31st ASI Meeting
ASI Conference Series, 2013, Vol. 9, pp 43 – 48
Edited by Pushpa Khare & C. H. Ishwara-Chandra

Solar coronal studies with Aditya-1 mission

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Abstract. Aditya-1 is India's first dedicated, low-earth dawn-dusk orbit, mission to study the Sun. The main payload on this mission is a visible emission line solar coronagraph to observe the solar corona simultaneously in the Green (Fe XIV) and Red (Fe X) emission lines over 3 solar radii ($\approx$ 1.5 degree) field-of-view (FOV). A larger FOV ($\approx$ 6 solar Radii; 3.0 degree) continuum channel is also added for the study of Coronal Mass Ejections (CMEs). The main scientific objectives of this mission are: (1) study of coronal wave heating mechanisms, (2) understanding the dynamical behaviour of small- and large-scale structures including the CMEs and (3) mapping the coronal magnetic topology. In this paper, a brief description of the scientific objectives are given. Some of the major technological challenges ahead during the payload realisation as well as in the data interpretation are also provided.

Keywords : solar corona – coronagraph – coronal mass ejections – coronal magnetic topology – temperature – density

1. Introduction

Aditya-1 is India's first dedicated solar mission in the low-earth orbit of around 800 km altitude. The uniqueness of this mission are: (i) to obtain high cadence, high spatial resolution and simultaneous coronal images in the visible emission lines, (ii) to obtain observations as close to the disk (targeted for 1.05 solar radii) as possible and (iii) to obtain simultaneous intensity or polarization images in the Green, Red and continuum channels. To achieve these objectives, a specialised instrument called an internally occulted coronagraph, (invented by Lyot; Lyot & Marshall (1933)), is being developed in order to observe the weak coronal signals ($\approx$ one millionth of the disk signal). The invention of the coronagraph has allowed coronal observations without

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the natural eclipses when the sky condition is good (especially with the aerosol and dust particle contents in the atmosphere). Such sky conditions are available only in very few places around the world and is limited to few months of a year. Space missions with coronagraph has advanced the knowledge on the coronal dynamics especially with respect to the coronal mass ejections (CMEs). However, such systems are low in spatial resolution as well as low time cadence limiting the coronal science which can be addressed. The low spatial resolution and time cadence realised so far are due to the limited payload volume and downlink capability of the earlier missions.

The planned visible emission line space solar coronagraph will provide high pixel resolution (1.4 arcsec) as well as large time cadence (upto 3-frames per second). Being a dedicated instrument with high data rate and large on-board storage capability, it will provide coronal data throughout the year which can be used to address some of the coronal science which was not feasible earlier from space. In this paper, we discuss the major science goals planned with the Aditya-1 mission. For a more detailed discussion on the science goals, the readers may go through the paper by Singh et al. (2011).

2. Primary science goals

The visible emission line space solar coronagraph was designed keeping in view the following primary science goals, (i) Studies of coronal mass ejections from 1.05 $R_\odot$ to 3.0 $R_\odot$, (ii) Polarization studies to derive the coronal magnetic topology and (iii) Small-scale coronal dynamics including the coronal oscillation studies.

2.1 Coronal mass ejections

Extensive studies on coronal mass ejections (CMEs) were already carried out by several authors using the LASCO coronagraphs aboard SoHO as well as with ground based radio observations. However, the studies carried out so far with the space coronagraphs were beyond 1.4 $R_\odot$. Lasco-C1 coronograph aboard SoHO yielded valuable coronal data below 1.4 $R_\odot$ and there have been interesting results from them, although its cadence and dynamic range were rather limited. At present, the understanding of CME initiation and acceleration in this height range is limited to inferences from on-disk data like EUV, soft X-ray and photospheric magnetograms. Extrapolations of CME height-time profile is used to study their dynamics close to the disk with limitations. Low frequency radio observations (Ramesh 2011) provide valuable data in this low height range albeit with their limited spatial resolution. However, the process of CME initiation ranges from a fraction of the active region size to nearly a solar radius with their timescales from few tenths of a second to several minutes. Limited high spatial and high temporal observations in the lower coronal regions (typically from 1.05 $R_\odot$ to 1.5 $R_\odot$) pose serious challenges in modeling CME initiation process.

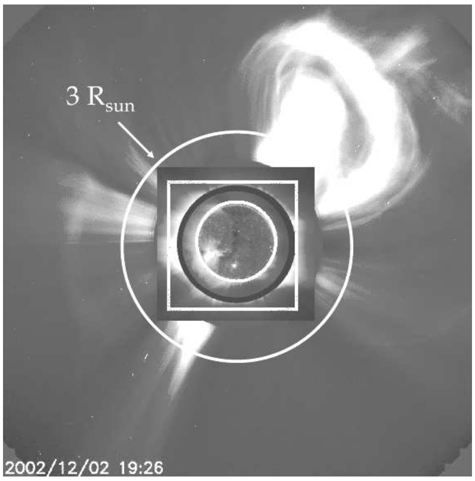

Figure 1. FOV of Aditya (white circle) on the composite picture obtained from SoHO.

Observations with the designed coronagraph for Aditya-1 will provide the required high spatial and temporal resolution data which will help us to understand the CME initiation process. CMEs are considered as the prime drivers for the inner solar system space environment and hence understanding their origin will provide us with a predictive capability which is a valuable information for space weather studies. A few possible important questions which can be addressed from this instrument are: (1) Does Coronal cavity/flux rope exist prior to eruption (Low 1996) or is a byproduct of reconnection (Antiochos et al. 1999)? Current observational evidence is available only for regions greater than 2 $R_\odot$, (2) Does the "trigger" reconnection initiation take place above (breakout model) or below (teether-cutting model)? and (3) Is magnetic complexity an absolute necessity for CME initiation, as required by the breakout model?

2.2 Coronal polarization

Measurement of coronal polarization in the emission lines and continuum provides information about the (i) coronal magnetic topology, (ii) coronal density and (iii) 3D diagnostics capability of CMEs. Field strength estimation requires very weak (0.01%) circular polarization measurement which will not be attempted in this mission. The linear polarization is insensitive to the total field strength but is either parallel or perpendicular to the direction of the magnetic field thus providing the coronal magnetic field topology. The magnetic topology will be useful in estimating the twist of the magnetic region to study eruptions like flare and CMEs in the corona. The coronal magnetic field measurements will still have to be relied upon the NLFF field type extrapolation using photospheric magnetograms or using radio measurement techniques at these heights (Ramesh et al. 2003). Combining the topology measurement along with the density diagnostics using the polarization brightness will provide valuable data on the evolution of large-scale structures in the corona like CMEs.

The polarization ratio method can be used to reconstruct the 3D structure of the CMEs. Though the first attempt in this direction was made very early (Poland & Munro 1976), the usefulness of this method was verified with the recent STEREO data (Moran & Davilla 2004; Dere et al. 2005; Mierla et al. 2008; Srivastava et al. 2009). The possible areas which can be addressed by this polarization measurements are: (1) Does CEL provide better estimates for the direction of the coronal magnetic field?, (2) Does the field direction provided by the high spatial resolution observations of CEL of coronal loops match with that of the intensity image?, and (3) Are there any large scale change in the topology of magnetic field before and after CMEs?

2.3 Coronal dynamics

It is believed that high frequency waves are one of the mechanisms which can heat the solar corona to million degrees (Stein & Leibacher 1974). Several studies have been carried out during solar eclipses for the detection of high frequency coronal waves using the visible emission lines (Koutchmy et al. 1983; Cowsik et al. 1999; Singh et al. 2009; Williams et al. 2001; Pasachoff et al. 2002).

Measurement of integrated line intensities in two different emission lines sensitive to two different coronal temperatures can provide accurate estimate of the coronal temperature using the well known line ratio method (Guhatakurta, 1993). It is observed using such measurements that some of the loop top shows hotter material whereas some other show cooler materials (Singh et al., 2004). It is important to measure the dynamics of these coronal loops in order to make a realistic model for the formation and evolution of these loops. These measurement can be compared with those obtained from EUV data though at the lower coronal heights. Some of the questions which can be answered with this mission are: (1) What are the source regions for high frequency coronal waves?, (2) How these waves related to density and temperature structures? and (3) Do all loops form by the same physical mechanisms? If so, why are some loop tops cooler and others hotter?

3. Summary

Aditya-1 aims at studying the solar coronal dynamics using the forbidden emission lines formed at the corona due to the high temperature and low density. The instrument is designed to be operated in different modes with flexibility so that any required observing program can be carried out. Table 1 lists out the basic modes of operation, its specifications and the main science objective for each mode.

There are several technological challenges to overcome for realising the payload.

Table 1. Basic modes of operation.

Modes	Channel	FOV ($R_\odot$)	Exposure (Sec)	Pixel Resolution (arcsec)	Main Science study
Mode-1	Green Red	1.05-1.5	0.25 - 1	1.4 - 14	Intensity Oscillation
Mode-2	Green Red	1.05-1.5	0.5 - 5	1.4 - 5.6	Loop Dynamics
Mode-3	Green Continuum	1.05 - 1.5	1 - 5	1.4 - 7	Magnetic Topology
Mode-4	Continuum	1.05 - 3.0	0.5 - 1	2.8 - 28	Coronal Mass Ejections

Notes: These modes are basic modes and different modes can be combined. Exposure time and pixel resolution are adjustable depending on the requirement.

The scientific objectives briefly described above require low scattered light coronagraphic system and large format fast read-out detectors. The coronagraph primary mirror needs to have very low micro-roughness ($\leq$1.5 Å) about an order better compared to regular telescope mirrors. Large FOV and high spatial resolution requires a large format (2K$\times$2K) detctor system. Fast read-out capability is essential to obtain data for high frequency oscillation studies. High spatial resolution and long observational requirements need high satellite and payload stability. The drift and jitter of the satellite has to be smaller than 0.25 arcsec/sec and 0.5 arcsec, respectively.

Solar corona is optically thin and hence all structures along the line-of-sight will contribute to the observed intensity and polarization. Forward modeling is absolutely necessary for proper interpretation of the observed data, especially while deriving the physical parameters and the magnetic topology at the corona (Judge 2002). The Aditya-1 mission along with the established facilities like Gauribidanur and Ooty Radio Telescope as well as the upcoming solar facilities like MAST and NLST will provide unique opportunities to study the solar atmosphere completely.

Acknowledgements

The author thanks the Aditya-1 core group as well as the science working group for their valuable inputs without which this paper would not have been possible.

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