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BEYOND ASTROSAT

# Beyond AstroSat: Astronomy missions under review

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**Abstract.** India has an expanding program in using space as a platform for research. Astrophysics research from satellites increasingly complement ground-based observations with unique wavelength coverage, more frequent temporal coverage and diffraction-limited observations. India's first dedicated space astronomy mission, AstroSat has completed five years in orbit and continues to generate important results. Most onboard systems are healthy and the mission is expected to continue to operate for many more years. Plans for space astronomy missions beyond AstroSat, are under discussion for some time. These are based on responses from the Indian research community to an announcement of Opportunity call in early 2018. Here we discuss, an outline of the science focus of future space astronomy missions, under consideration.

**Keywords.** Space astronomy—AstroSat—Indian space missions.

## 1. Introduction

With the advent of India's space program in the 60's, the country has sustained a modest but expanding program in space astronomy. As the country's launch capability rose, piggyback experiments evolved into full-scale dedicated satellites. AstroSat, India's first multiwavelength astronomy satellite (Rao *et al.* 2009), was a culmination of this effort with its launch in 2015 from the Satish Dhawan Space Center, Sriharikota using the highly dependable, PSLV rocket. AstroSat took two decades to emerge from initial discussions to realisation and launch. It had an important early phase involving numerous discussions and meetings among the research community in the country and ISRO teams, in evolving the thematic multiwavelength focus of the mission and to arrive at specific wavelength coverage desired of key experiments. It blended mature instrumentation techniques in the country with exploratory ones (e.g., UV detectors, X-ray optics and use of compound semiconductor X-ray detectors). AstroSat's unique proposal-driven observational program was a new experience for ISRO. It was also designed to respond quickly to Target-of-Opportunities when unexpected events/states occurring in cosmic sources, may force repointing of the spacecraft to new targets in the sky. This demands quick decision-making and disrupts ongoing observations, to maximise the science yield from the Observatory. The creation of Payload Operations Centers for each payload at associated lead institutes, has created an infrastructure for data transfer, data processing to higher level products and training of user scientists. This can be a continuing asset that can serve future space science programs. Finally, the integrated data repository for AstroSat, the Indian Space Science Data Center at Bylalu, near Bengaluru, has an experienced team in providing proposal processing support, data storage, archive and dissemination in accordance with ISRO release guidelines, to users around the world.

AstroSat created a new collaborative research environment in the country across many academic institutions and ISRO centers. The yearly cycle inviting scientific proposals to use AstroSat, has resulted in the creation of an active community of

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Indian astronomers, with many of the young researchers having matured adequately to contribute significantly to future programs. The AstroSat mission supplemented national efforts through the inclusion of international contributions (UK and Canada), thus building new bridges for global collaboration. This legacy built around the success of AstroSat, clearly should be leveraged to build and strengthen future space astronomy research in India.

## 2. Upcoming near-term astronomy missions

There are two astronomy missions already approved by the government and expected to be launched by ISRO in 2021, Xposat and Aditya-L1.

### 2.1 *Xposat*

Xposat will be the first of a new wave of X-ray polarimeters, emerging nearly 45 years after the first and only dedicated X-ray polarimeters in space which discovered polarisation from the Crab Nebula (Novick *et al.* 1972; Weisskopf *et al.* 1976). Xposat carries two X-ray payloads, POLIX and XSPECT. The X-ray polarimeter, POLIX (Rishin *et al.* 2010) measures intensity of polarised photons in the 8–30 keV energy range using the principle of Thompson scattering wherein the incident photon polarisation state defines a preferred scattering plane in aizmuth. It is made up of four orthogonally arranged position-sensing proportional counters into which incident X-ray photons are scattered from a Berilliyum disk scatterer. Xposat also carries a non-imaging, soft X-ray spectrometer (XSPECT), operating in the 0.8–15 keV range using an array of 16 large area swept charge detectors (each of 2 $cm^2$ geometric area) and good spectral resolution ($\sim$160 keV @ 6 keV). This is a near identical copy of the CLASS X-ray spectrometer, currently onboard Chandrayaan-2, being used to detect X-rays from the lunar surface (Radhakrishna *et al.* 2020). The observational program of POLIX involves long exposures ($\sim$a few weeks) at cosmic sources to reach a Minimum Detectable Polarisation (MDP) of 3% for bright sources (>40 milliCrab). A slow rotation ($\sim$0.2 rpm) about the view axis is planned to reduce impact of any unmodeled response of any of the four detectors, on the measured polarisation. This makes Xposat mission interesting for spacecraft operators, tasked with the delicate optimisation of maximising observation time with a rotating spacecraft during the night-side orbit and a non-rotating spacecraft during the sunlit part for charging of onboard batteries. The near-continuous, month-long spectral observations of the same source by the co-aligned XSPECT payload, adds unique data on the science of state transitions in binaries and could link polarisation and spectral state of source.

### 2.2 *Aditya-L1*

The question of what heats the solar corona is an important focus for the first dedicated solar mission from India. Utilising a slew of 7 payloads, Aditya-L1 observes the Sun with a high observational duty cycle from the unique vantage point of L1 (Seetha & Megala 2017). A Visible Emission Line Coronograph (VELC) (Prasad *et al.* 2017) observes specific lines of Fe XIV (530.3 nm), Fe XI (789.2 nm) and Fe XIII (1074.4 nm) with a spectral resolution of $\sim$30 mAng/pixel in the visible and $\sim$200 mAng/pixel in IR. The ability of the coronograph to observe the corona as close as $1.08R_{\rm sun}$ is an important capability of this instrument. The second major instrument is a UV imager with 11 filters (includes few narrow bands) covering the 200–400 nm range and used to monitor the total irradiance and to trace chromospheric activities (Tripathi *et al.* 2017). Two X-ray spectrometers provide the broad-band X-ray spectrum from solar flare events (Sankarasubramanian *et al.* 2017). These are well complemented by in-situ observations of particles and magnetic field measurements (Janardhan *et al.* 2017). This makes Aditya-L1 a unique solar observational facility in space. Together with the Parker probe (NASA) (Neugebauer *et al.* 2020) and the Solar Orbiter (ESA) (Muller *et al.* 2020), Aditya-L1 forms a trio of contemporaneous advanced solar missions for the global solar research community.

## 3. Future astronomy missions

AstroSat has created a large pool of user scientists and students in the country. For future programs to build on this success, it must further enhance the number and scope of new users and attract newer institutions into the critical areas of design and development of space payloads, advanced instrument calibration, analysis techniques and data modeling. Further, it must provide a platform for increased collaborations across institutes and academia and train a larger number of post-graduate students in the country in space science research.

In early 2018, ISRO invited proposals for new missions/experiments under an Announcement of Opportunity call, towards evolving a robust plan for future space astronomy missions following AstroSat. More than twenty proposals addressing missions to study the microwave background, UV, IR and exoplanet spectroscopy, X-ray polarimeters, solar missions and observational electromagnetic counterpart of gravitational merger events, were received and reviewed.

The review committee recommended the need to merge independent experiment proposals addressing both solar physics and those more aligned to space weather research, into a comprehensive solar mission as a follow-on mission to Aditya-L1. Motivated by the success of AstroSat, and a desire to build on the expected outcome from the soon-to-be launched Xposat mission, the high-energy community in India has expressed its keen interest for a broad-band (soft to hard X-rays) X-ray polarimetry mission. Multiple proposals addressing this research area were also requested to combine the requirements into a more optimised X-ray mission, retaining the polarimetric focus. This program requires initiating steps to strengthen key technologies that include multi-layer X-ray optics development, essential to increase the numerical aperture at hard X-rays. This exercise towards evolving a comprehensive, globally-competitive X-ray mission is still underway. A major mission concept addressing the next advancement in the cosmic microwave background studies, was also proposed. The associated development of many new technologies and the overall high cost of such a mission, could be partially justified through capacity building in the country in specific areas. Developmental initiatives in select high technology areas at academic/research institutes could enable such opportunities.

The review process short listed a few missions in these specific areas of research. These are discussed in brief:

### 3.1 *Exoplanet research*

The last 25 years of research on exoplanets has resulted in the emergence of an exciting field of study with current focus in two broad areas:

(1) discovery of more planets and
(2) improved characterisation of known ones.

The astronomy community in India and a small group from UK, led by the Indian Institute of Space Science and Technology (IIST), has embarked on a focused program to address the second area, specifically to study atmospheric composition of exoplanets using moderate to low-resolution spectroscopic observations across IR, optical and UV bands. To achieve adequate signal-to-noise ratio and photometric precision, this mission demands a large collecting optics of $\sim$2 meters and a parking orbit that shields the experiment from the thermal effects of Sun and Earth. Currently, a study has been undertaken to explore the feasibility of accommodating a large aperture telescope into ISRO's rocket with the largest faring, for a mission that places this experiment at about 1.5 million kilometers away from Earth, at the Sun–Earth Lagrange point 2.

### 3.2 *Gravitational wave followup*

The exciting discovery of gravitational waves by LIGO (Abbott *et al.* 2016) has paved the way for a long anticipated pursuit of gravitational wave astronomy to study astrophysical sources. The discovery of exciting signal from the coalescence of a binary neutron star system in 2017 (Abbott *et al.* 2017) and the subsequent discovery of associated emission at other wavelengths, triggered the hunt for detection of prompt emission from such events. A team led by the Indian Institute of Technology Bombay has proposed to build an all-sky X-ray detector that can see the prompt emission from such merger events and provide significantly improved localisation for other observatories to pursue deep, sensitive search for counterparts. The proposed twin satellite system which is required to ensure all-sky coverage, free of Earth occultation, has to be prototyped, designed and built in a short time to exploit the current observational gap.

### 3.3 *Search for epoch of re-ionisation signal*

The discovery of a redshifted 21-cm line feature at $\sim$70 MHz (Bowman *et al.* 2018) from the period of cosmic dawn has triggered a new interest globally to search for clear signatures from the Epoch of reionisation. It is believed that this is the period when the first stars and galaxies were formed. This is a very faint signal buried in the bright radio synchrotron emission of our galaxy from electrons interacting with the galactic magnetic field. The proposed experiment attempts to improve upon the ground-based developments (Girish *et al.* 2020) in this effort and reach sensitivities that are nearly a million times weaker than the foreground galactic emission using the unique vantage point of a far side lunar orbit. The blocking of the Radio Frequency Interference (RFI) noise from Earth by more than 70 dB, enables such a high sensitivity observation. This effort is being led by scientists at the Raman Research Institute (RRI).

### 3.4 *Advanced UV imaging and spectroscopy*

UV astronomy research has grown with the availability of high-resolution images from UVIT on AstroSat. This has triggered a strong desire for a UV spectroscopy mission. A new mission concept, led by the Indian Institute of Astrophysics (IIA) in partnership with Canada, is under review. It proposes a UV mission with moderate spectral resolution and an order of magnitude improvement in angular resolution over UVIT. It incorporates multi-object spectroscopic observation mode for a subset of the field-of-view (FoV) and slit-less spectroscopy over the full FOV. In addition to the usual astrophysical targets for focussed studies, this mission also attempts to carry out limited surveys of star-forming galaxies, tracing quasar outflows and UV studies of interacting galaxies. Such high angular resolution imaging and wide-field spectroscopy require fine-guidance systems, large advanced detector arrays, capability to select specific objects in the FoV for spectroscopic studies, etc. These are new and interesting challenges for the research community to pursue and are being partly addressed under a pre-project funding program.

## 4. Summary

The successful AstroSat mission has brought together a larger community of astronomers who are keen to work across wavelength regimes to address specific astrophysical problems. Major ground-based facilities accessible to Indian astronomers like the upgraded GMRT, the upgraded Ooty radio telescope, the upcoming large TeV Imaging telescope (MACE) and the new 3.6-m Devasthal Optical Telescope, are now being expanded in a major way with the Indian participation in Mega-projects like the Square Kilometer Array (SKA), the Thirty Meter Telescope (TMT) and the LIGO-India program. The new Indian space astronomy missions discussed here, build on existing strengths, both in research areas and experimental capabilities, but is also designed to push the community in India into new, challenging areas of technology, research pursuits and wider collaborations. An early success with the ongoing technology prototyping phase of short-listed proposals, will be key towards seeking formal government approvals for some of these proposed space astronomy missions.

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