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Aditya L-1: A Milestone in the History of Solar Missions Across the World

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Abstract:

'Aditya' in Sanskrit means the Sun. The solar probe, Aditya L-1, is India's first space observatory designed to study the various dynamic thermal and magnetic phenomena taking place on the Sun and resulting eruptions – solar flares, Coronal Mass Ejections (CMEs) and solar winds – which directly influence the Earth and affect space weather as well. India's national space agency's Solar Mission is a wholly indigenous effort with the participation of national institutions. Institutions which are part of the mission include the Indian Institute of Astrophysics (IIA), Inter-University Centre for Astronomy and Astrophysics, Pune, Laboratory for Electro-Optics Systems (LEOS), Bengaluru, Space Astronomy group (URSC) and Space Physics Laboratory (SPL), Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram. Most importantly, no solar mission of any other country has been developed with such superior technological features, at such a comparatively low costing, nor with such ambitiously high, fool-proof calculations and plans for studying solar phenomena.

Launched by the Indian Space Research Organisation (ISRO), Aditya L-1 aims at solving one of the greatest mysteries of space - the reason behind the extremely high temperatures of the Corona layer of the Sun, and will predict solar storms before they reach the Earth, preventing complete disruption of life caused by power, communication and satellite failures resulting from CMEs and other associated solar emissions/eruptions.
KEYWORDS: Coronal Mass Ejections (CMEs), solar flares, Lagrange points, halo orbit, solar disk, corona, chromosphere, payloads, spectrometer, coronagraph, spectrograph, and magnetometer.

1. Introduction:

1.1. Effects of Solar Phenomena:

The sun's energy, heat, and continuous flow of particles and magnetic fields all have an impact on Earth. The solar wind is the continuous outflow of particles from the sun, primarily made up of high-energy protons. A large portion of the known solar system is occupied by the solar wind and solar magnetic field. The solar wind influences the properties of space, as do other violent and eruptive solar occurrences like Coronal Mass Ejections (CMEs). The magnetic field and charge particle environment close to the planet change during such events. When it comes to Earth, a magnetic disturbance could be caused by the collision of the Earth's magnetic field with the field carried by a CME. The efficiency of space assets may be impacted by such occurrences. (ISRO, 2023)[1]

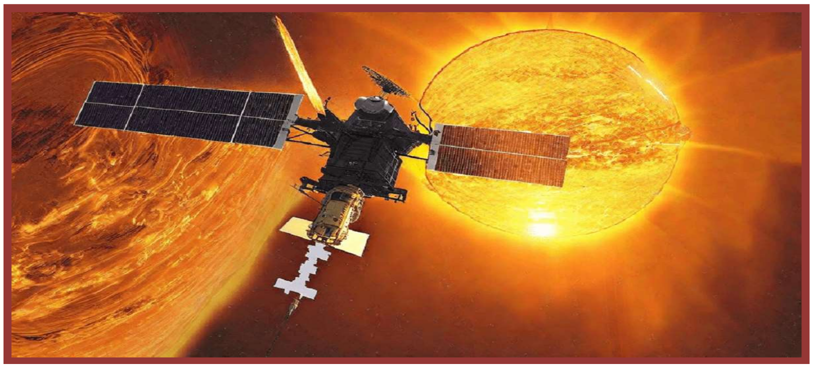

Fig-1: Aditya L-1 on its way to the Halo Orbit[2]

1.2. Positioning of Probe - Reasons:

Aditya L-1, India's first space-based observatory class solar mission to unlock the mysteries of the Sun, will be positioned in a halo orbit around the Sun-Earth system's Lagrangian point1 (L1), which is approximately 1.5 million kilometers away from Earth. A spacecraft in a halo orbit around the L1 point has the significant benefit of continuously observing the Sun without occultation or eclipse. This offers a better chance of consistent observation of solar activities. The spacecraft carries seven payloads that will use electromagnetic and particle detectors to investigate the photosphere, chromosphere, and the Sun's outermost layers (the corona). Four payloads will directly observe the Sun, while the remaining three will conduct in-situ particle and field research at the Lagrange point L1. (ISRO, 2023)[3]

In general, a Lagrange point is where the gravitational pull of two large masses precisely equals the centripetal force required for a small object to move with them (NASA, 2023)[4].Therefore, spacecraft positioned at Lagrange Points consume very less fuel. However, maintaining it at the exact L-point is difficult as at such a great distance from Earth, the system becomes relatively unstable. Hence, Aditya L-1 will be placed in a halo orbit around Lagrange Point-1. Interestingly, among the other L-points, L-4 and L-5 are relatively more stable, but those points were not chosen

[1]ISRO. (2023, September 2). *Aditya L-1 Mission Booklet*. www.isro.gov.in. Retrieved October 29, 2023, from https://www.isro.gov.in/media_isro/pdf/Aditya_L1_Booklet.pdf

[2]Retrieved from : https://timesofindia.indiatimes.com/city/bengaluru/aditya-l1-captures-first-glimpse-of-solar-flares/articleshow/105054088.cms

[3]Ibid; See Footnote-1.

[4]NASA. (2023, September 4). *What is a Lagrange Point?* https://science.nasa.gov. Retrieved October 28, 2023, from https://science.nasa.gov/resource/what-is-a-lagrange-point/

as space debris and asteroids at those 2 locations would have been highly likely to damage the solar probe.

The Aditya L-1 Payload suite is expected to provide critical information for understanding the problems of the Coronal Heating, Coronal Mass Ejection, Preflare and Flare activities and their characteristics, Space Weather Dynamic, Particle Propagation, Fields in the Interplanar medium, and so on.

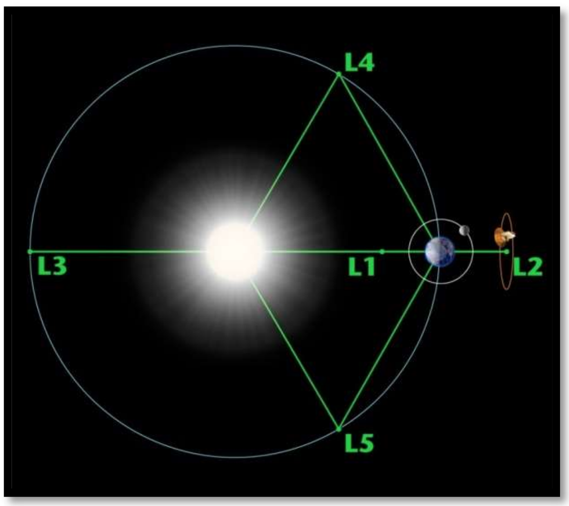

Fig-2: Depiction of Lagrange points of Sun-Earth system *[NASA/WMAP Science Team]*[5]

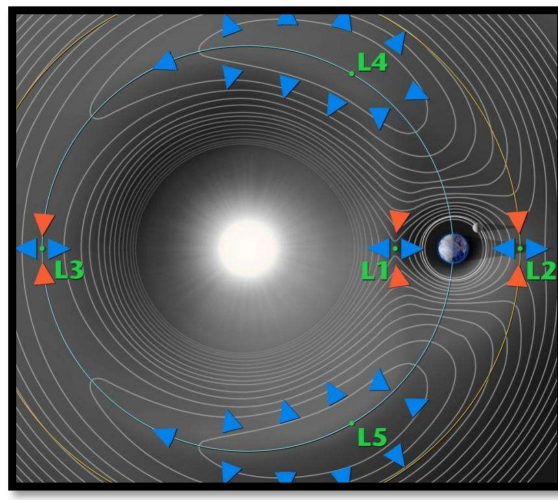

Fig-3: Lagrange Points and the Coriolis Force Effect[6]

1.3 Trajectory of Aditya L-1 to L-1 Point:

The Aditya-L1 mission, conducted by the Indian Space Research Organization (ISRO), will be launched from the Sathish Dhawan Space Centre in Sriharikota. The spacecraft will first be placed in a low earth orbit and then its orbit will be adjusted to become more elliptical. Using on-board propulsion, the spacecraft will be propelled towards the Lagrange point L1, where the mission aims to study the sun. As the spacecraft travels towards L1, it will exit the Earth's gravitational Sphere of Influence (SOI). After exiting SOI, the cruise phase will begin, and eventually, the spacecraft will be injected into a large halo orbit around L1. The total travel time from launch to L1 is approximately four months for the Aditya-L1 mission.

[5] NASA. (2023, September 4). *What is a Lagrange Point?* https://science.nasa.gov. Retrieved October 28, 2023, from https://science.nasa.gov/resource/what-is-a-lagrange-point/
[6] NASA. (2023, September 4). *What is a Lagrange Point?* https://science.nasa.gov. Retrieved October 28, 2023, from https://science.nasa.gov/resource/what-is-a-lagrange-point/

1.4 Uniqueness of Aditya-L1:

The Aditya-L1 mission has several unique objectives that contribute to a deeper understanding of the Sun. It plans to capture spatially resolved images of the solar disk in the near UV band, which has not been achieved before. This will enable scientists to study various solar phenomena in more detail. The mission also focuses on exploring the dynamics of Coronal Mass Ejections (CME) close to the solar disk, providing valuable insights into the acceleration regime of CME.

To optimize observations and data volume, the spacecraft incorporates onboard intelligence to detect CMEs and solar flares. This automated system will ensure that crucial events are captured and studied in depth. Additionally, Aditya-L1 aims to investigate the directional and energy anisotropy of solar wind. Using multi-direction observations, scientists will analyze the flow and characteristics of solar wind particles. Overall, the Aditya-L1 mission has ambitious scientific goals, including studying the solar disk, CME dynamics, and solar wind properties. By gaining a deeper understanding of these phenomena, scientists can enhance our knowledge of the Sun and its impact on Earth's space weather.

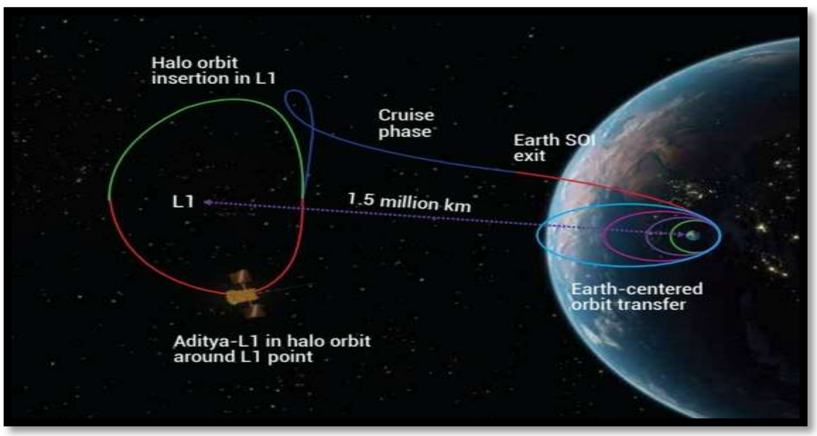

Fig-4: Trajectory of Aditya L-1 *[ISRO, 2023]*[7]

2. Aims and Objectives:

- Study of the dynamics of solar upper atmospheric layers, coronal and chromospheric heating
- Study of the physics of the partially ionized plasma, engendering cause of coronal mass ejections and flares
- Observation of in-situ particles and plasma environment providing data for the study of particle dynamics from the Sun
- Debunking the mystery behind the extreme temperatures at the coronal layer
- Temperature, velocity and density of coronal and coronal loops plasma

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[7]Retrieved from: https://www.isro.gov.in/media_isro/pdf/Aditya_L1_Booklet.pdf

- Development, dynamics and origin of CMEs.
- Identification of the sequence of processes that occur at the chromosphere, base and extended corona, which eventually leads to solar eruptions
- Magnetic field topology and measurements in the corona
- Origin, composition and dynamics of solar wind and other factores influencing space weather[8]

3. Indian Missions & Scientific Expeditions: Past to Present:

Launched in 1969, the Indian Space Research Organization (ISRO) has been India's leading space agency since then. With over 194 spacecraft missions and over 94 launches, ISRO ranks among the world's elite space organizations. The organization's most recent achievement was the successful lunar mission Chandrayaan-3, which landed on the moon. This makes India one of only four countries to have made a landing on the Moon. It also marks India's first landing on the south pole of the Moon. Following include some of ISRO's major achievements.

3.1 ARYABHATA, 1975:

Aryabhata was named after the famous Indian astronomer who first invented zero. The first Indian satellite was manufactured, designed and assembled entirely indigenously. The satellite weighed over 360 kg and was launched from the launch site of the former Soviet Union (now the Russian Space Agency) on April 19th, 1975. The satellite was launched by the Kosmos-3M rocket from the Volgograd Launch Station of the Russian Space Agency. This was the first of many successful Indian satellites.

3.2 Indian National Satellite System (INSAT) Series, 1983:

The INSAT[9] series revolutionized the telecommunications sector in India. Today, with 9 functional communication satellites in geostationary orbit, INSAT is one of India's largest domestic satellite communication satellite systems. INSAT is one of Asia-Pacific's largest satellite communication satellite systems with more than 200 correspondents. It offers television broadcasting, satellite news gathering, social media applications, weather prediction, disaster warning, Search and Rescue, etc.

3.3. GSAT Series:

The Geosynchronous Satellites (GSAT) is a series of communication satellites designed and manufactured in India. The primary applications of these satellites are digital audio, data and video

[8]ISRO. (2023, September 2). *Aditya _L-1*. www.isro.gov.in. Retrieved October 29, 2023, from https://www.isro.gov.in/media_isro/pdf/Aditya_L1_Booklet.pdf

[9]Jagran Prakashan Ltd. (2023). *List of ISRO successful missions.* www.jagranjosh.com Retrieved October 30, 2023, from: https://www.jagranjosh.com/general-knowledge/list-of-isro-successful-missions-1692796892-1

transmission. ISRO has launched a large number of GSAT satellites, of which 18 are still in operation.

3.4 Chandrayaan-1, 2008:

Chandrayaan-1 was India's first mission on the Moon. The mission launched successfully on 22 October 2008, and remains one of the most significant scientific discoveries to date, as it discovered water molecules on the Moon's surface. The discovery of water on the Moon was brought to the world's attention through the mission.

3.5. Mars Orbiter Mission (MOM), 2014:

India achieved a milestone in space exploration when it successfully launched Mangalyaan (MOM) to the red planet of Mars on its maiden mission, making it the first country to reach the planet on its own terms. This mission was also the first inter-planetary mission launched by India's space agency, ISRO. The mission, which was launched on 5 November 2013, was the fourth to successfully send a spacecraft into an orbit around Mars. Although the duration of the mission was initially set at six months, as of 24 September 2021, Mangalyaan has been in an orbit of seven years.

Fig-5: INSAT series spacecraft[10]

Fig-6: Aryabhata[11]

4. Solar Missions and Scientific Expeditions across the Globe:

4.1 Solar Mission in USA:

In 2018, the US space agency National Aeronautics and Space Administration (NASA) launched the Parker Solar Probe, which flew through the Sun's upper atmosphere, marking the first time a

[10]Jagran Prakashan Ltd. (2023). *List of ISRO successful missions.*www.jagranjosh.com Retrieved October 30, 2023, from:https://www.jagranjosh.com/general-knowledge/list-of-isro-successful-missions-1692796892-1

[11]Jagran Prakashan Ltd. (2023). *List of ISRO successful missions.*www.jagranjosh.com Retrieved October 30, 2023, from:https://www.jagranjosh.com/general-knowledge/list-of-isro-successful-missions-1692796892-1

spacecraft touched the Sun. In 2020, NASA and the ESA collaborated to launch The Solar Orbiter, aiming to collect data on the Sun's influence on the space environment. NASA has also launched other missions like the Advanced Composition Explorer, Solar Terrestrial Relations Observatory and Solar Dynamics Observatory. Additionally, in 1995, NASA, ESA, and the JAXA jointly launched the Solar and Heliospheric Observatory (SOHO).

4.2 Solar Mission in Japan:

Hinotori (ASTRO-A) was the Japan Aerospace Exploration Agency's (JAXA) first solar observation satellite launched in 1981 to study solar flares using hard X-rays. JAXA's other solar missions include Yohkoh (SOLAR-A), SOHO (in collaboration with NASA and ESA), Transient Region and Coronal Explorer (TRACE), and Hinode (SOLAR-B) launched in 2006.

4.3 Solar Mission in Europe:

European Space Agency (ESA) launched Ulysses in 1990 to study the environment of space around the Sun's poles. Proba-2, launched in 2001, is the second mission in the Proba (Project for On-Board Autonomy) series and includes solar observation experiments. Upcoming solar missions by ESA include Proba-3 (2024) and Smile (2025).

4.4 Solar Mission in China:

The Advanced Space-based Solar Observatory (ASO-S) was successfully launched by the National Space Science Center, Chinese Academy of Sciences (CAS), on October 8, 2022. (The Hindu, 2023)[12]

4.5 Other related Missions:

4.5.1 Interface Region Imaging Spectrograph (IRIS) Mission:

IRIS, launched on June 27, 2013, is a mission that aims to understand how matter, light, and energy move through the dense region of solar material at the bottom of the sun's atmosphere. By studying the interface between the sun's surface and its atmosphere, known as the corona, IRIS seeks to unravel the processes that drive heat, energy, solar flares, and coronal mass ejections. With advancements in technology, this region can now be studied in high resolution, which was previously impossible. IRIS travels in a polar, sun-synchronous orbit at an altitude of over 400 miles above Earth. This orbit allows for continuous observations, maximizing eclipse-free viewing of the sun. (Young, 2023)[13]

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[12]The Hindu. (2023, August 29). *Race for Sun heats up: These are the various solar missions*. www.thehindu.com Retrieved October 28, 2023, from https://www.thehindu.com/sci-tech/science/race-for-sun-heats-up-these-are-various-solar-missions/article67246208.ece

[13]Young, C. Alex. (2023). *All Solar Missions - The Sun Today: Solar Science and beyond*. Retrieved October 30, 2023, from https://www.thesuntoday.org/missions/all-missions/

4.5.2 Reuven Ramaty High Energy Solar Spectroscope Imager (RHESSI) Mission:

RHESSI, launched on February 05, 2002, is a space mission that combines high-resolution imaging and spectroscopy to study the physics of particle acceleration and energy release in solar flares. By studying these events, RHESSI aims to improve our understanding of the processes involved in generating solar flares and coronal mass ejections, which are extreme drivers of space weather and pose risks to both space and Earth. The spacecraft operates in a medium inclination orbit around Earth, at an altitude of approximately 400 miles.

4.5.3 Advanced Composition Explorer (ACE) Mission:

The Advanced Composition Explorer (ACE) mission, which was launched in August 1997, aims to observe and measure the composition of particles from solar wind and galactic cosmic rays with unprecedented accuracy. The mission's primary objective is to enhance our understanding of the composition of various substances associated with the sun, the interstellar medium, and the surrounding galaxy. Additionally, ACE delivers up-to-the-minute data on solar wind and magnetic fields to aid in forecasting space weather. This early knowledge of solar wind disturbances heading towards Earth can help mitigate the impact of geomagnetic storms, such as the overloading of power grids and disruptions in communications. ACE orbits the L1 Lagrangian point, situated approximately 950,000 miles from Earth and 92 million miles from the sun. This orbit allows ACE to occupy an ideal position in the flow of solar wind headed towards Earth. (Young, 2023)[14]

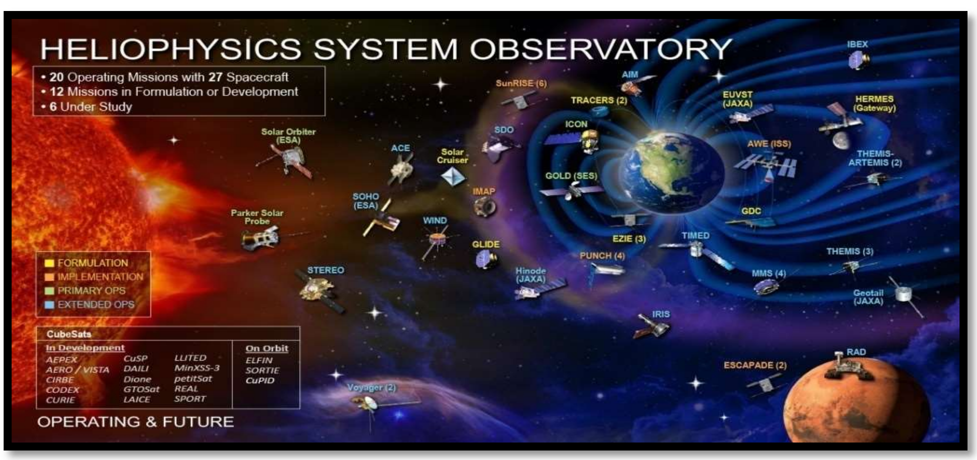

Fig-7: Solar Missions for Heliospheric studies in and around Lagrange points[15]

[14]Young, C. Alex. (2023). *All Solar Missions - The Sun Today: Solar Science and beyond*. www.thesuntoday.org. Retrieved October 30, 2023, from https://www.thesuntoday.org/missions/all-missions/
[15]Retrieved from : https://www.thesuntoday.org/missions/all-missions/

5. Aditya L-1 Mission:

5.1 PSLV-C57:

Planned from Second Launch Pad (SLP), SDSC, SHAR, PSLV-C57 is the 59th flight of PSLV and 25th mission using PSLV-XL configuration. It will launch Aditya-L1 spacecraft in a highly eccentric Earth-bound orbit. The spacecraft will perform orbital manoeuvres by using its LAM to reach Sun-Earth Lagrange point L1 (1.5 million kilometers from Earth, in a halo orbit).

5.2. Payloads:

The spacecraft carries 7 scientific payloads for systematic study of the Sun. All payloads are indigenously developed in collaboration with various ISRO Centers and Scientific Institutes.

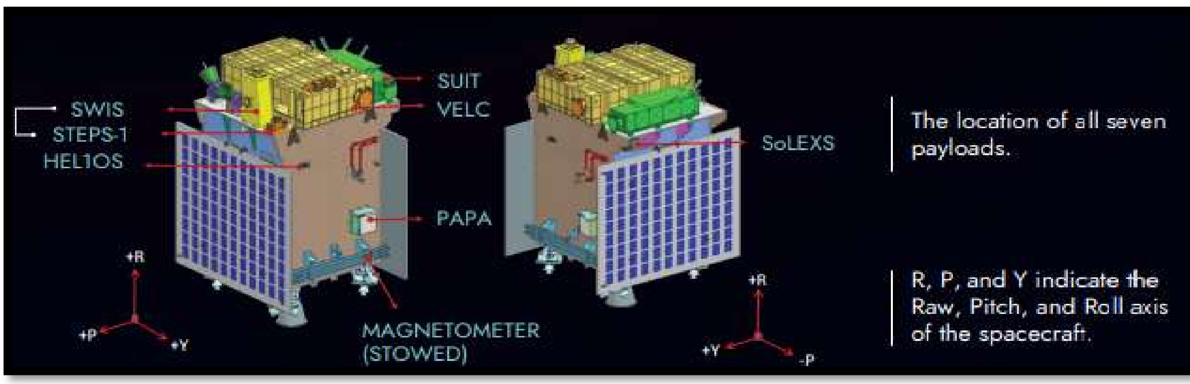

Fig-8: Aditya-L1 Payloads *[ISRO, 2023]*[16]

5.2.1. Visible Emission Line Coronagraph (VELC)[17]:

A reflective coronagraph with a multi-slit spectrograph, VELC is the primary payload of the spacecraft. Its main function includes observation of solar phenomena in 3 modes: imaging, Spectropolarimetry and Spectroscopy. It will measure temperature, velocity and density of coronal loops, coronal magnetic fields, aid in understanding of the processes that heat the Sun's corona, and investigate into origin, development and dynamics of CMEs. Its multi-slit spectrograph working in Littrow configuration will allow high spatial resolution and cadence of spectroscopic observations.

5.2.2 Solar Low Energy X-Ray Spectrometer (SoLEXS):

SoLEXS is a soft X-ray spectrometer designed to measure the solar soft X-ray flux to study solar flares. These soft X-ray measurements will aid in studying properties of the solar corona,

[16]Retrieved from: https://www.isro.gov.in/media_isro/pdf/AdityaL1_Mission_Brochure.pdf
[17]ISRO. (2023, September 2). *Aditya L-1 Payloads*. www.isro.gov.in. Retrieved October 29, 2023, from https://www.isro.gov.in/Aditya_L1_Payload.html

dominated by magnetic field dynamics and high temperature plasma of more than 1 million Kelvin. Its major functions include providing data for DC heating mechanism in coronal layer (complementary to data of VELC), detecting changes in abundance of low First Ionization Potential (FIP) elements like Silicon, Calcium and Iron, and coronal plasma abundance, along with conducting Flare-CME studies.[18]

Fig-9: VELC Payload *[ISRO, 2023]*[19]

Fig-10: SoLEXS *[ISRO, 2023]*[20]

5.2.3 Plasma Analyser Package for Aditya (PAPA):

It is designed to study solar winds and their composition by mass analysis of solar wind ions using SWEEP and SWICAR sensors for energy analysis of electrons and ions. It will also study proton temperature anisotropy and solar wind electron velocity distribution.

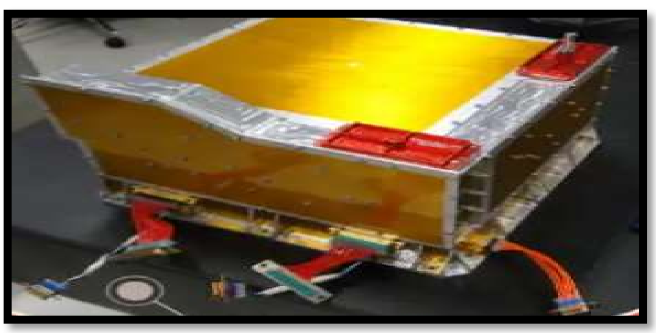

Fig-11: PAPA *[ISRO, 2023]*[21]

Fig-12: HEL1OS *[ISRO, 2023]*[22]

5.2.4 High Energy L1 Orbiting X-Ray Spectrometer (HEL-1OS):

Pronounced 'Helios', it is a hard X-ray spectrometer designed to study solar flares in the high energy X-rays. It contains 2 types of detectors – Cadmium Telluride (CdTe) and Cadmium Zinc

[18]ISRO. (2023, September 2). *Aditya L-1Mission Brochure*. www.isro.gov.in. Retrieved October 29, 2023, from: https://www.isro.gov.in/media_isro/pdf/AdityaL1_Mission_Brochure.pdf
[19]Retrieved from https://www.isro.gov.in/Aditya_L1_Payload.html
[20]Retrieved from https://www.isro.gov.in/Aditya_L1_Payload.html
[21]Retrieved from https://www.isro.gov.in/Aditya_L1_Payload.html
[22]Retrieved from https://www.isro.gov.in/Aditya_L1_Payload.html

Telluride (CZT) which help capture solar X-rays in the energy range of interest. It aims at studying explosive energy release, acceleration and transport of electrons, evolution of cut-off energy between thermal and non-thermal emissions and studying Quasi-Periodic Pulsations of hard X-rays, all using fast timing measurements and high-resolution spectra. (ISRO, 2023)

5.2.5Solar Ultraviolet Imaging Telescope (SUIT):

SUIT is a UV telescope to image the solar disk in the near ultra-violet wavelength range, using Narrow-band (NB) & Broad-band (BB) spectral filters in the range of 200-400 nm. Its main functions include investigating processes through which energy is channelized and transferred from the photosphere to chromosphere, relevance of solar irradiance on climatic variations of Earth, wavelengths at which flares radiate most energy, and the mechanisms responsible for stability, dynamics and eruption of solar prominences.

Fig-13: SUIT *[ISRO, 2023]*[23]

5.2.6. Aditya Solar Wind Particle Experiment (ASPEX):

It comprises 2 subsystems- SWIS AND STEPS. Solar Wind Ion Spectrometer (SWIS) is a low-energy spectrometer designed to measure the proton and alpha particles of the solar wind. Suprathermal and Energetic Particle Spectrometer (STEPS) is a high-energy spectrometer designed to measure high-energy ions of the solar wind.

5.2.7. Magnetometer (MAG):

MAG will measure the low intensity interplanetary magnetic field in space. It has two sets of Magnetic Sensors: one at the tip of a 6-meter deployable boom, and the other in the middle of the boom, 3 meters away from the spacecraft. (ISRO, 2023)[24].

[23]Retrieved from https://www.isro.gov.in/Aditya_L1_Payload.html

[24]ISRO. (2023, September 2). *Aditya L-1 Payloads*. www.isro.gov.in. Retrieved October 29, 2023, from https://www.isro.gov.in/Aditya_L1_Payload.html

6. Outputs Achieved:

On September 15, Aditya L-1 completed the 4 Earth-bound manoeuvres (EBNs 1, 2, 3, 4). On September 18, 2023, commencement of collection of scientific data by the spacecraft took place. September 30 reported the spacecraft's escape from the sphere of Earth's influence, and it is currently heading to the Sun-Earth Lagrange point. As of October 8, 2023, a Trajectory Correction Manoeuvre (TCM) was performed to ensure the spacecraft is on its intended path towards Halo Orbit insertion around L1 point. The VELC payload is expected to send 1440 images of the Sun per day to ground stations, for voluminous data tracking and observations. (ISRO, 2023)[25].

7. Future Missions:

After Aditya-L1, ISRO plans on Gaganyaan test vehicle launch (for validating in-flight crew escape system) by October first or second week, followed by GSLV launch of INSAT-3DS satellite for India. Next in line is the SSLV-D3 mission (third flight of India's newest and smaller rocket), then PSLV and LVM3. SPADEX and other ambitious missions are also on ISRO's schedule ahead.[26]

8. Reflections:

Despite its historical significance, the Aditya L1 mission has its own inherent constraints in terms of resources, capacity, and L1 point. As solar events are multidirectional, further missions should be conducted to investigate the multidirectional distribution of CMEs erupting from the sun. Additionally, future missions should be focused on the L5 point to study the Earth-directed events of CMEs and to gain a better understanding of the space weather. Furthermore, as the study of the solar magnetic field and polar dynamics is of paramount importance in understanding various solar processes, missions to the polar regions of the sun, despite the technological limitations of the spacecraft, would be beneficial in understanding the various solar processes.

Further missions to study the Sun and space weather should be encouraged. Additionally, the mystery behind black holes can be further investigated, if possible, to study the effects of such immense gravitational pull (inside the black hole) and relative slowing down of time – a concept behind speculations of possible time travel/exit from the known universe, or at least exploration of diverse space phenomena. Search for possibilities of any form of life on other planets may also be conducted to expand our understanding of the universe and development of potential alternatives of Earth.

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[25]ISRO. (2023, September 2). *Aditya L-1 Payloads*. www.isro.gov.in. Retrieved October 29, 2023, from https://www.isro.gov.in/Aditya_L1_Payload.html

[26]Wion News. (2023, September 1).*Here's the list of ISRO's upcoming missions for 2023-24*. www.wionews.comRetrieved October 28, 2023, from https://www.wionews.com/india-news/heres-the-list-of-isros-upcoming-missions-for-2023-24-631118

9. Conclusion:

The Aditya L 1 Mission provides a unique opportunity for solar scientists from various institutes across the country to participate in the use of space-based instruments and observations, as it includes a variety of payloads. The upgraded version of this mission will help to address the remaining challenges in solar physics, and provide a comprehensive understanding of the dynamic processes of the Sun, particularly Coronal Heating. As the Sun is the primary source of energy for our Solar System, it is essential to investigate its weather and environmental conditions, as they influence the development of each of the celestial bodies in the Solar System. The Aditya L2 Mission will help in the prediction of Earth-directed solar storms emanating from the Sun, as well as the effects of variations in the Solar Weather System, which can alter satellite orbits, shorten their lifespan, harm onboard electronics, and cause power outages on Earth.

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