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CENSSAT-1 mission concept: a CubeSat for space weather monitoring

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Abstract: This paper presents an introduction to the CENSSAT-1 mission, an 8U CubeSat, which aims to study space situational awareness. It will investigate the effects of space weather on Earth from a 500 km orbit, using a camera, multi-purpose particle detector, and a Langmuir probe. It will additionally monitor space debris using a radar instrument, and conduct experiments on optimal control and drag based manoeuvring. CENSSAT-1 is aiming for launch in 2027.

1 Introduction

The Centre for Space Sensors and Systems (CENSSS) is designing its first CubeSat - a space situational awareness platform to monitor space weather and debris. Hosted at the University of Oslo (UiO), with collaboration from industry and university partners, the 8U CubeSat (CENSSAT-1) will feature a novel collection of sensors designed to monitor the flux of solar energetic particles at Earth and characterise their effect on the Earth's atmosphere – effects such as aurora, airglow, and ozone depletion.
This paper will cover the science goals, the payloads that have been designed to meet these objectives, and the mission that will launch those payloads. Some of this has been

presented in a previous publication[1], since which time many of the unspecified details have been updated in preparation for the procurement of the satellite bus. In addition, the University of Tromsø – The Arctic University of Norway (UiT) have recently joined CENSSS, and are contributing two payloads to the mission: a space debris radar, and drag-based control experiments.

2 Science Case

CENSSAT-1 will be used to achieve multiple scientific objectives, with the primary aim of the mission being to investigate the effect of solar events on the Earths atmosphere. Solar events are enhancements in the solar wind plasma and particle environment, caused by, for example, Coronal Mass Ejections (CMEs) and solar flares. Energetic particles can originate from outside of the solar system in distant stellar phenomena, and events such as Gamma Ray Bursts (GRBs) create particle showers when impacting the upper atmosphere - all of which contribute to the flow of particles that impact on the Earth.

Upon reaching the Earth, Solar Energetic Particles (SEPs) interact with the environment in several distinct ways. Particles injected into the magnetosphere can affect the plasma environment in the ionosphere, which in turn impact airglow and can create aurora. The precipitation of charged particles, resulting from interactions in the upper atmosphere, can create reactive species which destroy ozone through catalytic reactions[2] .

The scientific objectives, shown in Table 1, drive the design of the mission and payloads. To further compliment this goal, UiT are contributing two space environment related objectives: a study on space debris [SO-5] and study on orbital drag [SO-6] - a process that could depend on the conditions of the local plasma environment.

Table 1: Table of the scientific objectives for CENSSAT-1.

ID	Description
SO-1	The mission shall investigate the effects of transient solar events and local plasma parameters of atmospheric emissions and ozone content within the upper atmosphere.
SO-1.1	The mission shall investigate how plasma parameters are affected by various solar transient events.
SO-1.2	The mission shall investigate the link between plasma parameters, SEPs and auroral emissions intensity and peak height.
SO-1.3	The mission shall investigate how plasma parameter variations impact airglow intensity and peak height.
SO-1.4	The mission shall investigate changes to ozone following SEP events.
SO-2	The mission shall take measurements of neutron lifetime.
SO-3	The mission shall investigate how the Earth is affected by GRB.
SO-4	The mission shall perform optimal control experiments.
SO-5	The mission shall demonstrate capabilities for detecting mm-sized space debris.
SO-6	The mission shall perform orbital drag experiments.

Finally, CENSSSat-1 will develop, test, and flight-validate a novel optimal control strategy based on model-predictive control with frequency-domain guarantees [SO-04].

3 Payloads

To meet the science objectives four hardware payloads and two software payloads are under design. The hardware payloads are: a camera, a multi-purpose particle detector (ASTRA-LEO), a multi-Needle Langmuir Probe (m-NLP), and a space debris radar. The software payloads are an optimal control experiment, and an orbital drag experiment.

3.1 Camera

The camera is Commercial-Off-The-Shelf (COTS) hardware that will be modified for space worthiness and equipped with a set of optical filters (427, 557 and 630 nm) for imaging aurora [SO-1.2] and airglow emissions lines [SO-1.3], as well as a UV filter (320 nm) for quantifying any changes to the mesospheric ozone layer caused by a change in solar activity [SO-1.4].
The camera should be placed in the aft (anti-ram) direction, to allow it to perform limb imaging of aurora whilst leaving the ram direction free for the m-NLP (see Section 3.3).

3.2 ASTRA-LEO

The Advanced Spaceborne Telescope for Radiation Analysis in Low Earth Orbit is a custom particle detector, that will quantify solar activity level by detecting SEPs: providing an alert functionality to activate the other instruments for monitoring the atmospheric response [SO-1].
The front-end of the instrument is a segmented scintillator design that is sensitive to SEPs, gamma-rays and epithermal to thermal neutrons: allowing it to contribute to neutron lifetime measurements [SO-2] and gamma-ray burst [SO-3] identification. Figure 1 shows a top level description of the functionality of the instrument.

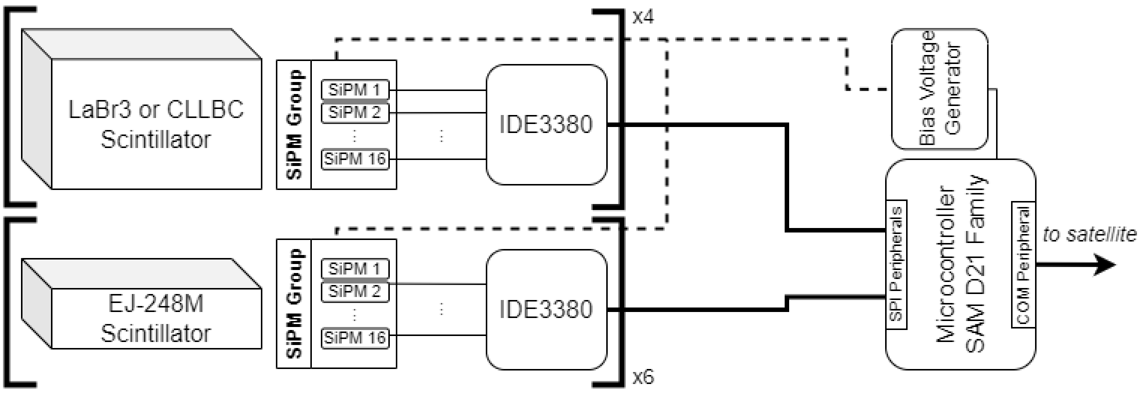

Figure 1: Block diagram of the functionality of ASTRA-LEO's readout electronics

The scintillator units are directly coupled to multiple arrays of Silicon Photomultipliers (SiPMs), responsible for converting the photons generated in a scintillation event into electrical current. These signals are measured via the IDE3380 Application Specific Integrated Circuit (ASIC) – a dedicated SiPM readout module designed by IDEAS, Norway[3]. The ASICs perform pulse-height spectroscopy and make the data available over Serial Peripheral Interface (SPI).

A microcontroller is connected to read this data and compress it in preparation for transmission to the ground station. The SAM D21 family of microcontrollers has been identified for this role; the multiple SPI peripherals allow for a greater degree of parallelism in the readout process.
The final block on the diagram is the bias voltage generator. The SiPMs require a reverse bias of around -40 V, but the exact applied voltage depends on the temperature of the instrument. As the SiPMs rise in temperature, their gain drops: this must be compensated for by increasing the bias voltage[4].
The pulse heights are measured across each SiPM channel (using the IDE3380), grouped into bins of a pre-specified width (within the microcontroller), and sent to the satellite bus for communication to the ground station.
By comparing the flux of neutrons coming from the nadir direction (emitted from the Earths atmosphere) to the flux from the zenith direction (returning from their arced paths) it is possible to estimate the neutron lifetime[5]. Therefore ASTRA-LEO must consist of two independent units, one nadir and one zenith facing.

3.3 m-NLP

The m-NLP is COTS hardware [6] developed by UiO and commercialised by Eidel AS. By applying bias voltages across four probes, a small amount of current is able to flow through the charged plasma. Measuring this current provides insight to both electron and ion densities and temperatures with high temporal resolution, to quantify small disturbances in the plasma [SO-1.1] [7].
This instrument must be placed in the ram (fore) face of the satellite during nominal operation, to ensure there is no interference from the plasma wake of the satellite.

3.4 Space debris radar

Detection and tracking capabilities of small-sized space debris from the ground are limited or non-existent, depending on the size of the object. Nevertheless, this data is needed for space debris models to ensure safe space travel. While data for space debris in the sub-millimetre range is being obtained by in-orbit impact sensors, flux data for the millimetre-size range is scarce. Therefore, this space debris radar has the objective to demonstrate in-orbit detection capabilities of millimetre-sized space debris [SO-5].
The development of this radar system is based upon on-going projects at UiT [8]. The intention is to use a millimetre-wave radar with frequencies of around 80 GHz and phased array antennas, which will cover the area of between 1U and 1.5U of the CubeSat. The system will run as a Frequency Modulated Continuous Wave (FMCW) radar to receive velocity, as well as range data, of the passing objects. Relative velocities of the space debris of up to 15 km/s are to be expected in an orientation where the radar is positioned in the ram or aft direction of the satellite. Due to the limited space on the CubeSat, the space debris radar will be located at the aft face.

3.5 Optimal control

This is a custom flight controller software package, that aims to demonstrate the usage of real-time optimisation techniques, such as Model-Predictive Control (MPC), in gen-

erating manoeuvres. This can be used to autonomously plan actions that minimise fuel consumption or maximise pointing time on target, for example [1]. The experiment will also demonstrate the usage of neural networks in spacecraft control applications.
This payload will require the satellite to be equipped with Guidance, Navigation and Control (GNC) controller that can accept custom software, or a secondary GNC system that can be switched in for the duration of the experiment.

3.6 Drag experiment

The drag experiment aims to perform in-situ tests of new passive orbital control algorithms which rely solely on the atmospheric drag force as a means of orbital control. This drag force is achieved through suitable attitude manoeuvrers of the CENSSAT-1 spacecraft.
The conventional method for drag-based orbital control involves adjusting a spacecraft's ballistic coefficient: this coefficient is the ratio of the spacecraft's mass to the product of its aerodynamic drag coefficient and its cross-sectional area. However, since the drag coefficient is constant, and small propulsionless spacecraft do not experience changes in mass due to fuel consumption, the key is to manage the spacecraft's surface interacting with the spacecraft-atmosphere relative velocity. We denote this surface as the spacecraft's effective surface, where ”effective” means the only surface capable of generating a net drag force variation per unit of mass to vary the spacecraft's orbital motion.
The total experiment (originally planned for the QBDebris mission [8, 9]) consists of two sub-experiments. The first, called the ”Surface Experiment,” aims to obtain a specific desired profile of the effective surface. This sub-experiment will enable the testing of new ad hoc attitude controllers to regulate the effective surface: unlike traditional attitude controllers, these new algorithms regulate the angular velocity directly rather than tracking a pre-computed attitude profile [10].
The second sub-experiment, ”Differential Drag Relative Positioning,” focuses on achieving relative positioning between CENSSAT-1 and a virtual spacecraft whose trajectory is simulated in real-time by the onboard computer [11, 12, 13].
Because CENSSAT-1 lacks tiltable drag panels or other devices that provide surface variations (unlike, for example, AeroCube-4 CubeSats [14]), the spacecraft ADCS system plays a crucial role: it must perform attitude manoeuvrers to provide proper rotations to grant the desired effective surface profile. As a result, this second sub-experiment will allow the testing of a 6 Degrees of Freedom (DoF) orbit-attitude control algorithm [15].

4 Mission Design

A Sun-synchronous polar orbit, with insertion altitude of approximately 500 km, has been selected for the mission. The polar orbit will place the satellite in position to regularly view any aurora, and a Sun-synchronous orbit provides predictable environmental conditions - simplifying the thermal and electrical power modelling, and proving consistent lighting for the camera to operate. It is also one of the more popular orbits, which increases the launch opportunities. Nominal mission lifetime is expected to be 1 year, after a 3-month commissioning phase. The insertion altitude of 500 km is consistent with a natural de-orbiting timeline of 5 years after mission launch, as laid out in ESA's zero debris charter [16].

Figure 2 shows the proposed layout of the CENSSAT-1 satellite, created to hold the instruments necessary to fulfil the science objectives. This 3D model has been created from the Interface Control Documents (ICDs) provided by the instrument teams. From these documents an 'envelope' that describes the largest envisioned size for each instrument was created. These were positioned within a 8U CubeSat frame so as to meet the various positional requirements as indicated within the respective ICD, as discussed above.

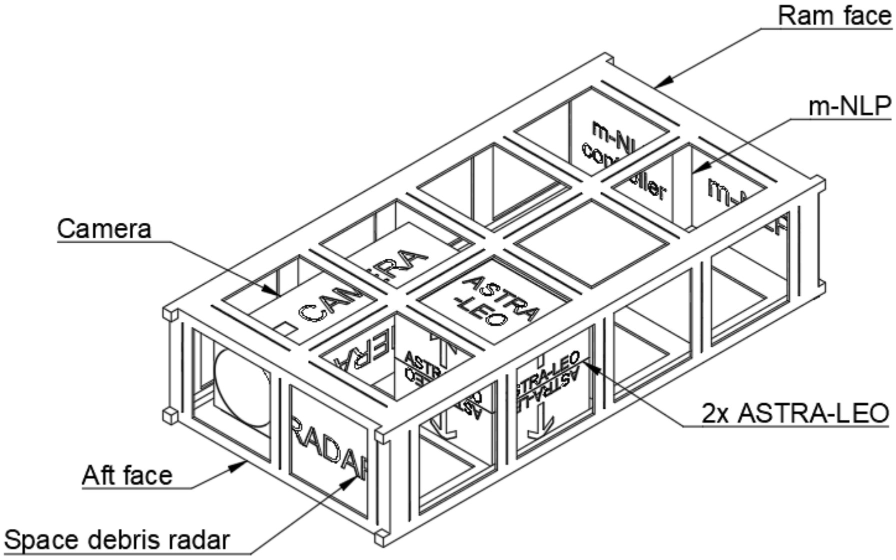

Figure 2: Low fidelity mock-up of the CENNSAT-1 satellite demonstrating the sizes of the payloads within an 8U CubeSat frame, as well as the position and orientation requirements of the instruments. The instruments are shown as bounding boxes dimensioned from their maximum proposed sizes.

Large amounts of empty space have been purposely added to the layout for the inclusion of the necessary flight hardware by the vendor: attitude determination and control systems, on-board computer, electrical power system, etc.
The 8U CubeSat frame was modelled from information available in the CubeSat Design Specification [17]. However, as an 8U design is not a standard configuration, the dimensions were arrived at by scaling the available 6U layout. This was deemed acceptable: the frame was modelled to give appropriate reference for the size and position of the instruments, and did not form a requirement on the vendor.
Tables 2 and 3 show the most recent mass, data and power budget for CENSSAT-1. These have been prepared as part of the procurement process, they will form the bases for scoping the bus size, electrical power system and communications hardware.

5 Conclusion

CENSSAT-1 is proceeding on-time for a predicted launch of late 2027. The satellite bus is currently being procured, with a goal of taking delivery of a FlatSat (representative hardware for the satellite bus in a breadboard form for ease of prototyping) in October 2025. Critical Design Review (CDR) is expected to take place in May 2026.

Table 2: Mass and data budget for CENSSAT-1. Bracket percentages show the margin for error, which is unique for each instrument and estimated by the instrument teams.

	Mass (kg)	Total Mass (kg)	Data Rate (MB/Orbit)	Total Data Rate (MB/Orbit)
Camera	0.7 (+20%)	0.8	5 (+10%)	5.5
ASTRA-LEO	4 (+20%)	4.8	39.8 (+20%)	47.8
m-NLP	0.5 (+5%)	0.5	50 (+5%)	52.5
Space Debris Radar	0.08 (+20%)	0.1	5 (+5%)	5.3
Total		6.2		111.1

Table 3: Power budget for CENSSAT-1, including expected duty cycles.

	Power (W)	Margin (%)	Duty Cycle	Total Power (W)
Camera	4	20	0.3	1.4
ASTRA-LEO	10	20	0.9	10.8
m-NLP	2	5	0.9	1.9
Space Debris Radar	12.5	5	0.3	3.9
Total				18.0

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