University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

NanoSAM-IV

1. Approvals

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3. Problem/Need

The primary objective of the NanoSAM (Nano-Stratospheric Aerosol Measurement) project is to improve upon heritage missions' methods of measuring aerosol in the Earth's atmosphere. Providing data that can be used to map aerosol density as a function of altitude will allow future remote sensing missions to account for the associated attenuation in solar irradiance in their senor data which will lead to more accurate measurements. Another great instance of potential applications for NanoSAM is the SAGE-II (Stratospheric Aerosol and Gas Experiment) mission, which measured the depletion in the ozone layer above the South Pole and effectively proved that it was largely due to Polar Stratospheric Cloud formation. SAGE-II and other heritage missions were limited by the size of their instruments, which were unable to track the sun well. NanoSAM attempts to address this by reducing the size to a 0.5U cubesat form factor which will allow the slewing of the spacecraft to steer the optical sensor's field of view with greater precision and faster timing.

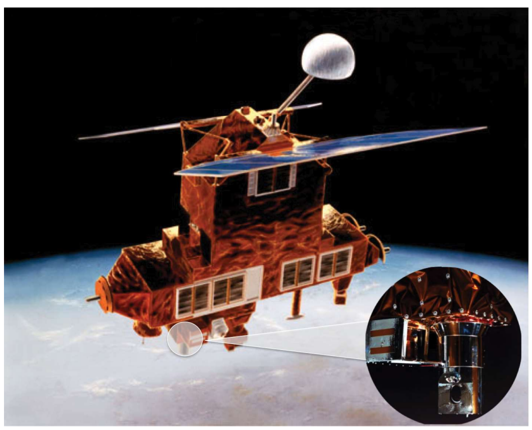

Fig. 1: SAGE-II Satellite

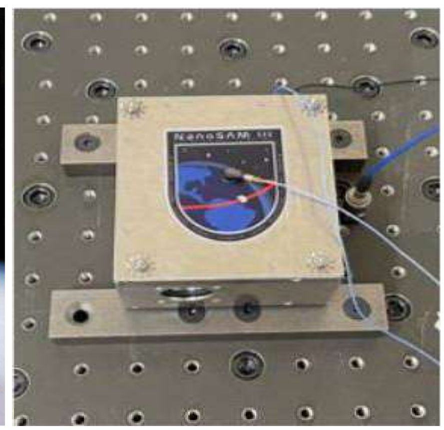

Fig. 2: NanoSAM III

For this fourth iteration of NanoSAM, team CU-LATR (Light Aerosol Trace Recognition) aims to fulfill the customer's need of collecting data from a controlled light source emitting at known frequencies to demonstrate that the optical sensor is capable of accurately recording an irradiance profile over time. This technical demonstration shall prove vital for subsequent iterations in order to generate meaningful data necessary to predict NanoSAM's on-orbit functionality and serve as a baseline to normalize radiometric data from an attenuated signal. The current iteration (NanoSAM-IV) may rely heavily on the test benches of previous iterations to conduct this demonstration; some revisions or modifications may be necessary in order to produce adequate results.

4. Previous Work

In July 1975, during the Apollo-Soyuz Test Project, the first Stratospheric Aerosol Measurement (SAM) was flown on an Apollo spacecraft. The device consisted of a sun photometer used to measure the sun's intensity and a camera. After a successful mission, the experimental results demonstrated that solar occultation measurements by photometer and camera could be used to determine the vertical distribution of stratospheric aerosols. Then, from 1978 to 1993, the SAM II experiment was launched on the Nimbus-7 spacecraft. The goal of this project was to develop a stratospheric aerosol database for the polar regions. During the mission, SAM II provided vertical profiles of aerosol in both the Arctic and Antarctic polar regions [7].

The SAM instruments family eventually led to the birth of the Stratospheric Aerosol and Gas Experiment (SAGE) projects. On February 18th, 1979, SAGE I was launched on the Applications Explorer Mission-B (AEM-B) satellite with the purpose of measuring the profile of stratospheric aerosol extinction coefficient, ozone (O_3), and nitrogen dioxide (NO_2) [8]. In October 1984, SAGE II was designed to measure stratospheric aerosols, ozone, nitrogen dioxide, and water vapor with solar occultation techniques during each sunrise and sunset encountered by the orbiting spacecraft. The Earth Radiation Budget Satellite (ERBS) hosted the SAGE II instrument during the mission. Compared to its predecessor, SAGE II was able to provide data for long-term missions (21 years) [9]. However, the experiment results of SAGE II were proven invaluable in ozone studies. The third-generation instrument, SAGE III/M3M, was first launched on the Russian spacecraft Meteop-3M in December 2001 [10]. Then, in 2017, the most recent version of this instrument was SAGE III/ISS. The latter is the fourth generation of a series of NASA Earth-observing instruments and was launched on the SpaceX CRS-10 mission using a Falcon 9 with Dragon. Just like its predecessors, SAGE III on ISS retrieves vertical profiles of multi-wavelength aerosol extinction coefficient along with other gaseous measurements such as ozone (O_3), water vapor (H_2O), and Nitrogen dioxide (NO_2) using solar occultation technique [11]. The large size, weight, and cost of SAGE III was not correlating with its performance of collecting only 30 aerosol measurements per day. Therefore, the NanoSAM project series was created to design, build, and test a low cost, light-weight Stratospheric Aerosol Measurement device.

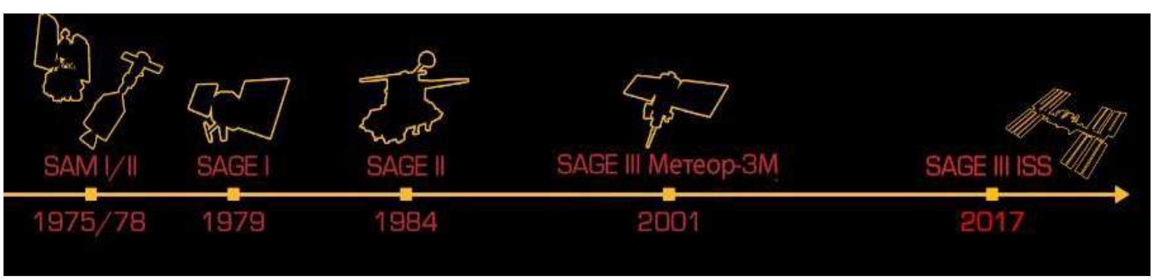

Fig. 3: History of the SAM and SAGE missions

NanoSAM I, first iteration of the NanoSAM series, was designed to construct a functional optics and radiometer system for irradiation detection in a narrow spectral band at 1 micrometer. The team successfully designed and constructed the optic system to measure the solar irradiance at the specific narrow band. Furthermore, their electronic system was able to collect data and present it. However, some improvements were needed for the optical system's alignment and the analog-to-digital converter (ADC) [6]. NanoSAM II was then focused on aligning and improving the optic system designed by NanoSAM I. On the structural side, the focus was on creating a 0.5U structure that could withstand the launch conditions. At the end of the project, the team was able to reduce the size of the instrument but NanoSAM II could not withstand the vibrations of the launch environment [5]. The third iteration of the NanoSAM project is NanoSAM III. The mission's main goals were to ameliorate the optical bench for the launch environment survival and to reduce the components cost. Overall, the NanoSAM III team took a step towards the flight readiness of the instrument [4].

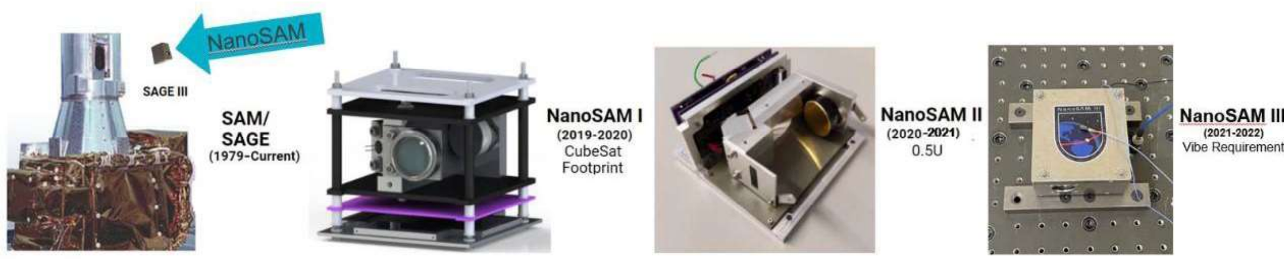

Fig. 4: NanoSAM project history

The previous iterations of NanoSAM were unable to collect data from a light source. Therefore, this year, the NanoSAM IV team will design an embedded system that will take light as an input and output its formatted data through a controller interface.

5. Specific Objectives

The method in which NanoSAM IV will carry out its technical demonstration will be the same as NanoSAM II. This will include filtering the signal from a light source to a desired wavelength (~103 µm), converting it into an electrical signal via a photodiode, and, finally, digitizing and storing the signal for processing. On orbit, the instrument will utilize Solar Occultation to self-calibrate the instrument. Below are the criteria for minimum mission success (level 1) as well as goals which the team is hoping to achieve (level 2) with this iteration of NanoSAM.

Level 1:

The fundamental objective of NanoSAM-IV is to introduce data collection to previous iterations of the mission. As an absolute minimum for the project, team CU-LATR aims to establish a single intensity profile over time of an un-attenuated light signal. This profile will scan across the center of the light source from "edge-to-edge". NanoSAM-IV shall also demonstrate a means of communication with the satellite/spacecraft's ADCS electronics. A control simulation will be implemented that allows the operator to trigger the optics to collect the light. The light will be digitized, stored, and the resulting data will then be transmitted back to the controller interface. Included in this data packet will be housekeeping information such as timestamps, voltage, and luminosity data. The NanoSAM-IV team shall attempt to use the previously built NanoSAM-III test bench optics to capture the light. This may require the optical bench to be realigned. If previous test benches are not capable of data collecting then a new test bench will be produced based upon previous missions' schematics.

Level 2:
Should team CU-LATR fully succeed with all Level 1 objectives, a series of reference profiles relating different full, un-attenuated light conditions at varying altitudes shall be created. Included in these profiles' data packets will be pointing and positioning data of the test bench optics. Further experimentation shall demonstrate the ability to detect attenuated light signals and compare them against the normalized profiles established for a given spacecraft attitude and observation altitude. Continued development of the control simulator will allow the system to detect its current altitude, capture light, and transmit data without operator input.

6. High Level Functional Requirements

The high-level functional requirements listed below are based on the specific objectives developed in Section 5. These requirements will become more specific and well defined in preceding design documents.

Number	Name	Requirement Description
1	Data Capture	The supporting electronics and software shall digitize, packetize, and store housekeeping data and information collected from the photodiode and spacecraft ACDS.
2	Communications	The supporting electronics and software shall downlink data to the ground station and receive commands from it.
3	Electronics	The embedded system shall be run from photodiode signal to delivered data with a control simulator and a controller interface.
4	Cost	The project shall limit all spending to a budget of $4,000.

Table 1: High-Level Functional Requirements

In order to establish useful intensity profiles over time, the data acquisition system must be able to successfully transform an analog signal (sunlight) to a digital signal and communicate with the ground station. Functional requirements 1 and 2 cover this performance. Finally, during the mission, the command center will be able to trigger observations and receive data through a control simulator. Functional requirement 3 enforces this need.

6.1: Mission CONOPS

Since NanoSAM is a payload on a spacecraft, it is important to keep the context of what the overall mission will look like in mind. The mission for NanoSAM is illustrated below in figure 5.

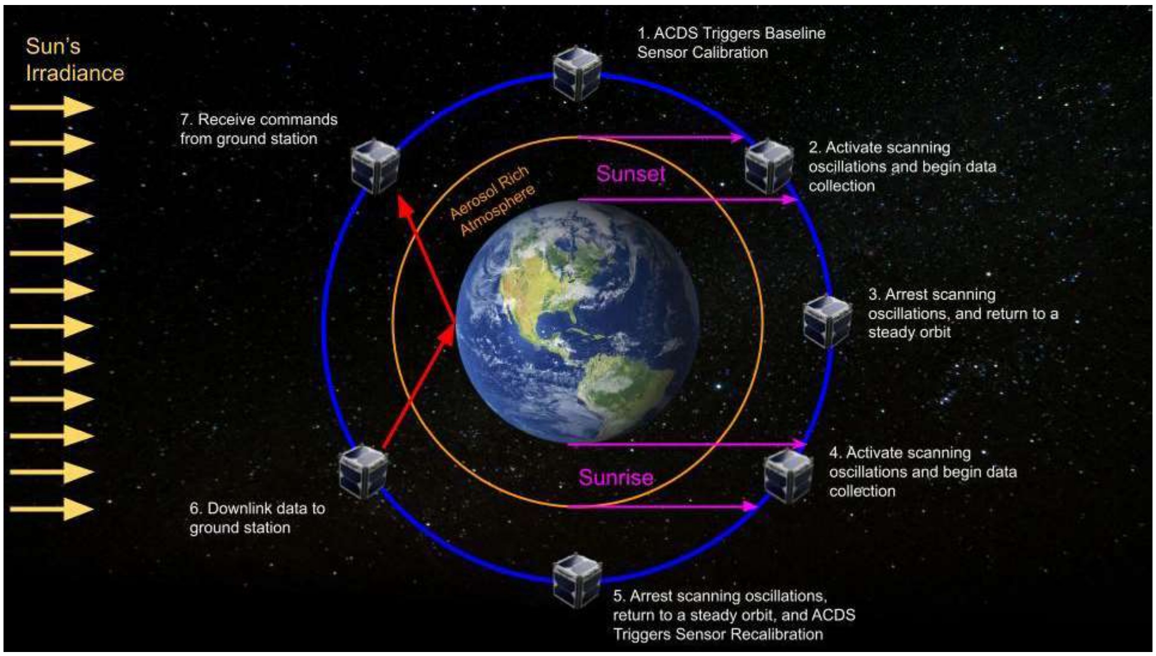

Fig 5: NanoSAM Mission CONOPS

As shown above, the on orbit operation of NanoSAM depends heavily on the other subsystems within the spacecraft. The experimentation will begin after launch, deployment, and commissioning of the spacecraft. For the sunset case, the sensor will take its first measurement, which should be just above where any attenuation in irradiance from molecular species could take place. This first measurement will be used to calibrate the measurements that follow as the tangential altitude of the spacecraft decreases. During these measurements, the payload shall request attitude changes from CDH to allow the optical sensor to scan up and down across the solar disk. When the spacecraft enters eclipse, the scan will terminate, and the spacecraft will wait until it exits eclipse to restart the scan. NanoSAM will be constantly fed positioning information from the ADCS sensors which will allow it to know when to start and stop scans. The sunrise case will perform the same tasks as the sunset case, but in reverse order.

6.2: NanoSAM-IV CONOPS

NanoSAM IV will focus around generating baseline data and verifying functionality of the optical sensor. The testing process for generating this data is shown below in figure 6.

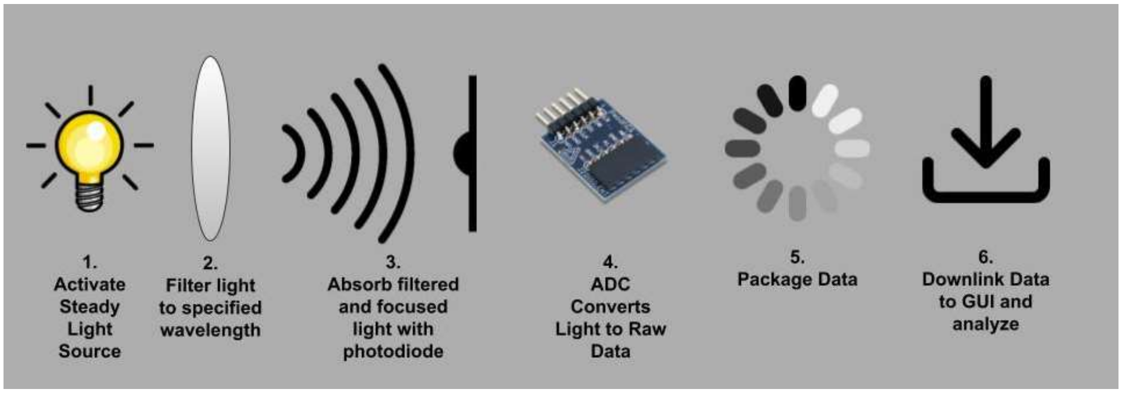

Fig. 6: NanoSAM IV CONOPS

The test will begin with the light source (emitting at predetermined TBD wavelengths) being turned on to some specified (TBD) intensity W/m^2. The signal from the light source will then enter the optical sensor and a series of filters will allow light at a given wavelength to pass through. The focused light will then directly hit the photodiode on the other side of the pinhole, which will convert the light into an analog electrical signal. This electrical signal will then be conditioned to remove noise and sent to an ADC to be digitized. The digitized signal is sent to the microprocessor which will packetize the data along with timestamps and housekeeping data. Packets will be sent through a mock cubesat controller and stored locally on a computer. Finally, the data will be processed, plotted, and analyzed by the software team. Multiple trials of the test will be conducted to verify accuracy and consistency of data collection.

7. Critical Project Elements

The critical project elements (CPEs) of the NanoSAM-III project are tasks that must be completed in order to ensure we meet the demands of the customer. These project elements have been identified as critical to the success of the mission based on the customer's current demands, but are subject to change if the customer's demands change. The CPEs should guide the team's efforts to ensure that specific objectives and high level requirements are met. CPEs for this project fall under the scopes of software, electronics, mechanical & manufacturing, finances, testing & validation, and optics. Details pertaining to these elements are described below to help the team better understand what tasks each CPE must complete. Other elements of the project not outlined here are not critical to the success of the mission.

CPE #	Name	Description
E1	Software	Previous NanoSAMs have not generated adequate data. Thus, software will be required for proper data collection including: receiving, digitizing, and storing/sending data through a controller interface. Data should be formatted and cleaned, and packed along with timing and spacecraft attitude information. The software side requires heavy support from the functionality of the embedded systems and electronics.
E2	Electronics	Integrate previous NanoSAM's electronics work. All three previous NanoSAM teams designed their own respective electronics setup; adaptation from this previous work is dependent on the functionality of NanoSAM-III's electronics. Depending on the previous teams' electronics setup, a microcontroller or PCB for processing photodiode data could be critical. After running through E1, the resulting data should be transmitted for analysis.
E3	Mechanical & Manufacturing	An optical test bench (which currently exists) is required for E6. An overall test bench or location to perform sufficient testing is required. Mechanical components are required to tilt the spacecraft, effectively changing the attitude. These mechanical components must be controllable from the controller interface. The test bench must be aligned properly with the light source to ensure accurate and repeatable data collection.
E4	Finances	An LED light source + wiring and light filters are necessary for the project, as one of the major goals is generating a light source that simulates the sunrise and sunset conditions for testing. Furthermore, some mechanical components are needed to rotate the optics setup to allow scanning of the light source. If alterations are made to the electronics setup from NanoSAM-III then PCBs might have to be generated as well as a microcontroller such as an Arduino. These purchases should not exceed the $4000 budget, and with the remaining money we could use for expedited shipping on important components.
E5	Testing & Validation	Testing requires validation of critical project elements E1-E3 and E6. These tests will be performed at CU unless needed facilities do not exist on campus. If deemed necessary and possible, Ball Aerospace's facilities may be used.

E6	Optics	Previous years work focussed on developing optic setups. Specifically, optical alignment and a proper photodiode response through filters. Due to E1 and E2 requiring more attention, the scope of E6 is constrained to implementing previous diodes into the system and ensuring alignment.

8. Sub-System Breakdown & Interdependencies

Sub-System	Breakdown	Interdependencies
Software	Data handling and manipulation, controller interface.	Electronics
Electronics	Signal conditioning and analog to digital conversion, light source powering.	Software, Optics, Mechanical
Optics	Source light transformed into a suitable form for photodiodes.	Electronics, Mechanical
Mechanics	Create a stable light source, ensure test bench setup is sufficient to perform testing that simulates the conditions the customer wants tested	Electronics, Optics

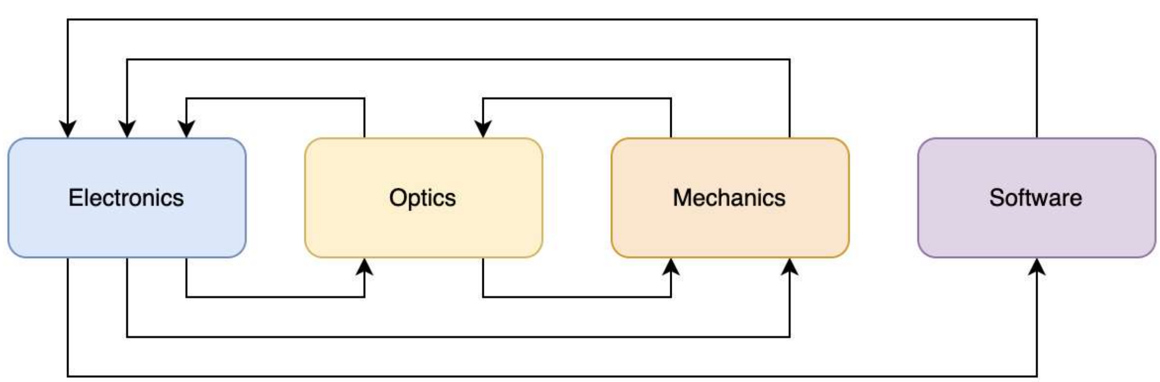

Fig. 7: NanoSAM IV Sub-System Interdependencies Block Diagram

9. Team Skills and Interests

Team Member	Skills/Interests	CPE(s)
Gerald Yoho	Leadership, prototyping/manufacturing, 3D modeling/design, propulsion/aerodynamics, thermodynamics, RF & electrical engineering	PM, Mechanical & Manufacturing (E3), Electronics (E2), Optics (E6)
Lucca Trapani	Software, Attitude determination and control, Orbital mechanics, Optics	Software(E1), Optics (E6)
Lucio Murillo	Thermal Modeling, systems engineering, AI&T, limited PCB design exp. (Altium), MATLAB	Software, Electrical, Mechanical & Manufacturing (E1-E3), Testing/Validation (E5), Optics (E6)
CJ Kennedy	Computer-assisted engineering, computer science, electronics and embedded system, controls	Software (E1), Electrical (E2)
David Hightower	Manufacturing, Integrated Systems, MATLAB, ANSYS Simulation, SolidWorks, GUI Interface Development	Mechanical & Manufacturing (E3), Testing/Validation (E5), Software (E1)
Abdoulaye Diallo	Software (Python, C++), Dynamics & Controls (Non-linear & linear systems), Robotics and Simulation	Software (E1), Electrical (E2), Testing/Validation (E5)
Benji Brandenburger	Propulsion, Thermodynamics, Electrical Engineering, Finances	Finances (E4) (CFO) Mechanical & Manufacturing (E3), Electronics (E2)
Garret Bell	Manufacturing, limited prototyping, establishing and integrating testing procedures, MATLAB	Electrical (E2), Mechanical & Manufacturing (E3), Testing/Validation (E5), Optics (E6)
Jade Babcock-Chi	Computer Science Minor (C/C++, MATLAB, Python, Linux, willing to learn new languages), interest in software, orbital mechanics, leadership, embedded systems, electronics	Software (E1), Electrical (E2), Testing/Validation (E5)

10. Resources

Critical Project Element	Resource/Source
Software (E1)	Austin Bathgate (NanoSAM-III Electronics & Software Lead), Josh Mellin
Electronics (E2)	Austin Bathgate, CU Aerospace Dept. Electronics Lab/Team
Mechanical/Manufacturing (E3)	Matt Rhode, CU Aerospace Dept. Machine Shop
Finances (E4)	Jim Baer, Jaykob Velasquez, Patric Wessels (Ball Representatives)
Testing/Validation (E5)	Ball Aerospace Facilities (Boulder, CO), Designated testing space in the Aerospace Building or on campus, dark room
Optics (E6)	NanoSAM III, Jim Baer (retired optical systems engineer for SAGE-III)

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