. The Kp-index, a scale from 0 to 9, reflects the level of disturbance in the horizontal component of the Earth's magnetic field (remember that magnetic field is a vector quantity and is resolved into three perpendicular components; here we are referring to the component that is horizontal to the Earth), based on readings from ground-based magnetometers (instruments that measure magnetic fields), with higher numbers implying more intense storms. The Dst-index, on the other hand, gives a broader picture of the storm's impact by tracking changes in the horizontal magnetic field near the equator; lower (more negative) Dst values correspond to stronger storms. These indices are crucial for understanding and predicting how geomagnetic storms might affect our technological infrastructure, including power grids, satellites, and communication networks.

Coming to Solar flares, as mentioned, they are powerful bursts of energy from the Sun, and are classified based on their X-ray intensity, measured by satellites orbiting Earth. The classification system uses letters and numbers, as summarised below:

- **A-class:** These are the weakest flares, producing barely detectable X-ray emissions.
- **B-class:** Slightly stronger than A-class, but still relatively minor.

- **C-class:** These are small flares with some noticeable effects, but generally pose little risk to Earth.
- **M-class:** Medium-sized flares that can cause minor to moderate radio blackouts and geomagnetic storms.
- **X-class:** The most powerful flares, capable of causing major radio blackouts, strong geomagnetic storms, and significant disruptions to satellites and power grids. Within each letter class, a numerical scale from 1 to 9 (or higher for X-class) further refines the intensity, with higher numbers indicating stronger flares (e.g., X9 is more intense than X1).

The artificial satellites are vulnerable to space weather impacts. A vagary in the solar eruption may cause damages to the satellites, which may eventually affect the satellite-based communication, navigation and Earth Observation infrastructure. At the higher latitudes, the space weather impacts may even affect the ground-based electrical infrastructure like power grids, telegraph lines, etc.

To understand the space weather and its impacts on Earth, we need to have a thorough understanding of the Sun-Earth connection.

Understanding the Sun-Earth Connection and Context of Aditya-L1

Understanding the Sun-Earth connection, or, in other words, the effects of solar disturbances on the Earth, requires the knowledge of the following three aspects.

First, it is important to know about the science of the Sun. It involves the understanding of the energy generation process within the Sun, transport of the energy from the Sun's core to its outer layers, movement of the plasma inside as well as at the surface of the Sun, instability of the solar plasma fluid, to name a few. Study of the Sun is referred to as 'Solar physics'. The Aditya-L1 mission, which is the matter of discussion here, is a Solar Physics mission. It is aimed at studying the solar disturbances.

Second, it is important to know how the solar disturbances (CMEs, solar flares, solar wind particles and the IMF associated) propagate in space. As these disturbances propagate in space, their effects become weaker with increasing distance from the Sun. The effects of these disturbances become negligible at a distance of about 125 AU (AU is called the Astronomical Unit; the Sun-Earth distance is 1 AU). If you imagine a sphere with this radius, centred around the Sun, it is called the heliosphere. Thus, heliosphere is the region where the solar effects are predominant. Beyond the heliosphere, the effects of the solar disturbances become almost non-existent. The imaginary boundary that represents the edge of the heliosphere is called the heliopause. Within the heliosphere, the propagation of the solar wind, IMF, CMEs, solar flares are not obstructed; they are often obstructed by the presence of the other members of the solar system, which include the planets, dwarf planets, natural satellites, asteroids, comets, etc.. Depending on the characteristics (presence of atmosphere, magnetic field, size, etc.) of these obstacles, the nature of interaction of the solar disturbances with them varies. The physics of the propagation of the solar disturbances in the heliosphere and their interactions with the other members of the solar system is referred to as 'Heliophysics'. The effects of these solar disturbances on the diverse members of the solar system collectively fall under the topic 'planetary space weather'.

In the context of the space weather around the Earth, the **third aspect** to understand the Sun-Earth connection is the physics and chemistry of the interaction of the solar disturbances with the Earth's upper atmosphere, ionosphgere and the magnetosphere. In general, the branch of study that addresses the Physics and Chemistry of the Earth's upper atmosphere (it includes the study of the ionosphere, thermosphere as well as the magnetosphere, to a certain extent) is called 'Aeronomy'. ISRO is presently preparing for an aeronomy mission called DISHA. Ideally, a solar physics mission and an aeronomy mission, when operated simultaneously, would provide an effective way to understand the solar disturbances and its effects on Earth.

For a detailed discussion on the Sun-Earth connection, listen to the video **[3]**.

Scientific Instruments (payloads) in Aditya-L1 Mission

Aditya-L1 carries seven scientific instruments (also called scientific payloads), each designed to observe a different aspect of the Sun. Following is a brief description of the payloads in Aditya-L1.

- **VELC:** This acts like a telescope that lets us see the Sun's faint outer layer, the corona, by blocking the bright solar disc with a circular blocker disc (like the way we can see the solar corona during a total solar eclipse). It helps us study solar eruptions.
- **SUIT:** This is like a UV camera, taking pictures of the whole Sun in ultraviolet light to understand some of its layers.
- **SoLEXS and HEL1OS:** These are like X-ray cameras, measuring X-rays from the Sun to study powerful events like solar flares.
- **ASPEX and PAPA:** These are particle detectors, measuring the stream of particles coming from the Sun, called the solar wind.
- **Magnetometers:** These are like magnetic field detectors, measuring the IMF to measure the Sun's magnetic at the Sun-Earth L1 point. There are two such magnetometers mounted on a stick-like structure (called a ‘boom’) at two different distances from the spacecraft.

These instruments work together to give us a comprehensive picture of the Sun and its eruptions, which, in turn, help understanding the space weather. Out of these, the VELC, SUIT, SoLEXS and HEl1OS fall under the category of 'remote sensing' instruments, as they remotely study the radiation from the Sun (at different wavelengths). On the other hand, the ASPEX, PAPA and Magnetometer payloads fall under the category of 'in-situ' instruments, which means, they are in direct contact with the subject of their measurement. Figure 6 depicts the mounting locations of these scientific payloads on the Aditya-L1 spacecraft, with the boom in stowed configuration.

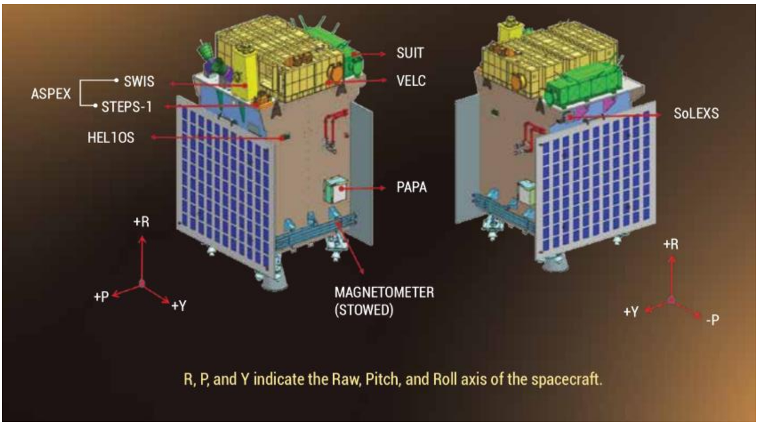

Figure 6: Locations of the scientici payloads on Aditya-L1 spacerfat. The two magnetometers are not visible in the picture, as the boom is shown in the stowed (folded) configuration. Image courtesy: ISRO

Figure 7 depicts the Aditya-L1 with its boom (stick-like structure) in deployed (unfolded) condition, and showing the mounting locations of the two magnetometers. The boom is six meters long, with one of the magnetometers mounted at its tip, and the other one at the middle of the boom. Two magnetometers are necessary in order to decipher the IMF measurement from the background magnetic field generated by the Aditya-L1 spacecraft itself.

Out of these instruments, the SUIT and VELC instruments were developed by IUCAA (Inter University Centre for Astronomy and Astrophysics, located at Pune, within the campus of the Lune University) and IIA (Indian Institute of Astrophysics, Bengaluru) respectively, with support from several ISRO centres. The SoLEXS and HEL1OS instruments were developed by the U R Rao Satellite Centre (URSC), ISRO. The ASPEX and PAPA instruments were developed respectively at PRL (Physical Research Laboratory, at Ahmedabad) and SPL (Space Physics Laboratory, a unit under the Vikram Sarabhai Space Centre of ISRO, at Thiruvananthapuram). Lastly, the magnetometers were developed at LEOS (Laboratory for Electro Optic Systems, at Bengaluru).

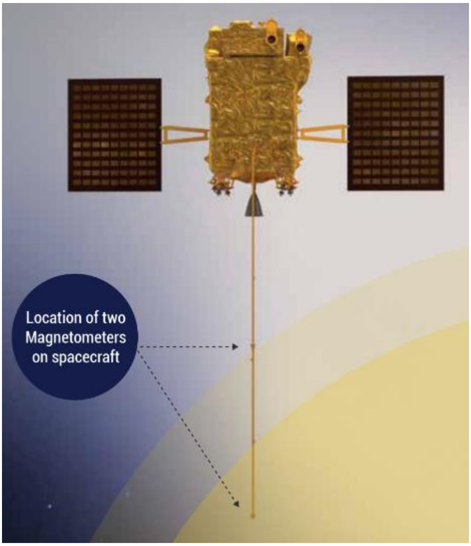

Figure 7: Aditya-L1 with its boom deployed. The locations of the two magnetospheres are shown. Image courtesy: ISRO

Availability of the Aditya-L1 Data

The information gathered by Aditya-L1 includes important scientific details about the Sun's surface, its middle layer, and its outer atmosphere, as well as measurements of particles and magnetic fields at the L1 point. This data is available to everyone through the Indian Space Science Data Centre (ISSDC) website. You can find it by going to the website (https://pradan1.issdc.gov.in/al1). ISRO hopes that scientists, researchers, and students will use this data. Guides on how to analyze the Aditya-L1 data are also provided on the website after you register.

Importance of the Aditya-L1 Data

By January 2025, the Aditya-L1 spacecraft has completed two orbits around the Sun-Earth L1 point. It continues to rotate at the rate of approximately 178 days per orbit.

Aditya-L1, at present, is not the only solar observatory at the first Sun-Earth Lagrange point. There are NASA and ESA observatories named SOHO, WIND and ACE. They all study the solar disturbances.

Even though other solar observatories like SOHO, WIND, and ACE exist at the Sun-Earth L1 point, Aditya-L1 brings unique capabilities. Unlike the others, it focuses on the Sun's inner corona and the dynamics of its atmosphere. It is currently the only space-based solar observatory providing full-disk imaging-spectroscopy in UV light, and it also studies X-rays. While it complements the other observatories in measuring things like photons and solar wind, its unique instruments provide data highly valuable to solar physicists. ISRO released its first data on January 6, 2025, which saw immediate and significant downloads.

Aditya-L1 is observing the Sun during its active period, the solar maximum. One highlight is the Visible Emission Line Coronagraph (VELC) observation of a Coronal Mass Ejection (CME) on July 16, 2024, linked to a strong solar flare. VELC tracked the movement of solar material using a specific green light emission, revealing a temporary dimming of the corona, turbulence with increased temperature, and magnetic field activity that deflected the CME. This detailed observation of a CME's dynamics was published in a scientific paper. Additionally, Aditya-L1 recorded other solar events in May 2024, with summaries available on ISRO's website. With the data now accessible to the global scientific community, it's anticipated that many more discoveries about the Sun will emerge.

Scientific Outcomes from Aditya-L1

Science from VELC

Many of us choose to leave our family behind and start a new journey altogether for higher education, profession, and create enormous impacts on the society and nation. Those impacts we create are well-noticed and discussed. Did anyone ask, exactly how did our family members feel at the very moment when we left our home? Nobody might have cared to ask that question to those who bade you goodbye. Had somebody asked, the stories of gloom, restlessness, and eventual process of normalisation of the family would have surfaced. But, nobody does.

Aditya-L1 asked this question to the Sun, “How does it feel to sacrifice a portion of yourself, however small, to space, and allow it to wander in oblivion?” The Sun cared to answer. That made Aditya-L1 unique.

The Sun’s corona, which is also known as the solar atmosphere, has a very high temperature, which may reach even a few million degree Centigrade. The temperature is so high, that it can remove multiple electrons even from the heavy elements present in the Sun. At this incredible temperature, these heavily ionized elements emit light (by energy state transition), which is studied by the scientists to understand what is happening in the Sun's corona. Such a light comes from the Sun's corona, which is due to a heavily ionized state of iron (Fe). That light has a wavelength of 5303 Angstrom (1 Angstrom is 0.0000000001 meter). Such a wave appears green in colour to the human eyes, and thus, is referred to as the 'green line' of the Sun's corona. The Aditya-L1 has the VELC instrument onboard, which is capable of studying the Sun's corona by observing that particular light.

Scientists, by studying this light from the Sun's corona, have witnessed the dramatic phenomenon at the edge of the Sun, all for the first time, wherefrom a chunk of the solar material was dislodged and flung away from the Sun as a Coronal Mass Ejection. As the chunk of the solar material was disengaging itself from the bulk of the Sun, the specific region of the Sun's corona became dim (less bright). In fact, the brightness of the Sun's corona at that region reduced by fifty percent. It remained dim for about six hours, before the brightness became normal again. You need to remember that this phenomenon was noticed at a specific region of the Sun, and not uniformly on the entire solar disc. Refer the figure 8 for this description.

It was also noticed that as the chunk was about to bid goodbye to the Sun, the plasma material that made up that region of the Sun became unusually restless, exhibiting a state of enhanced chaos. We call this phenomenon ‘turbulence of plasma’. It is, as if, the solar material at that particular location became so sad to bid goodbye to their kin that they not only lost their brightness for some time, but also displayed restlessness. Scientists gathered evidences for their restlessness by studying the energy of the light emitted from those regions.

Finally, as the solar material (we may call them the ‘Coronal Mass’) freed itself from the Sun, scientists found that it flung away in a direction away from the Aditya-L1 spacecraft. Had it been directed towards the Aditya-L1 spacecraft, the Earth would have to face an effect of its energy, which would have manifested in its upper atmosphere.

Next time, when you come to know that any Coronal Mass has been ejected from the Sun, some of you may remember this discussion about how do the rest of the plasma feel about the departure of their family member; they become dim in sorrow, become restless, and finally, the coronal mass travels away from the Sun. And, all of these have been revealed by

India’s Aditya-L1 mission. A note on this discovery was published in the ISRO website **[6]**.

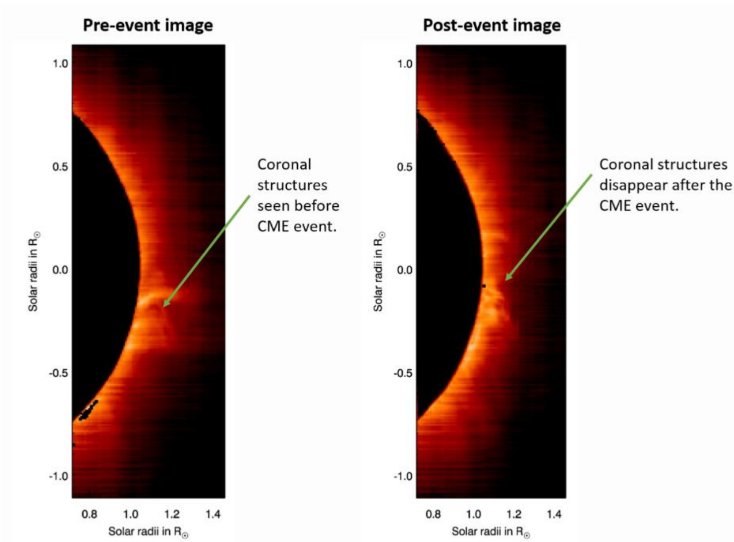

Figure 8: Images of the west limb of the Sun (where the CME occurred) that were captured with VELC, before and after the CME. It is seen that the coronal structures in the pre-event image have disappeared in the post-event image. Image courtesy: VELC team, IIA

You will remember forever that Aditya-L1 cared to ask the Sun, “how does it feel to sacrifice a part of yours”, and the Sun cared to answer. Why don’t you sing this song along:

Where plasma danced, in sunlit grace,
A sudden void, silence, emptiness.
A plasma departs, breaking away,

from the Sun, causing a restless sway,
Those who remained, dimmed in gloom,
A few long hours before they resume
The fiery dance around the ball,
Aditya-L1 witnessed them all.

> **"While everyone talks about how solar storms affect the Earth, India's Aditya-L1 spacecraft actually looked directly at the Sun where these storms start. It is revealed that when a big chunk of the Sun's atmosphere (a coronal mass ejection) blasts off, the area it came from on the Sun gets noticeably darker, and the surrounding material becomes very disturbed for a few hours."**

Science from SUIT

Did you ever think that the conditions of life (and also our happiness, mood, health) might have their clues hidden at the deep layers of the Sun? This is true because everything that happens require energy, and the prime source of energy for us is the Sun. It matters how the energy travels from the Sun's core, reaches at the top of the Sun's surface through several layers, before propagating to the space, and reaching (a part of it) to the Earth.

Sun's Ultra Violet (UV) light (especially in the wavelength range of 200-400 nm) is an important part of the energy emitted by the Sun. It works as a catalyst for chemical reactions in Earth’s upper atmosphere, and certain indirect effects on Earth’s weather and climate. Looking back at the Sun to see where this UV light originates helps us understand how the Sun's energy travels and affects Earth. For example, UV light from the Sun's surface (photosphere) tells us about its temperature and what elements are there. UV light from the layer above (chromosphere) lets us map its structure, including jets of hot gas. Studying cooler, darker areas (filaments and sunspots) using UV light helps us figure out their temperature and magnetic fields. Brighter areas (plages) show increased magnetic activity in UV. How the Sun gets dimmer at its edges (limb darkening) in UV light helps us understand how the Sun's atmosphere changes as you move away from its surface.

Ideally, there should have been a dedicated telescope stationed in deep space to view the whole of the Sun, at UV wavelength, twenty-four-by-seven, so that not a single piece of information about the solar drama is missed. That would have been a tool to monitor the Sun’s energy transfer process in almost (Sunlight takes around eight minutes to reach the Earth) real time. This was a major gap area, until the Aditya-L1 mission was sent by India.

The Solar Ultra Violet Imaging Telescope (SUIT) Aditya-L1 takes pictures of the whole Sun using UV light in the 200-400nm range. It has taken ‘full figure photographs’ of the Sun at several wavelengths for the first time in the world, depicting several processes of energy transfer within the Sun. Interpretations of these images lead to scientific results, that would help not only to understand the energy transfer within the Sun, but also provide insight to some of their potential effects on the Earth.

Following is a summary of different aspects of the Sun and solar physics, facilitated by the SUIT instrument.

1. **Solar Atmosphere Studies:**
   - **Photosphere and Chromosphere:** Radiation in the 200 to 400 nm (Near UV – NUV) wavelength range originates from the Sun's photosphere and chromosphere. Observing these layers helps scientists understand the magnetic coupling and dynamics within the solar atmosphere.
   - **Magnetic Coupling:** NUV observations are crucial for studying how magnetic fields transfer energy between different layers of the solar atmosphere.
2. **Solar Spectral Irradiance:**
   - **Variability:** The NUV range is central to measuring and monitoring the variability of solar spectral irradiance (Solar spectral irradiance refers to the power per unit area per unit wavelength of solar electromagnetic radiation received from the Sun. It is a measure of how much sunlight, at each specific wavelength, reaches a certain point, like the top of Earth's atmosphere). This

variability affects the Earth's atmosphere and climate.

- **Potential Effects on the Chemistry of Earth's Atmosphere:** NUV radiation influences the chemistry of ozone and oxygen in the Earth's stratosphere, impacting the Sun-climate relationship.

3. **Solar Flares and Eruptions:**

- **Energy Distribution:** Observing solar flares in the NUV range helps determine the wavelength at which flares radiate most of their energy and the fraction of energy contained within this range.
- **Eruptive Phenomena:** NUV observations can identify chromospheric signatures and counterparts of solar eruptions like jets and macro-spicules.

Aditya-L1 instruments have also observed an X6.3- class solar flare, one of the most intense categories of solar eruptions. What makes this discovery unique is that, **SUIT detected brightening in the near ultraviolet wavelength range — a wavelength range never observed before in such detail [7]. Suit recorded the first-ever image of a solar flare 'kernel'[3] in the solar**

[3] A solar flare kernel is a small, intensely bright region in the lower solar atmosphere, where a flare's energy is initially released. A solar flare kernel begins with interaction between the magnetic field lines (called magnetic reconnection) high in the corona, where magnetic field lines violently rearrange, accelerating particles to near-relativistic speeds. These energized particles,

photosphere and chromosphere. This kernel manifested as brightening in the NUV wavelength band, which was never observed in such great details. This finding provides insight to how solar energy is released from the solar flare through different layers of the Sun's atmosphere.

These observations confirm and ascertain that the energy from the flare spread through different layers of the Sun's atmosphere, providing new insights into the complex physics behind these massive solar explosions [8]. Refer the figure 9 for more details.

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primarily electrons, then stream down along magnetic field lines, impacting the denser layers of the sun's lower atmosphere, the chromosphere and photosphere. This collision releases a massive surge of energy, rapidly heating the surrounding plasma. This intense heating causes the plasma to emit a burst of radiation across the electromagnetic spectrum, particularly in X-ray, ultraviolet, and visible light, resulting in the characteristic bright appearance of the kernel. Thus, the kernel is the site where the kinetic energy of accelerated particles is converted into light and heat, marking the point where the flare's energy is deposited into the lower solar atmosphere. By studying the light coming from these kernels, especially in X-rays and UV light, scientists can figure out how the sun shoots out fast-moving particles and how the energy from the flare travels. In a lighter sense, kernels are like the crime scene of a solar flare, giving us clues to how these powerful explosions happen and how energy moves around in the sun.

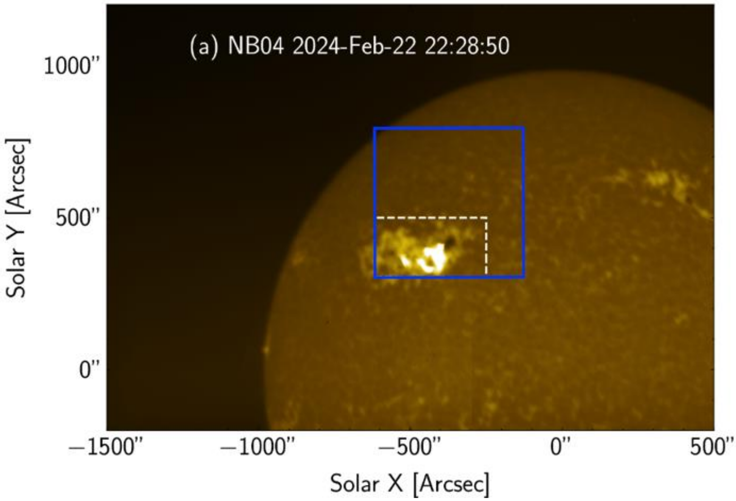


Figure 9: Observation of the flare as obtained from various SUIT filters. Image courtesy: SUIT team, IUCAA

That's where the ingenuity of the SUIT instrument comes. SUIT is the world's first camera that takes the photo of the complete Sun, all in UV wavelength of 200 to 400 nm. There are eleven channels in the camera, which means that there are eleven fine ranges of wavelengths that cover this wavelength range. All these channels collectively allow the study of the energy transfer within the Sun, that would surface out, while some of the energy may affect the Earth's atmosphere.

The following table (taken from the ISRO website) presents the features of the Sun studied by each channel of SUIT. Figures 10 through 12 depict how does the same Sun looks different at different wavelengths (instead of showing all the channels, only three are shown here), emphasising on several features of the Sun. It shows that every region of the electromagnetic spectrum tells a different story of the same target.

Name of the channel (emission lines) **NB means narrow band; BB means broadband**	**Wavelength**	**Solar features studied**
NB1	214	Photosphere, Sunspot, ages and limb darkening
NB2	276	Photosphere, Sunspot, Plages, limb darkening
NB3 (Mg II k)	279	Chromosphere, Sunspots, Plages, Quiet Sun, filaments
NB4 (Mg II h)	280	Chromosphere, Sunspots, Plages, Quiet Sun, filaments
NB5	283	Photosphere, Sunspot, Plages, limb darkening
NB6	300	Photosphere, Sunspot, Plages, limb darkening
NB7	388	Photosphere, Sunspot, limb darkening
NB8 (Ca II h)	396.8	Chromosphere, Sunspots, Plages, Quiet Sun,
BB1	200-242	Photosphere, limb darkening, Plages, Sunspots

Name of the channel (emission lines) **NB means narrow band; BB means broadband**	**Wavelength**	**Solar features studied**
BB2	242-300	Photosphere, limb darkening, Plages, Sunspots
BB3	320-360	Photosphere, limb darkening, Sunspots

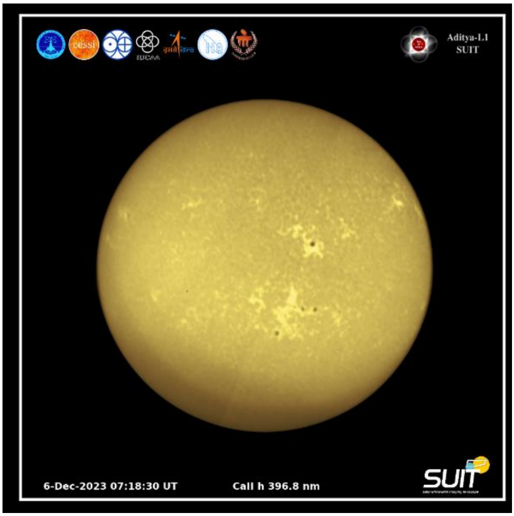


Figure 10: Image of the Sun taken at 396.8 nm wavelength using the SUIT telescope in Aditya-L1, depicting Chromosphere, Sunspots, Plages, Quiet Sun zone.

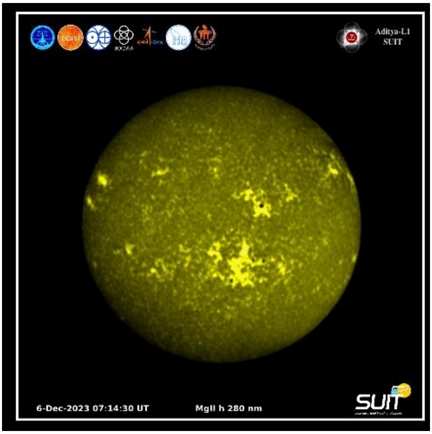


Figure 11: Image of the Sun taken at 280 nm wavelength using the SUIT telescope in Aditya-L1, depicting Chromosphere, Sunspots, Plages, Quiet Sun, filaments of the Sun.

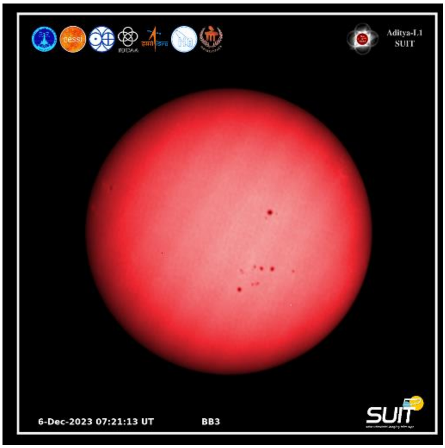


Figure 12: Image of the Sun taken at BB3 channel (320-360 nm wavelength range) using the SUIT telescope in Aditya-L1, depicting Photosphere, limb darkening, Sunspots.

Science from the In-Situ Payloads

Aditya-L1 has studied **the strong solar storm that hit the Earth in May 2024.** This was the biggest solar storm of last two decades and was studied by using Aditya-L1 payloads. A report of the same was published on ISRO website **[4,5]**.

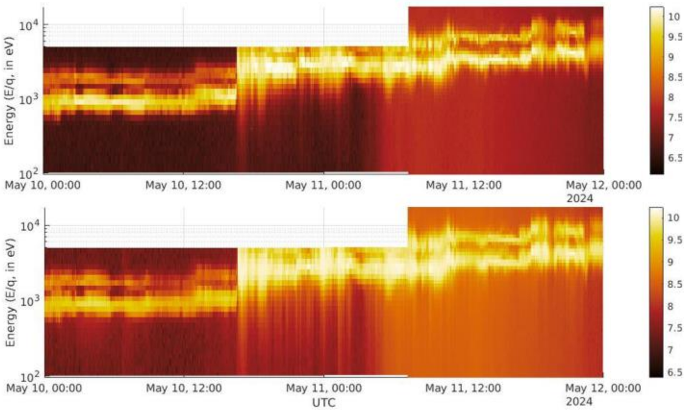
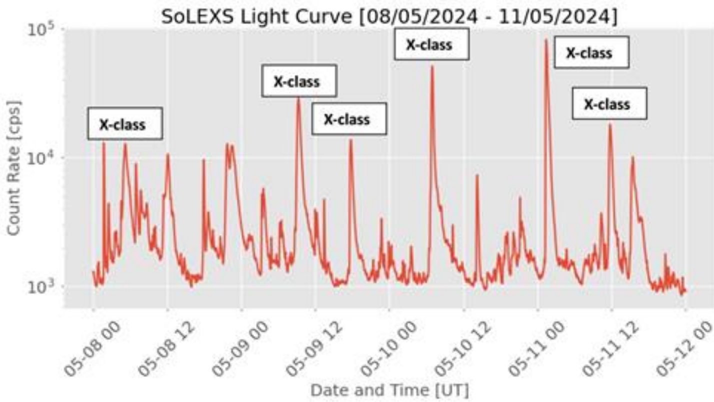


Figure 13: The sudden enhancement of the particle energy and the number during the Solar storm, as captured by the ASPEX instrument. Note the sudden discontinuity in the bright lines. Image courtesy: ASPEX Team, PRL

Figure 13 depicts how the ASPEX instrument captured the sudden enhancement of the particle energy and number during the solar storm. The two bright horizontal lines in the figure correspond to Hydrogen and Helium (most abundant species erupted by Sun). As it can be seen, the particles originated due to solar storm reached Aditya-L1 on the May 10, 2024, at the late hours (time is marked in UT

– the Universal Time or Greenwich Mean Time) and continues until May 12, 2024 00:00UT.



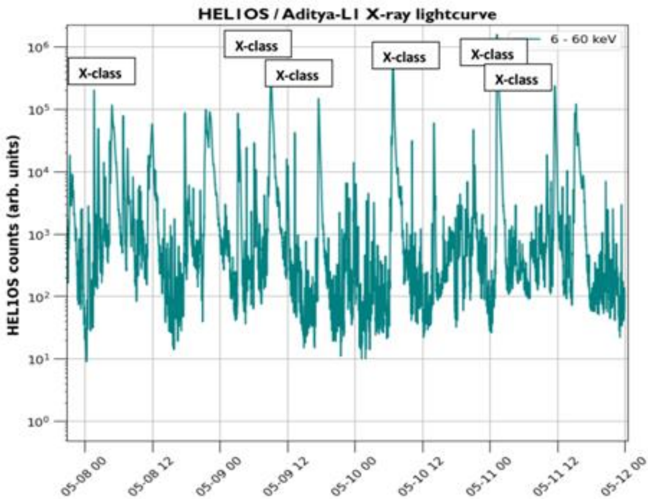


Figure 14 (Top) : X-class solar flares observed with the SoLEX instrument in soft X-Ray; Figure 15 (Bottom): X class solar flares observed with HEL1OS in hard X-Ray

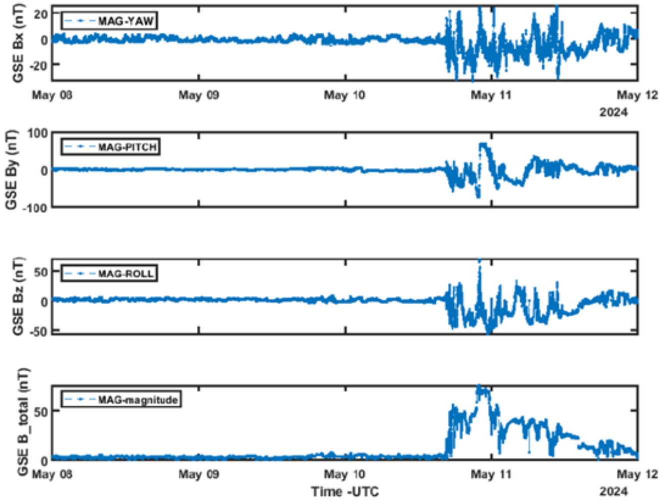


Figure 6: The sudden changes in all the three components of the IMF during the solar storm, as captured with the magnetometers in Aditya-L1

This shows the continuous enhanced particle environments at L1 during the solar storm. These particles eventually reach Earth within few hours

Figures 14 and 15 depict the X class of solar flares, as captured with SoLEX (in soft X-Ray range of 2 to 22 keV) and HEL1OS (in hard X-Ray range of 10 to 150 keV) respectively. Figure 16 depicts the strong change in the IMF during the solar storm, as recorded by the magnetometers of Aditya-1.

Summary

To summarise, Aditya-L1, India's first solar mission, orbits the Sun-Earth L1 Lagrange point, providing a unique opportunity to study the Sun, as it provides continuous (uninterrupted) view of the Sun from a place which is not affected by the atmosphere and the Earth’s magnetic field **[9, 10]**. It focuses on solar physics, crucial for the understanding of space weather. The spacecraft carries seven payloads, including imagers and particle detectors, to observe the Sun's corona, UV and X-ray emissions, solar wind, and magnetic fields.

Data from Aditya-L1, available through the ISSDC website, are vital for studying solar disturbances like flares and coronal mass ejections (CMEs). Unlike other L1 observatories, Aditya-L1 offers unique full-disk UV imaging-spectroscopy and X-ray observations. Recent findings include detailed observations of a significant CME in July 2024, revealing coronal dimming and temperature increases, and the detection of an X6.3-class solar flare with unprecedented detail at UV wavelengths. These observations contribute significantly to our understanding of solar dynamics and space weather, with more discoveries expected as more data are analyzed.

Online Resources for Detailed Study

If this article inspires you, you are encouraged to visit the following websites for more information on the Aditya-L1 mission. A few of these links lead to lectures delivered by eminent scientists who contributed to this field of research.

[1] Aditya-L1 webpage in ISRO website: https://www.isro.gov.in/Aditya_L1.html

[2] The Sun: Our Star; lecture by Prof. Arnab Rai Chowdhury https://youtu.be/CdBXtQEKBRM?si=7UJyiCj5F7ws4uZs

[3] Towards a Better Understanding of the Sun-Earth Connection: Avenues for Next Two Decades; lecture by Prof. Gurubaran, IIG https://youtu.be/wUrtQdaTBOA?si=YnnZMD0E15tQCP2E

[4] https://www.isro.gov.in/ISROCapturestheSignaturesoftheRecentSolarEruptiveEvents.html

[5] https://www.isro.gov.in/Aditya_L1_SUIT_VELC_Capture_SolarFury.html

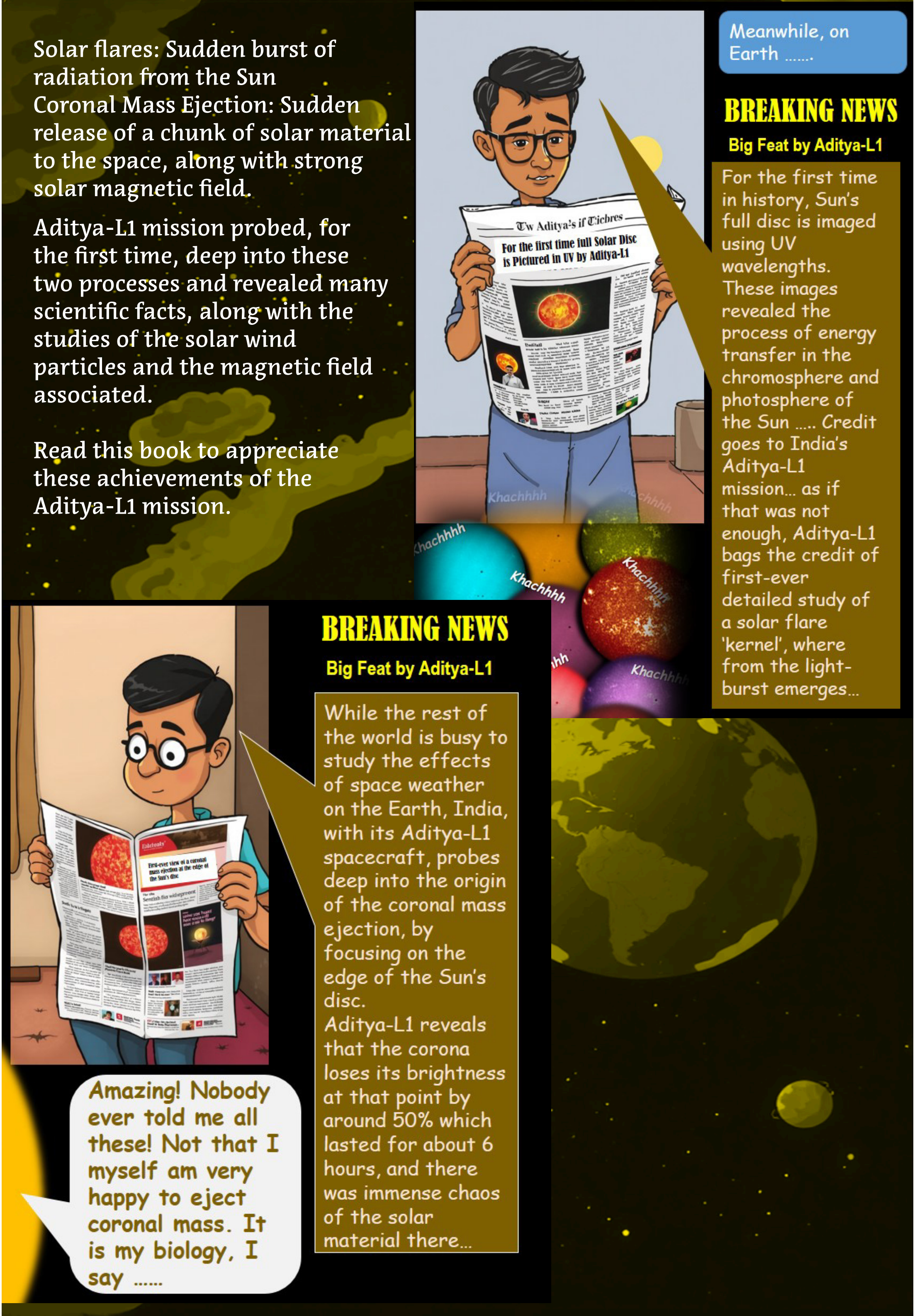
[6] https://www.isro.gov.in/Aditya_L1_Observations_Coronal_Mass_Ejection.html

[7] https://www.isro.gov.in/Aditya_L1_SUIT.html

[8] https://www.isro.gov.in/SUIT_Aditya-L1_Captures_SolarFlare.html#:~:text=What%20did%20researchers%20observe%20from,intense%20categories%20of%20solar%20eruptions.

[9] https://youtu.be/6MVrNcSoWtE?si=E4fdmdVsgKW-DUU_

[10] https://youtu.be/OMwAbb0fzUU?si=QEj1pR17GaXZLOl2


Solar flares: Sudden burst of radiation from the Sun
Coronal Mass Ejection: Sudden release of a chunk of solar material to the space, along with strong solar magnetic field.
Aditya-L1 mission probed, for the first time, deep into these two processes and revealed many scientific facts, along with the studies of the solar wind particles and the magnetic field associated.
Read this book to appreciate these achievements of the Aditya-L1 mission.
Meanwhile, on Earth ....
For the first time full Solar Disc is Pictured in UV by Aditya-L1
BREAKING NEWS
Big Feat by Aditya-L1
For the first time in history, Sun's full disc is imaged using UV wavelengths. These images revealed the process of energy transfer in the chromosphere and photosphere of the Sun ..... Credit goes to India's Aditya-L1 mission... as if that was not enough, Aditya-L1 bags the credit of first-ever detailed study of a solar flare 'kernel', where from the light-burst emerges...
Khachhhh
BREAKING NEWS
Big Feat by Aditya-L1
While the rest of the world is busy to study the effects of space weather on the Earth, India, with its Aditya-L1 spacecraft, probes deep into the origin of the coronal mass ejection, by focusing on the edge of the Sun's disc.
Aditya-L1 reveals that the corona loses its brightness at that point by around 50% which lasted for about 6 hours, and there was immense chaos of the solar material there...
First-ever view of a coronal mass ejection at the edge of the Sun's disc
Amazing! Nobody ever told me all these! Not that I myself am very happy to eject coronal mass. It is my biology, I say ......