

Scanning Sky Monitor on-board AstroSat

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Scanning Sky Monitor (SSM) on-board AstroSat is a wide-field imager to monitor the X-ray sky in the energy band 2.5–10 keV. The primary science objective of SSM is to detect and locate transient X-ray sources in the sky. Once detected the information is to be provided to the astronomical community for follow-up observations to do a more detailed study of the source. Long-term monitoring of known X-ray transient sources is also one of the science objectives of SSM. The instrument constitutes three units of 1D position-sensitive proportional counters with coded masks on each, all three mounted on a platform capable of rotation to scan about 50% of the sky in one full rotation. The angular resolution of each unit in SSM is $12' \times 2.5^\circ$. Sensitivity of SSM is ~ 30 milliCrab at 3 sigma in 10 min integration time. This article briefly discusses the instrument and a few early results since the launch of AstroSat.

Keywords:

Introduction

ASTROSAT^{1,2}, India's first multi-wavelength satellite to observe the Universe in the broad energy band spanning from optical, near-UV (NUV), far-UV (FUV), soft X-rays to hard X-rays, was launched on 28 September 2015, by the Indian Space Research Organization (ISRO). There are five payloads on-board AstroSat: Ultra Violet Imaging Telescope (UVIT), Soft X-ray Telescope (SXT), Scanning Sky Monitor (SSM), Large Area X-ray Proportional Counter (LAXPC) and Cadmium–Zinc Telluride Imager (CZTI).

X-ray transients are the brightest class of X-ray objects in the sky. These transient X-ray sources, which are usually below detection level, exhibit increase in their

intensities by factors of few tens to hundreds, which in turn can be different every time an outburst occurs. It is necessary to detect these transient sources during the outbursts for a detailed study of the emission mechanisms and the physics driving such intense X-ray emissions. In order to detect these sources during an outburst, it is required to keep scanning as much of the sky as possible with wide-field instruments, called sky monitors, which detect and locate these sources in the sky.

A number of Sky monitors own till date have helped discover several of X-ray sources and a fairly good knowledge of these systems exists today due to detailed study of these sources. The All Sky Monitor (ASM) on RXTE³ had done long-term observations of the X-ray sky adding a number of new X-ray sources to the already existing source catalogue generated by earlier sky monitors. SSM⁴ on-board AstroSat is a wide field X-ray sky imager to scan the sky for X-ray transient sources in the energy range 2.5–10 keV. At present, in addition to SSM onboard AstroSat, the Monitor of All-sky X-ray Image (MAXI)⁵ on-board the International Space Station (ISS) is doing an all-sky survey for X-ray sources.

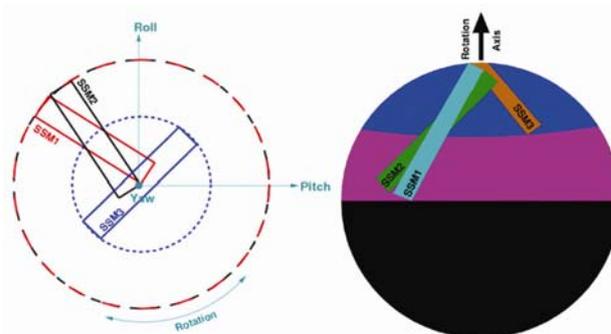


Figure 1. (Left) FOVs of three units of the scanning sky monitor (SSM). (Right) Sky coverage in one full rotation of SSM. Blue region is covered by SSM3, while blue and purple together are covered by SSM1 and SSM2.

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SPECIAL SECTION:

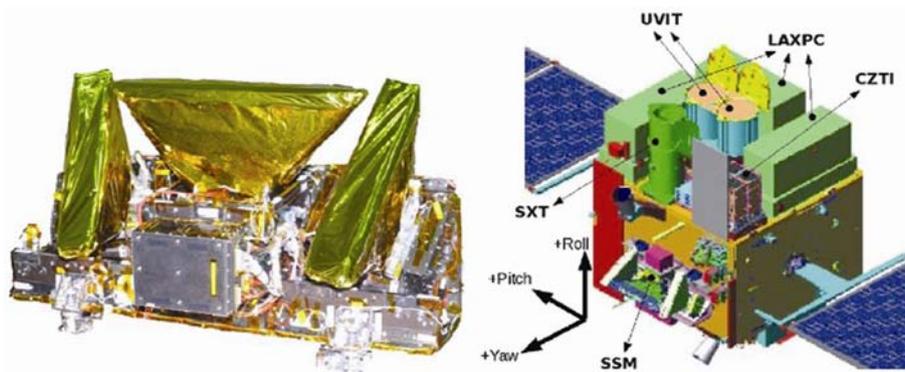


Figure 2. (Left) Photograph of SSM flight payload⁷. (Right) Schematic of AstroSat.

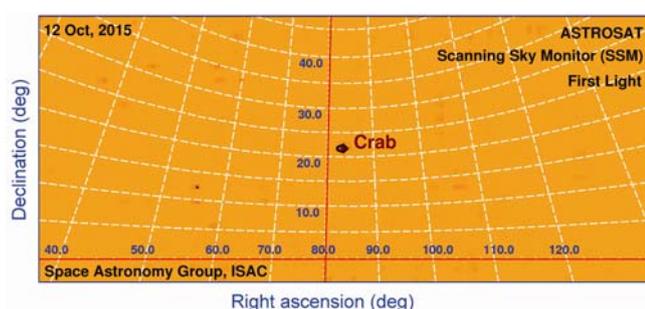


Figure 3. X-ray sky image with Crab at the centre of the FOV as observed by SSM1 (ref. 7).

Instrument details

Scanning Sky Monitor, as the name suggests, is a sky monitor with wide-field imaging capability with 1D coded mask, a first of its kind in India, with every element of it made indigenously. It comprises of three almost identical, position-sensitive, gas-filled proportional counters. Each unit has a collimator to define its field of view (FOV) with a 1-D coded mask mounted at the top. The wide-field imaging in SSM to find the location of the transient is possible with the help of the coded mask and the position-sensing capability of the anode wires in the detectors. Each unit has its own electronics associated with it to do the processing of every event incident on the detector. Each camera has a FOV of $\sim 22^\circ \times 100^\circ$ (for centre SSM) and $\sim 26.8^\circ \times 100^\circ$ (for edge SSMs). The two edge cameras (SSM1 and SSM2) are slanted with respect to each other and overlap near their centres, as shown in Figure 1. The angular separation between the long axes of these cameras is 24° . This arrangements enables one to obtain better localization for any source along the long (Y) axis of the camera, which for a single camera reconstruction is geometrically limited to about 2.5° . The two edge cameras are canted by 45° from the base of the platform. Figure 1 also shows the sky coverage in one full rotation of SSM. SSM scans almost 50% of the sky in one full rotation.

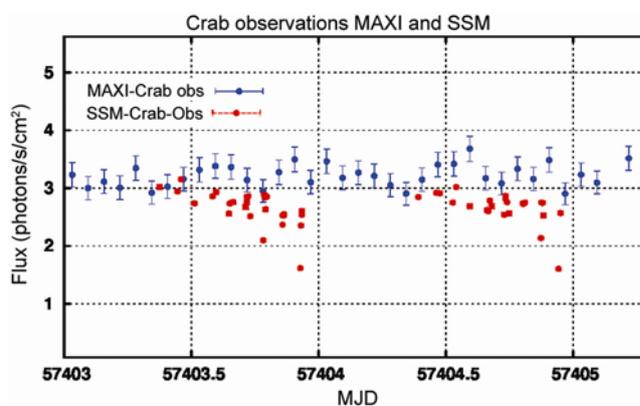


Figure 4. Light of the X-ray source, Crab, by SSM as observed during January 2016. The flux reported by SSM is compared with that of MAXI.

The three detector units and all the associated electronics boxes are mounted on a platform capable of rotation. Figure 2 shows a photograph of the three cameras of SSM with electronics mounted on a single platform. The platform can be rotated with the help of a rotating mechanism⁸ and its respective electronics, so that the instrument can scan the sky. SSM is mounted on the +YAW side of the spacecraft, as shown in Figure 2. All the other instruments point to the +ROLL axis of the spacecraft. More detailed description of the instrument can be found in Ramadevi *et al.*⁹.

Angular resolution of SSM is 12 arcmin in the coding direction and that across is 2.5° . Energy resolution of SSM is about 25% at 6 keV, and position resolution is ~ 1 mm at 6 keV. Sensitivity of each SSM unit is ~ 30 milliCrab at 3 sigma for 10 min integration. SSM with its large FOV covers almost 50% of the sky in 6 h in step and stare mode of 10° step with stare time of 10 min each, with one full rotation of the platform.

On-board performance of SSM

Following the successful launch of AstroSat on 28 September 2015, SSM was powered ON, on the 12

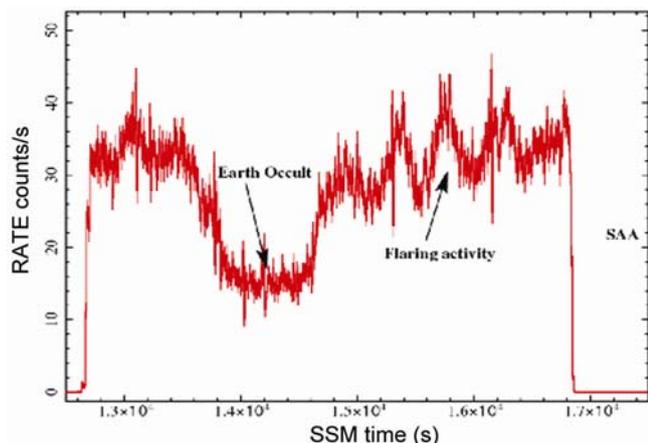


Figure 5. Light curve of the Be X-ray Pulsar, 4U0115 + 63, during its outburst in October 2015, as observed by SSM from one of the orbits. Temporal data from SSM of the FOV with the bright pulsar are plotted, showing the flaring activity of the pulsar.

October 2015. The standard X-ray source Crab was in the field of view of SSM1 and SSM2 cameras during the first power ON, while SSM3 was seeing a different FOV in the sky.

The first orbit data with filtration of events from SAA regions and Earth-occult regions were processed to get the sky image with Crab at the centre of its FOV (Figure 3)⁷. Figure 4 shows the light curve of Crab X-ray source, for a short period, generated with flux extraction of the source after coded-mask imaging. The light curve is compared with the corresponding light curve from MAXI⁵ which is a sky monitor by JAXA on-board ISS at present. It can be seen that there is a one day periodic variation in the light curve, expected to be due to orbital variations that needs to be modelled and removed, which is underway. More information on initial results can be found in Ramadevi *et al.*¹⁰.

Conclusion

Following the successful power ON of all the three SSM cameras, various interesting observations were carried out. These include detecting the beta class variability of the enigmatic black hole source GRS 1915+105 (ref. 11) and detecting pulsations in known pulsars like Cen X3, Vela X1 and Her X1. Also the Be X-ray pulsar 4U 0115 + 63 was caught in its outburst in October 2015 and

pulsations were detected in the source. Figure 5 shows a select region of the light curve of the Be pulsar during its outburst, which is generated from the temporal data of SSM. With all these interesting results in the initial phase of operation, SSM is expected to bring out more interesting observations in its current phase of operations.

1. Agrawal, P. C., A broad spectral band Indian Astronomy satellite AstroSat. *Adv. Space Res.*, 2006, **38**, 2989-2994.
2. Singh, K. P. *et al.*, AstroSat mission. *Proc. SPIE*, 2014, **91442T**, 9144-100; doi:10.1117/12.2062667.
3. Levine, A. M. *et al.*, First results from the All-Sky Monitor on the Rossi X-ray Timing Explorer. *ApJ*, 1996, **469**, L33.
4. Seetha, S. *et al.*, The Scanning Sky Monitor (SSM) on AstroSat. *Adv. Space Res.*, 2006, **38**, 2995-2998.
5. Matsuoka, M. *et al.*, The MAXI Mission on the ISS: science and instruments for monitoring All-Sky X-ray images. *PASJ*, 2009, **61**, 999.
6. Ramadevi, M. C. and Seetha, S., RXTE observations of a new X-ray transient SWIFT J1753.5-0127 in its low/hard state outburst. *Mon. Not. R. Astron. Soc.*, 2007, **378**, 182-188.
7. Ramadevi, M. C. *et al.*, Scanning Sky Monitor (SSM) on-board AstroSat, submitted to *Experimental Astronomy*, December 2016.
8. Balaji K., Narendra, S., Nagesh, G., Sridharamurthy, V. and Bhat, N. C., Development of mechanisms for AstroSat. In *Proceedings of the 5th National Seminar and Exhibition on Aerospace and Related Mechanisms*, ISRO Satellite Centre, Bengaluru, 18-19 November 2005, ARMS-05-MSA-02, pp. 67-73.
9. Ramadevi, M. C., Seetha, S., Babu, V. C. Ashoka, B. N. and Sree-kumar, P., Optimization of gas proportional counters for Scanning Sky Monitor (SSM) onboard AstroSat, *Adv. Space Res.*, 2006, **38**, 3002-3004.
10. Ramadevi, M. C. *et al.*, Early in-orbit performance of Scanning Sky Monitor onboard AstroSat, submitted to *JAA*, December 2016.
11. Ramadevi, M. C. *et al.*, Detection of beta-class variability in black hole source GRS 1915 + 105 by AstroSat Scanning Sky Monitor. *The Astronomer's Telegram ATel #8185*, 2015.

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