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State of the art of solar missions in the 20th century

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Abstract
Quest of knowledge issuch an intrinsic property of human mind by which the existing knowledge is not only analysed critically,it is always curious to create new knowledge. The doubting and examining the existing knowledge and its understanding creates new and advanced knowledge and its systematic understanding. There are two basic approaches: the first is the theory and its validation and second one is the observations recorded and based on these observations constructing a model, its formulation and understanding. Sun is the source of life on earth. The quest of knowledge invites at first to know about the Sun regarding its composition, physical processes within it and the spectra of emissions radiated out. This is possible only when we observe the emissions coming out from the Sun and analysing the same. In this communication, we have attempted to present objectively the various missions designed, installed and activated for observations of emissions from solar corona till the end of 20th century. The analysis and understanding of these observations became the well - established knowledge of the first decade of 21st century and now ready for fabrication in form of technology to serve the society on one hand and assist the advancement in future research on second hand. These observations allow us to establish the coherent and consistent theoretical models of the fundamental plasma physics along with processes that operate in the solar corona and in other high temperature astrophysical plasmas.
Keywords: *Solar Missions; Solar Corona Emissions.*

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I. Introduction

Solar physics has evolved over three distinctly different phases using structured and successivelymore sophisticated and progressive observing tools. The first phase was of naked-eye observations. This dates back over several thousands of years as a curiosity of human mind to know and create knowledge. As an invention, in the form of Kepler's laws of planetary motion and Newton's law of gravitation, the first phase has been concerned with observations and reports of solar eclipses along with role of the Sun in celestial mechanics. Ground-based solar-dedicated telescopes, spectrometers, coronagraphs and radio telescopes were built in the second phase which lasted nearly a century before the space age began. Using these instruments, the age of quantitative measurements of solar phenomena started and systematic documentation developed with the passage of time. Using these measurements, the basic geometric and physical parameters of solar corona have been probed. During the third phase, that started around 1950 in the space age, the solar-dedicated spacecrafts were launched and observations from space started. These observations, in form of all possible wavelengths emitted, high-resolution images and spectral measurements of sun and its radiations empowered us to evolve quantitative physical modelling of solar phenomena and themodels were supported by numerical simulations by using the theories of magneto-hydrodynamics and plasma particle physics.

In this communication, chronologically we are going to present the physical insights developed from the observations obtained from various space missions. The period 1992-2002, was the first and most stimulating and fruitful in the exploration of the various space mission observations in form of wavelengths, unprecedented extraordinary pictures, movies and high-accuracy spectral and temporal data.

II. Historical development of Solar corona observations

2.1 Optical Observations:

In daily life what we see with our eyes (first phase of observations) from our Sun or from the various stars in our galaxy is nothing but the optical radiation that is emitted at the surface of the star, that region of star is known as photosphere. Extending from centre to the surface, the Sun has six layers categorised in two parts: Inner layers and outer layers. Convective zone, radiative zone and core constitute the three inner layers respectively going towards the centre of the sun and photosphere, chromosphere and corona are the layers going towards the surface of the Sun.The temperature of photosphere is of the order of 5000K while that of corona is of the order of 10^6K. Butthe optical emission produced in the corona region of sun by Thomson scattering, in many orders of magnitude less intense than the photosphere emission (because of its high temperature and low density). So, the question which arises is how to observe these optical emissions? The answer lies in the fact that when we observe solar emission, when the solar surface is occulted i.e., during total solar eclipse when the photosphere emissions are absent. The first observations of solar corona have been made during ancient solar eclipses according to the reports of Indian Babylonian and the Chinese sources. A detailed account of historical eclipses can be found in the book of Guillermier & Koutchmy, 1999[1], which mentions, the Chinese solar eclipse-2000 BC; solar eclipse-28 May 585 BC or the solar eclipse-29 May 1919 in Brazil and West Africa. Einstein's general theory of relativity was proved by the solar eclipse of 29th May 1919 making it one of the most famous solar eclipses till date.With the eclipse of 1842 regular observations of solar eclipses and prominences was started while the collection of photographic records was started from the eclipse of 1851. Also, in the 19th century the visual and spectroscopic observations of prominence loops were carried out.In the year 1868, Jules Janssen a French astronomer was the first one to discover the element "Helium" in the solar corona. By constructing spectroheliograph in 1892, George Ellery Haleobserved the coronal line during the solar eclipses. But, the basic problem with these observations was that we have to wait for solar eclipse to occur in one hand and on the other hand find the perfect latitude and longitude from where it can be observed as a complete solar eclipse. This problem was addressed by Bernard Lyot by constructing his first coronagraph at the Pic-du-Midi observatory in 1930, an instrument that occults the bright solar disc and thus allows for routine coronal observations without the need to wait for one of the rare total solar events. Using this in 1942, Edlen identified forbidden lines of highly ionized atoms and in this way for the first time he established the million-degree temperature of the corona. These early coronal observations from ground are given in Bray et al.1991[2].

2.2 X-rays, EUV and Gamma-Rays observations:

In case of optical wavelengths, the photosphere emissions are intense while the coronal emissions are very weak. But in other wavelengths for instance in soft-X rays, hard X-rays, radio wavelengths, extreme ultraviolet (EUV) wavelength or γ-raywavelengths, the brightest emission comes from the corona, while regarding these wavelengths the photosphere is invisible.Regarding these coronal wavelength's observations, the ground station observations are not effective due to earth's atmosphere, climatic conditions, aerosols scattering, absorption and reflection processes for radiation. To overcome these limitations, the break-through was given by the space observations era in form of rocket flights and spacecraft missions for coronal observations of these different bright wavelengths. These missions enabled to overcome the limitations of earth station observations for soft X-rays and extreme ultraviolet(EUV) observations[Fig1].

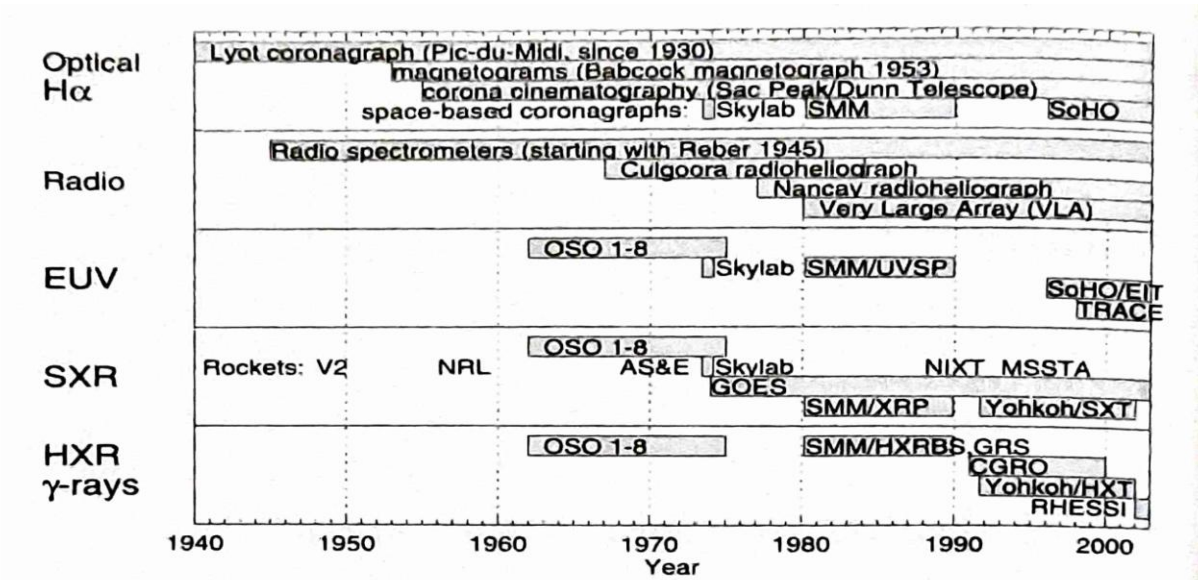

Fig.1: The operation periods of major instruments and space missions that provided unique observations of the solar corona are shown in historical order, sorted in different wavelength regimes.[14]

First, the rocket flights we used for coronal observations in space. Early Aerobe rocket flights were conducted by United states (US), Naval Research Laboratory (NRL) in 1946 and 1952, with resolution of EUV wavelength to 190nm and Lyman-α emission of hydrogen at 121.6 nm. In 1974 the observations of EUV wavelengths of He-I, He-II, O-IV, O-V, Ne-VII with high resolution ≈ 4". On 19th April, 1960 the first crude X-ray photograph of the Sun was clicked with a pinhole camera. Later, rocket flights helped in obtaining these photographs in the year 1963. The limitation of the observations through these rocket flights in space was that the rocket flights lastedusually for about 7 minutes and only short glimpses of coronal radiations could be obtained.

To overcome the limitations of the rocket flight observations, the spacecraft missions were materialised in practice. During 1962-1975, for long term observations, a series of satellite orbiting solar observatory(050-1 to 050-8) were launched into the earth's orbit. These were equipped with non-imaging EUV, soft X-ray, hard X-rayspectrometers and spectroheliographs. The launch of Skylab from 14th May 1973 to 8th Feb 1974, a new era was initiated which started multi-wavelength solar observations from space. The Skylab mission recorded ≈ 32,000 photographs during its mission with the installed equipment in it as white-light coronagraph, two grazing-incidence X-ray telescopes, EUV Spectro heliometers/Spectroheliographs and an UV spectrograph [2]. The coronal observations in the space age are reviewed in the encyclopaedia article of Alexander and Action, 2002[3] & [4].

US launched the Solar Maximum Mission (SMM)on 14th February, 1980 first solar-dedicated space missionwhich lasted a full solar cycle until orbit decay on 2nd December 1989.

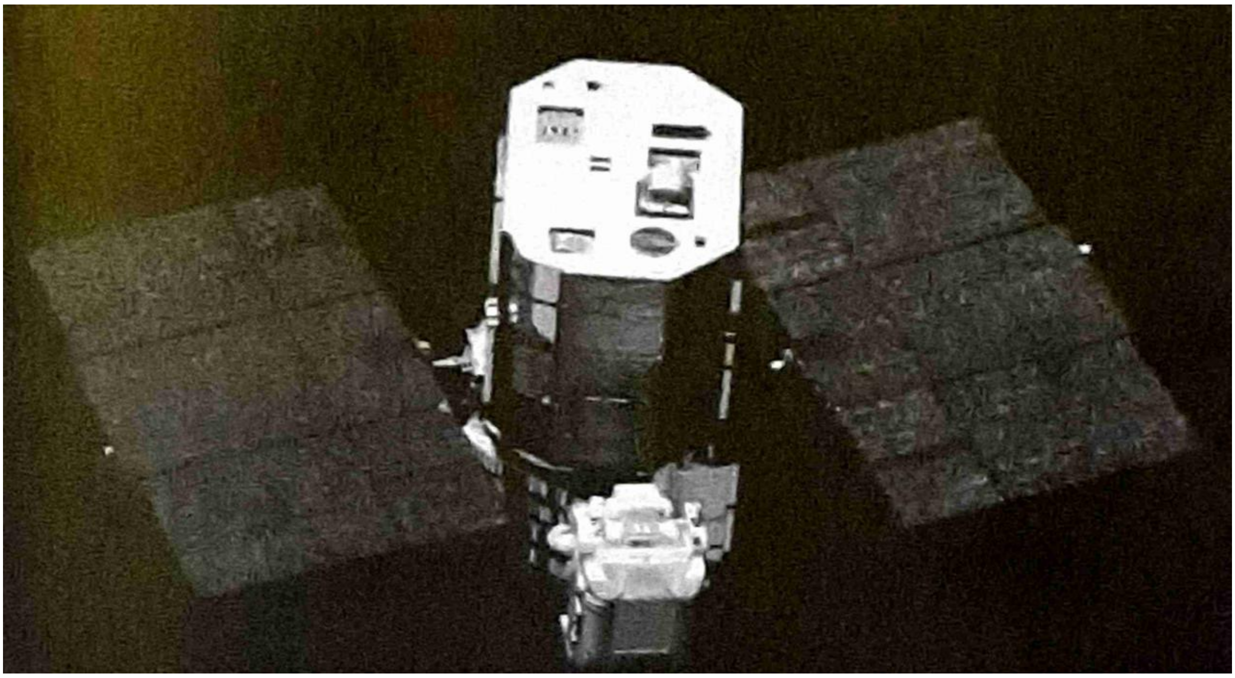

Fig.2: The Solar Maximum Mission (SMM) satellite was operated during 1980-1989. Repairs of the satellite were performed by "Pinky" Nelson and Dick Scobee from the Space Shuttle Challenger in April 1984.[14]

This was very novel of its kind not being only first but also equipped with advanced instruments of: a Gamma-Ray Spectrometer(GRS), a Hard X-Ray Burst Spectrometer (HXRBS), a Hard X-Ray Imaging Spectrometer (HXRIS), two soft X-ray Spectrometers [Bent Crystal Spectrometer (BCS) and Flat Crystal Spectrometer (FCS)], an Ultraviolet Spectrometer/Polarimeter (UVSP), a white light Coronagraph /Polarimeter (CP), an active cavity Radiometer Irradiance Monitor (ACRIM). This SMM made a number of scientific discoveries by observing around 12,000 solar flares and several hundred Coronal Mass Ejections (CME) which are summarised by Strong et al. 1999[5]. Nearly in same duration but for part of a solar cycle, a Japanese mission (Hinotori) was launched with similarinstrumentation from 21st February 1981 to 11th February 1982, and its details are comprehensively summarized in Makishima, 1982 [6] and Takakura et al. 1983a [7].

In April 1991, the Compton Gamma-Ray observatory (CGRO)was deployed by USto detect X-ray bursts from astrophysical and cosmological objects.

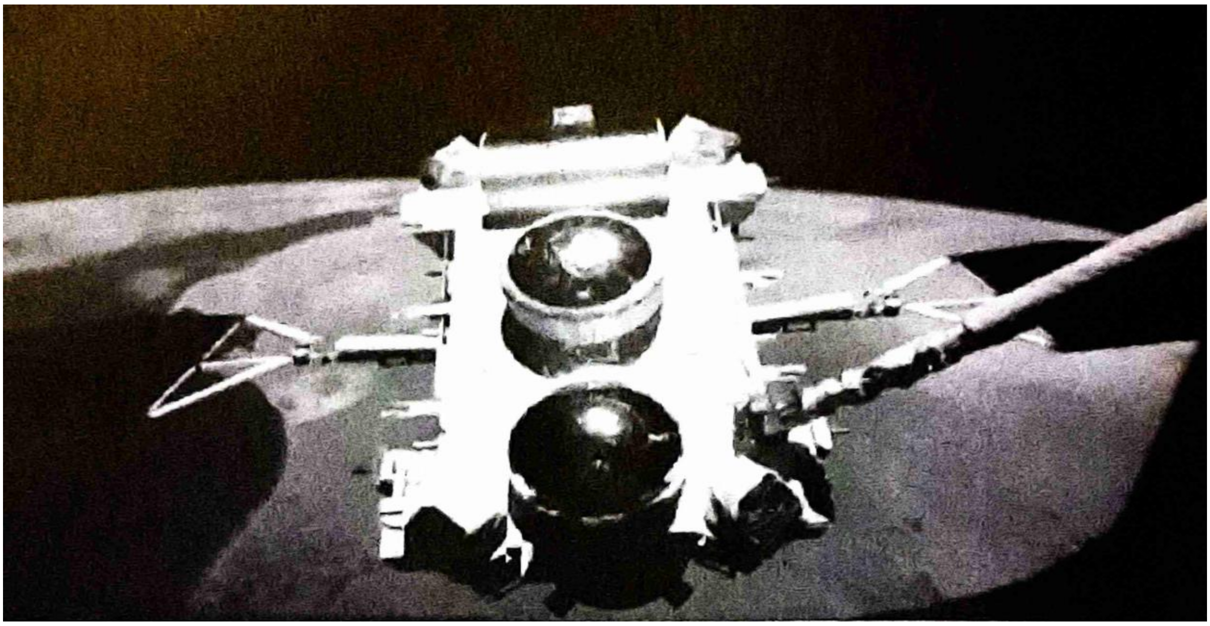

Fig.3: Deployment of the Compton Gamma-Ray Observatory (CGRO) in 1991.[14]

The novelty of this was that actually it recorded more high energy X-ray and hard X-ray photons from solar flares than from rest of the Universe, which was unexpected. Due its high sensitivity, in particular the Burst and Transient Source Experiment (BATSE) delivered unprecedented photon statistics, so that the energy-dependent electron time-of-flight delays could be determined in solar flares down to accuracies of milliseconds order and thus crucially contributed to a precise localisation of particle acceleration sources in solar flares. Crucial measurements of X-ray lines in a no. of large x-class flares were obtained from the Oriented Scintillation Spectrometer Experiment (OSSE) [8]. The CGRO recorded in total of some 8000 flares during its lifetime. The truck-heavy spacecraft was de-orbited by NASA in May 2000 because of its gyroscope malfunctions.

An advanced Japanese mission Yohkoh, Ogawara et al.1991 [9] was launched which provided a great breakthrough in soft X-ray imaging of solar corona and flares. This mission contained four instruments:

The Hard X-ray Telescope (HXT) with four energy channels and a spatial resolution of ≈ 8”, Kosugi et al. 1991[10]; the soft X-ray Telescope (SXT) with multiple filters sensitive to temperature of T> 1.5 MK, having a spatial resolution of 5” in full-disc images and 2.5” in partial frames, Tsuneta et al., 1991 [11]; a Wide Band Spectrometer (WBS) containing soft X-ray, hard X-ray and X-ray spectrometer, Yoshimori et al. 1991[12]; and a Bent Crystal Spectrometer (BCS), Culhane et al.1991 [13]. Soft X-rays images from the solar disc and from flare were provided by Yohkoh for about a full decade. Because of the observations obtained from the Yohkoh revelations about the geometry and topology of large-scale magnetic field configurations and magnetic connection processes in flares could be made for the very first time. However, in December 2001, the satellite lost its pointing due to an erroneous command during a solar eclipse.

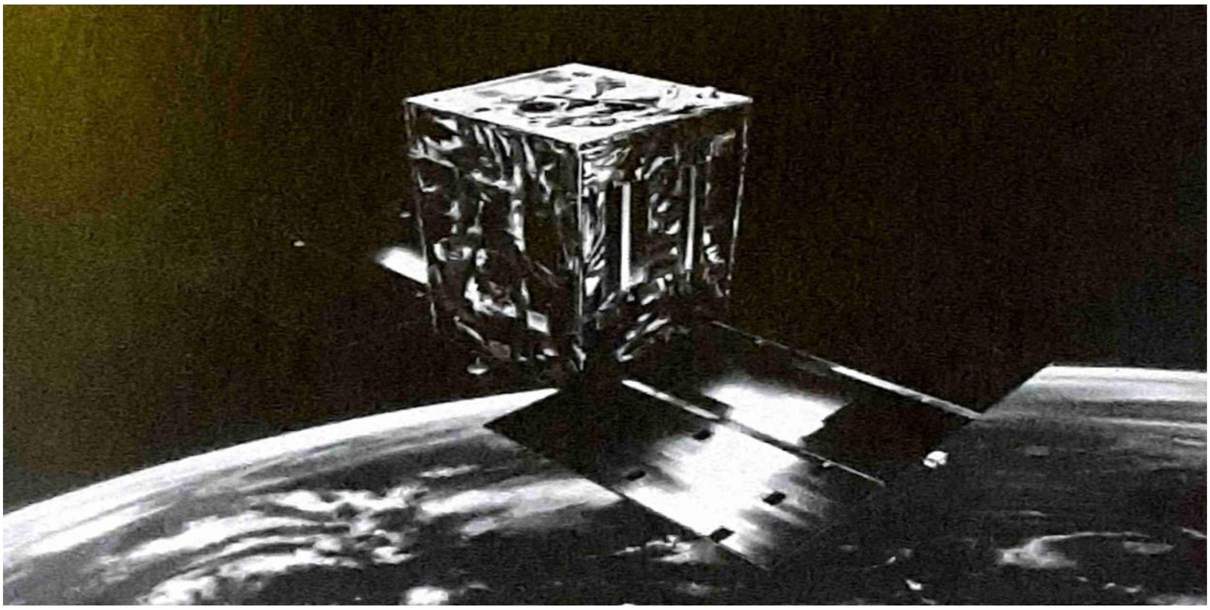

Fig.4: On 30 August 1991, the Yohkoh satellite was launched into space from the Kagoshima Space Centre (KSC) in Southern Japan [14].

For the first time a joint space mission was carried out by European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) to observe the sun from inside out to 30 solar radii in the heliosphere. Both organisationsjointly-built the spacecraft Solar and Heliosphere observatory (SOHO) which was launched it on 2nd December 1995. It is still being fully operational under extension agreements. Over 200 co-investigators participated in this mission along with 12 instrument teams.

The SoHO spacecraft includes following 12 instrument packages:

- 03 instruments for helioseismology:
  GOLF: Global Oscillations at Low Frequency
  VIRGO: Variability of solar Irradiance and Gravity Oscillations
  SOI/MDI: Solar Oscillations Investigations/Michelson Doppler Imager

- 05 instruments for observing the solar atmosphere:
  SUMER: Solar Ultraviolet Measurements of Emitted Radiation
  CDS: Coronal Diagnostic Spectrometer
  EIT: Extreme-Ultraviolet Imaging Telescope
  UVCS: Ultraviolet Coronagraph Spectrometer
  LASCO: Large Angle Solar Coronagraph
- 04 particle detector instruments that monitor the solar wind:
  CELIAS: Change Element and Isotope Analysis
  COSTEP: Comprehensive Supra Thermal and Energetic Particle Analyser
  ERNE: Energetic and Relativistic Nuclei and Electron Experiment
  SWAN: Solar Wind Anisotropies

It is shown in the following Fig.5. The SoHO observatory is a highly successful mission which still provides the data desired on dynamic processes in the solar corona.

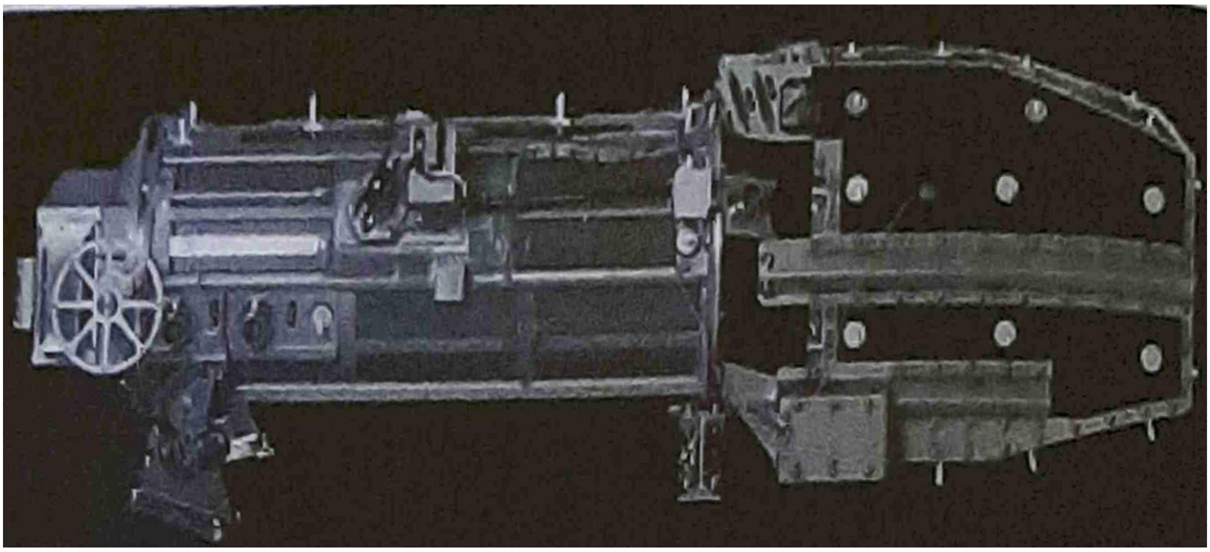

Fig.5: The Extreme-ultraviolet Imaging Telescope (EIT) on board the Solar and Heliospheric Observatory (SoHO) is a normal-incidence, multi-layer telescope (Delaboudiniere et al. 1995) [14].

Transition Region and Coronal Explorer (TRACE) was last but not the least solar mission of 20th century;as shown in the given figure.

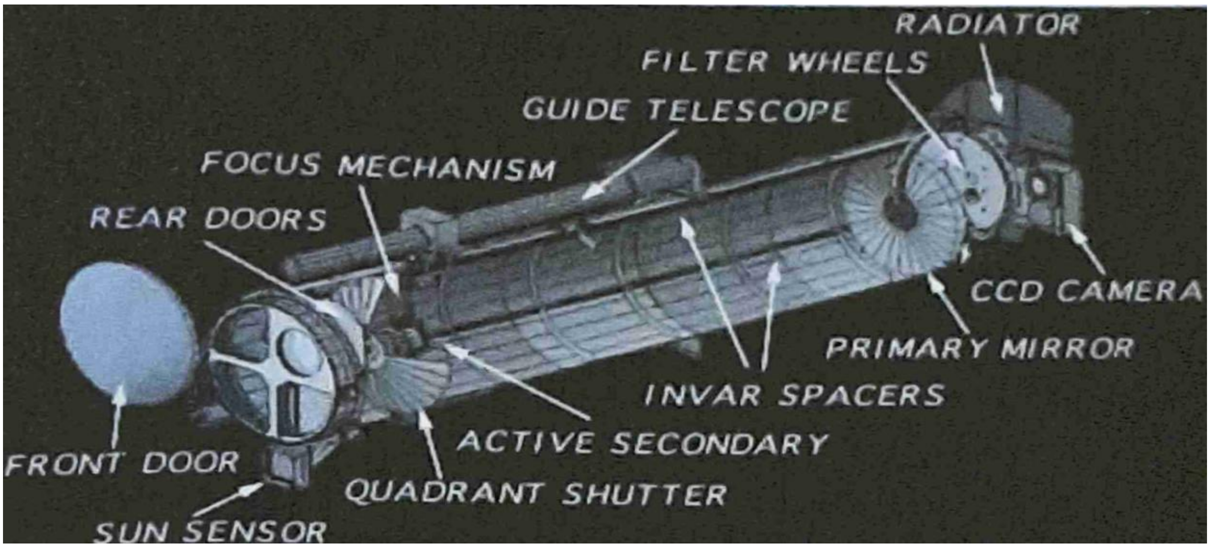

Fig.6: A cut-away view of the Transition Region and Coronal Explorer (TRACE) telescope is shown. The 30-cm aperture TRACE telescope uses four normal-incidence coatings for the EUV and UV on quadrants of the primary and secondary mirrors.[14]

It was launched on April 2, 1998 and was successfully operated till 21st June 2010 and was then deactivated. TRACE was created to explore the connections between fine-scale magnetic fields and the associated plasma structures on the Sun by providing high resolution images and observations of the Solar Photosphere, the Transition Region and the Solar coronaby NASA Heliophysics and Solar observatory. Fascinating details about coronal plasma dynamics, coronal heating and coolingwere revealed fromimages and observationsobtained from TRACE and about magnetic reconnection processes which were planned to be studied from the data supplied by the TRACE [14].

All over the world, the Imaging Radio Observations of the solar corona have mainly been accomplished by:

- The Culgoora Radioheliograph in Australia (1967-1984)
- The Nancy Radioheliograph in France (since 1977)
- The Very Large Array (VLA), in New Mexico (since 1980)
- The Owens Valley Radio Observatory (OVRO) in California (since 1978)
- The RATAN-600 in Russia (since 1972)
- The Nobeyama Radio Observatory in Japan (since 1992)

Along with these Radio Observatories, there is also a large number of Radio Spectrometers distributed all around the world with dynamic spectra of high temporal and spectral resolution which complement imaging radio telescopes in perfect way.

III. Analysis of Observations in various Solar Missions

3.1 First Mission (SMM):

In the first solar-dedicated space mission the SMM, the GRS was of energy range 10keV-160MeV, the HXRBS was of the energy range 20-300keV, the MXIS was of moderate spatial resolution 8" pixels in the energy range of 3.5-30keV; the BCS was of wavelength range 1.7-3.3A^o and the FCS was of wavelength range 1.4-22A^o, the UVSP was of wavelength range 1150-3600A^o, white-light CP was of wavelength range 4448-6543A^o and the ACRIM was in the ultraviolet and infrared wavelengths range.

3.2 Second Mission (CGRO):

In the second solar-dedicated space mission, CGRO, the BATSE was of very high sensitivity with collecting area of 2000 cm^2 in each of its 8 detectors having energy range of 25-300keV;The OSSE provided the γ-ray lines measurement in the energy range of 50keV-10MeV.

3.3 Third Mission (Yohkoh):

In the third solar-dedicated space mission Yohkoh, the HXT was equipped with four energy channels with energy range of: 14-23keV; 23-33keV; 33-53keV and 53-93keV with spatial resolution of ≈8"; the SXT with spatial resolution of 5" in full disc images and 2.5" in partial frames.

3.4 Fourth Mission (SoHO):

In the fourth solar-dedicated space mission, ESA/NASA jointly-built space craft SoHO, the SUMER telescope and spectrometer in the 500-1610A^o wavelength range, the EDS was in the wavelength range 150-800A^o, the EIT was in the wavelength range of Fe IX (171A^o, Fe XII (195A^o) , Fe XV (284A^o) and He II (304A^o)few full disc images; the UVCS was equipped to provide spectral line diagnostics between 1 and 3 solar radii; the LASCO was capable to provide the images of heliosphere ranging 1.1-30 solar radii.

3.5 Fifth Mission (TRACE):

In TRACE the last solar mission of the 20^{th} century, the 30-cm Cassegrain telescope works with a field of view (FOV) of 8.5x8.5 arc of minutes and it operates in 3 coronal EUV wavelengths (Fe IX/X, 171A^o; Fe XII/XXIV, 195A^o; and Fe XV, 248A^o) as well as in HI Layman-α (1216A^o), C IV (1550A^o) UV continuum (1600A^o) and white light (5000A^o). This wavelength set covers temperatures from 6000K-10MK with the main sensitivity for the EUV filters in the range of 1-2 MK.

IV. Conclusions:

i. To know and understand more deeper in terms of composition of a star like Sun and dynamics within an active region of it, we have to take images and other observations with higher and higher resolutions of energy, wavelengths and temperatures.

ii. Researchers were able to progress in the physical understanding of the structure and dynamics of solar-corona due to the high-resolution imagers which captured the Soft X-rays and Hard X-rays emitted by the solar corona in the EUV with greater precision and accuracy.

iii. The space mission images and observations facilitated the first decade of 21^{st} century to understand and formulate the concepts of: Coronal holes, Helmet streamers, Loop arcades, soft X-ray jets, Post flare loops,Cup-shaped loops, Sigmoid structures; Microflares and Nanoflares; Coronal mass ejections, Filaments and Prominences.

iv. All the observations, images and data, derived by all these solar missions described,immensely helpedin understanding the physics ofSolar Corona as:Solar magnetic cycle; Magnetic field pattern; Geometric concepts; Density structure; Temperature structure; Plasma-β parameter; Chemical composition and the Radiation Spectrum.

v. In the era of the versatility and sensitivity of space solar-missions, the ground-based observatories have their own importance. There are essentially two wavelength regimes: optical and radio wavelengths, that are observable from the ground itself and provides sufficient information of the solar corona emissions.

V. Suggested work:

- To illustrate the historical advancement in space solar missions during 2000-2020 of this 21st century.
- Idea and methodology to know about an object which does not emit forexample: dark matter.

References:

[1]. Guillermier, P.& Koutchmy S., 1999, *Total eclipse, science observations, myths and legends*, Springer-Praxis Series in Astronomy, Springer-Verlag, Berlin and Praxis Publishing Chichester, UK.
[2]. Bray, R.J., Cram, L.E., Durrant, C.J., and Loughhead, R.E., 1991, *Plasma Loops in the solar corona*, Cambridge University Press, Cambridge.
[3]. Alexander, D. & Action, L. W., 2002, *The Active Sun* (in Bleeker et al.2002).
[4]. Bleeker, J., Geiss, J.& Huber, M.C.E(eds.), 2002, *The Century of space science*, Kluwer Academic Publishers, Dordrecht, The Netherlands.
[5]. Strong, K.T., Saba, J.L.R, Haisch, B.M. et al.(eds), 1999, *The Many faces of the Sun*, a summary of the results from the NASA's Solar Maximum Mission, Springer, Berlin.
[6]. Makishima, K., 1982, *Proc*-1982-Tanaka, 120.
[7]. Takakura, T., Tsuneta, S., Nitta, N. et al., 1983a, *ApJ* 270, L83.
[8]. Kurfess, J.D., Bertsch, D.L., Fishman, G.J. et al., 1998, *Proc*-1998-Dermer, 509.
[9]. Ogawara, Y.; Takona, T., Kato, T., et al., 1991, *SP* 136, 1.
[10]. Kosugi, T., Makishima, K., Murakami, T., et al., 1991,*SP* 136, 17.
[11]. Tsuneta, S., Action, L., Bruner, M., et al., 1991, *SP* 136, 37.
[12]. Yoshimori, M., Okudaira, K., Hiroshima, Y., et al., 1991, *SP* 136, 69.
[13]. Culhane, J.L., Hiei, E., Doschek, G.A., et al., 1991, *SP* 136, 89.
[14]. Aschwanden, M.J., 2004, *Physics of Solar-Corona, an Introduction*, Springer, U.K.