Nuclear Instruments and Methods in Physics Research A 808 (2016) 11–20

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

The loss cone imager

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ARTICLE INFO

Article history:
Received 10 August 2015
Received in revised form
30 October 2015
Accepted 5 November 2015
Available online 19 November 2015

Keywords:
Electron spectrometer
Solid state detector
Electron
Collimator
Radiation belts
Loss cone

ABSTRACT

The Loss Cone Imager (LCI) instrument package on the US Air Force's Demonstration and Science eXperiment (DSX) mission is expected to provide in-situ measurements of energetic charged particles in the Earth's radiation belts. The LCI comprises an 18-pixel imaging electron spectrometer known as the Fixed Sensor Head (FSH) and a single pixel, narrow view angle, large geometric factor, charged particle telescope known as the High-Sensitivity Telescope (HST). The LCI is anticipated to be flown in a 6000 km × 12,000 km orbit at 42° inclination to allow sampling of the inner and outer radiation belts as well as the slot region.

1. Introduction

The mission of the Demonstration and Science Experiments (DSX) satellite being developed by the Air Force Research Laboratory, Space Vehicles Directorate (AFRL/RV) is to "…research technologies needed to significantly advance Department of Defense (DoD) capabilities to operate spacecraft in the harsh radiation environment of Medium-Earth Orbits (MEO)" [1]. One of the significant features of the MEO environment is the intense fluxes of very energetic electrons that are trapped by the geomagnetic field in stable radiation belts. For electrons these belts, known as the Van Allen radiation belts, typically consist of an inner and an outer zone separated by a "slot" region. The existence of the slot region remains an active topic of research. Electromagnetic waves in the VLF frequency range are believed to interact with the trapped electrons and deplete their fluxes in the slot region. The ratio of the velocity components of these electrons parallel to and perpendicular to the local geomagnetic field defines a parameter known as the electron pitch angle. As the magnitude of $v_{\parallel}$ increases with respect to $v_{\perp}$ the electron will mirror closer to the atmosphere. The VLF waves present in this region resonate with the gyrating electrons and extract energy from the perpendicular component of the electron's velocity. There are multiple sources which can introduce VLF waves into the magnetospheric slot region such as lighting from thunderstorms and harmonics of the man-made power grids around the world. An additional source of these waves can be produced locally by plasma instabilities such as the whister-mode instability of Kennel and Petschek [2]. The slot is continually being replenished by fluxes which are radially diffusing inward while conserving their first two adiabatic invariants. This is particularly noteable during and following large geomagnetic storms [3]. Recent measurements from the Van Allen probes have demonstrated that there are processes at work in the slot that may actually energize electrons with chorus wave heating associated with the plasmapause or fast magnetosonic waves active in the slot region [4]. Such wave heating has been proposed to explain some unexpected electron pitch angle distributions observed in the slot. The main objective for the DSX space flight experiment is to investigate and quantify the electromagnetic wave–particle interactions in the MEO region of space by resolving the critical feasibility issues of injecting VLF waves into the magnetosphere to determine how efficiently, how effectively, and to what degree of efficacy this can be accomplished and to what degree the electron pitch angle distribution can be modified [1]. The determination of these effects will be the primary responsibility of the instrument known as the Loss Cone Imager (LCI).

The Loss Cone Imager is an instrument package developed to measure the energy and pitch angle distribution of trapped energetic particles with a particular focus on the loss cone. The LCI

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http://dx.doi.org/10.1016/j.nima.2015.11.010

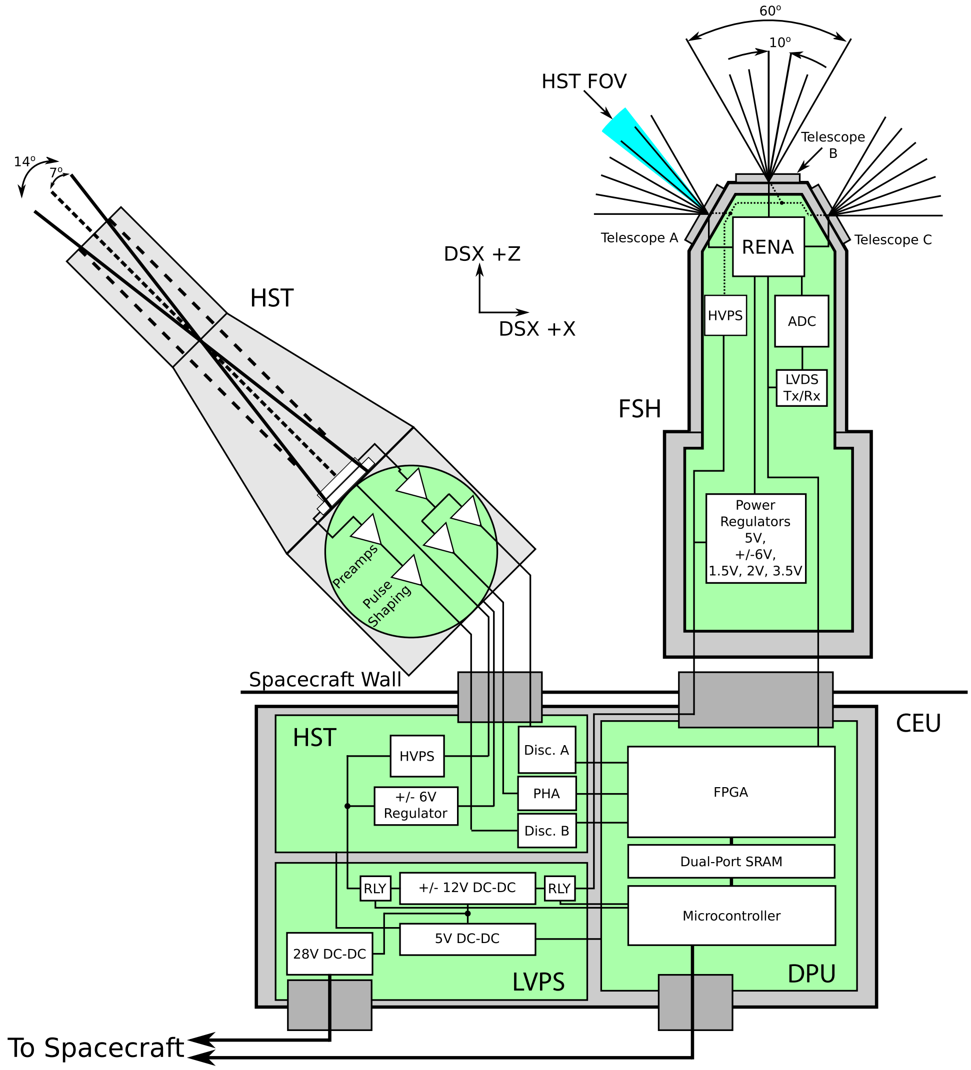

Fig. 1. A block diagram of the LCI package comprising the Fixed Sensor Head (FSH), High Sensitivity Telescope (HST), and Central Processing Unit.

comprises an imaging electron spectrometer (FSH), a large geometrical factor telescope (HST), and a digital processing unit (DPU). A block diagram of the LCI is shown in Fig. 1. The FSH and HST are capable of independent operation. The DSX spacecraft will have a loss-cone tracking mode in which the attitude of the spacecraft will be maintained such that the HST field-of-view (FOV) is pointed along the local geomagnetic field vector and the FSH is observing the local pitch-angle distribution.

The LCI is expected to provide a characterization of the loss-cone flux, with the pitch angle context, as it responds to various stimuli including lightning, ground-based VLF transmitters, and space-based VLF transmitters. To do this, the FSH is expected to measure the local pitch-angle distribution and flux of 30–550 keV particles with a sampling rate of 2, 6, or 20 Hz and an energy resolution of 2.4 keV. The HST is expected to simultaneously measure the loss-cone flux of 30–850 keV particles with pitch-angles of less than 7° from field-aligned, and an energy resolution of 3.7 keV. Both instruments are controlled by the DPU which aggregates their data and handles all communication with the spacecraft. The LCI parameters are summarized in Table 1. The fields-of-view of the instruments are shown with respect to the spacecraft coordinate system in Fig. 2.

Table 1
Summary of LCI parameters.

Parameter	FSH	HST
Detector type	6-pixel Si PIP	Si surface barrier
Detector thickness (μm)	1000	1500, 1000
Geometrical factor ($cm^2 sr$)	0.0045 (18 × 0.00025)	0.088
Energy range (keV)	30–550	30–850
Energy resolution (keV)	2.4	3.7
Sampling rates (Hz)	2, 6, 20	2, 6, 20/100
Event channels	5	11
FOV	18 × 10° × 10°	7° half cone angle
Look direction (center, DSX XZ plane)	$+Z_{DSX}$	45° from $+Z_{DSX}$ towards $-X_{DSX}$
Mass (kg)	2.44	7.5
Power (W)	4.2	2.8

2. Fixed sensor head

The Fixed Sensor Head, based on the imaging electron spectrometers from the previous Cluster [5] and POLAR [6] missions, was developed as part of the dissertation work of David L. Voss while at Boston University [7]. The term *fixed* differentiates the instrument from a series of prior mechanical configurations in