Measuring the Ratio of Water to other Atmospheric Gas Concentration at Different Altitudes

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Abstract

The SpectroSat project investigates the relationship between water vapor and other atmospheric gases across different altitudes in the troposphere and lower stratosphere. A high-altitude balloon payload equipped with a NASA STELLA 1.1 spectrometer collected spectral irradiance and environmental data at regular intervals during flight. Gas concentrations were estimated by analyzing absorption features at specific wavelengths corresponding to known atmospheric gases.

During this project electrical difficulties led to the loss of any data collected during flight. To make up for this, additional data was acquired via the project by Dylan using similar equipment. As such all data displayed below was acquired by use of a spectral triad as7265x sensor rather than the STELLA VIS and NIR sensors.

The results acquired show that during the first 30 minutes of flight, water vapor absorption (940 nm) decreases with altitude, while oxygen absorption (760 nm) remains relatively stable. Ozone-related wavelengths (500–700 nm) exhibit an increasing trend at higher altitudes. Correlation analysis indicates strong agreement between expected absorption bands and measured data, with the highest correlations observed at 940 nm for water vapor ($R = 1.0000$), 760 nm for oxygen ($R = 1.0000$), and wavelengths between 510–560 nm for ozone ($R \approx 0.83$).

These findings support the hypothesis that spectroscopic measurements can be used to identify relative gas concentrations and trends in the atmosphere.

Introduction

The Earth Observation Network Science Challenge (EONS) is a statewide program focused on developing spectroscopy-based instruments to study environmental systems. The SpectroSat project was designed to measure atmospheric composition using a high-altitude balloon payload, with a focus on identifying relationships between water vapor and other atmospheric gases.

The primary goal of this project was to determine how the concentration of water vapor varies relative to oxygen and ozone as altitude increases. The working hypothesis was that there would be a statistically significant relationship between other atmospheric gases and water vapor made clear by measuring both at varying altitudes.

To achieve this, the payload incorporating the NASA STELLA 1.1 spectrometer was developed. The system collected spectral irradiance data across visible and near-infrared wavelengths using their corresponding sensors (VIS and NIR). By comparing light intensity at wavelengths associated with known absorption features, relative gas concentrations could be inferred.

This project contributes to atmospheric science by demonstrating that compact, low-cost instrumentation can be used to measure vertical gas distribution trends, which may support future studies in weather prediction and atmospheric modeling.

After flight it was discovered that electrical difficulties led to the loss of any data collected. The data used here was collected from the demosat project of Dylan using similar equipment. As such the data does not reflect that of the VIS and NIR sensors used in the STELLA kit. Instead, the sensor used is a spectral triad as7265x which measures at different wavelengths.

Materials

The instrument constructed in this study was a NASA STELLA-1.1, a low-cost, handheld, multi-sensor spectrometer developed by NASA Goddard Space Flight Center for environmental monitoring and remote sensing education.

Sensors

The main processing unit of the system is a Feather RP2040 microcontroller, which ran CircuitPython code. The microcontroller is paired with an Adalogger FeatherWing, which uses an integrated real-time clock (PCF8523) to write time-stamped data to a microSD card. An 8 GB microSD card was used for data storage. Spectral measurements were obtained using two six-channel sensors: the AS7262 VIS Spectral Sensor and the AS7263 NIR Spectral Sensor. These sensors measure irradiance across discrete wavelength bands spanning approximately 450–860 nm, enabling multispectral analysis of surface reflectance and environmental features .

The STELLA device also contains three environmental sensors: the MCP9808 Air Temperature Sensor for high-precision ambient temperature, the BME280 Ambient Weather Sensor for relative humidity and barometric pressure measurements, and the MLX90614 Infrared Thermometer for temperature estimation using thermal infrared radiation .

The electronics were assembled on an Adafruit Full Sized Perma Proto board in adherence to the STELLA-1.1 wiring architecture.

Additional components

Finally, the STELLA also uses additional electronic components including 10 μF aluminum electrolytic capacitors, and 0.1 μF ceramic capacitors, resistors (100 Ω and 10 kΩ), and a red. User input (power on/off) was made possible using using pushbutton switch. The device was powered by a 2200 mAh lithium-ion battery. A CR1220 coin cell battery was used to maintain the real-time clock in the Adalogger Featherwing. A USB-C cable provided power and data connectivity during programming and testing, and a USB-C microSD card reader was used for data retrieval.

Methods

The payload was constructed using the NASA STELLA 1.1 architecture, and using the STELLA in built in drone mode, measurements were taken every 5 seconds once turned on. The Feather RP2040 microcontroller interfaced with all sensors via a shared I^2C bus, and all components were secured within a foam enclosure designed for high-altitude balloon flight. The enclosure had holes for sensors to reach the outside environment. Due to electrical failure during flight, the amount of usable data recovered from the STELLA 1.1 payload was too little to do analysis on. To complete the analysis, a similar dataset was obtained from a DemoSat project using a AS7265x spectral sensor.

The AS7265x sensor differs from the STELLA VIS and NIR sensors in that it provides 18 discrete spectral channels spanning approximately 410–940 nm, rather than two separate 6-channel sensors. The wavelength coverage between the AS7265x sensor overlaps with the wavelength coverage on the two STELLA sensors, which allows for sufficient analysis of the planned atmospheric absorption features. The substituted dataset was collected on the same high-altitude balloon, with measurements taken approximately every second during flight.
Raw spectral intensity values were extracted from the dataset and organized by wavelength and time. Specific wavelengths corresponding to atmospheric gases absorption bands were selected for analysis: the 940 nm band, which can be used to determine water vapor levels (Liou 2002, p. 83); the 760 nm band, which can be used to determine oxygen levels (Adkins et al. 2025); and the 500–700 nm range, which can be used to determine ozone levels (Kokhanovsky et al. 2021).

To evaluate relationships between gases, intensity values were normalized to account for variation in overall light levels during flight. Differences between spectral intensity in bands corresponding to water vapor and other gasses over time were compared to identify relative trends. Correlation coefficients were computed between each of these wavelength bands. These correlations were used to assess the amount to which water vapor corresponds to other gasses in the lower atmosphere

Testing

The payload underwent a series of structural, sensor, and software validation to ensure flight readiness. These tests were designed to simulate conditions encountered during handling, transport, and flight under expected operating conditions.

Structural Tests

Structural testing was conducted to evaluate the physical durability of the device. A drop test was performed to assess the instrument's ability to withstand impact, confirming that all components remained secure and operational after a drop from a height of ~15 meters. The payload passed this test with no issues.

A cold test evaluated system performance in low temperatures, ensuring that the electronics, battery, and sensors continued to function within acceptable limits. For this test, the payload was placed in a freezer for 2 hours while taking measurements every 5 seconds. During this test, the payload recorded expected data without interruption.

A whip test was conducted to simulate directional changes, such as those experienced during launch, landing, or in turbulence. To conduct this test, the payload was attached to a string that was manually spun at high speeds for ~1 minute. The payload remained completely intact and

Finally, a stair pitch test was used to simulate rough vibrations such as those experienced in launch and landing. The payload was pitched down a flight of stairs and remained intact, sustaining no damage.

Additional tests

All electronic components were tested individually before integration. Any faulty components were replaced. Before flight, the device was tested being lifted approximately 10 feet, and data was extracted and interpreted to ensure sensing, data extraction, and interpretation went as expected. The rigorous testing demonstrated that the payload was capable of reliable data acquisition and storage through any issues that may occur during flight.

Results

Spectroscopy Data

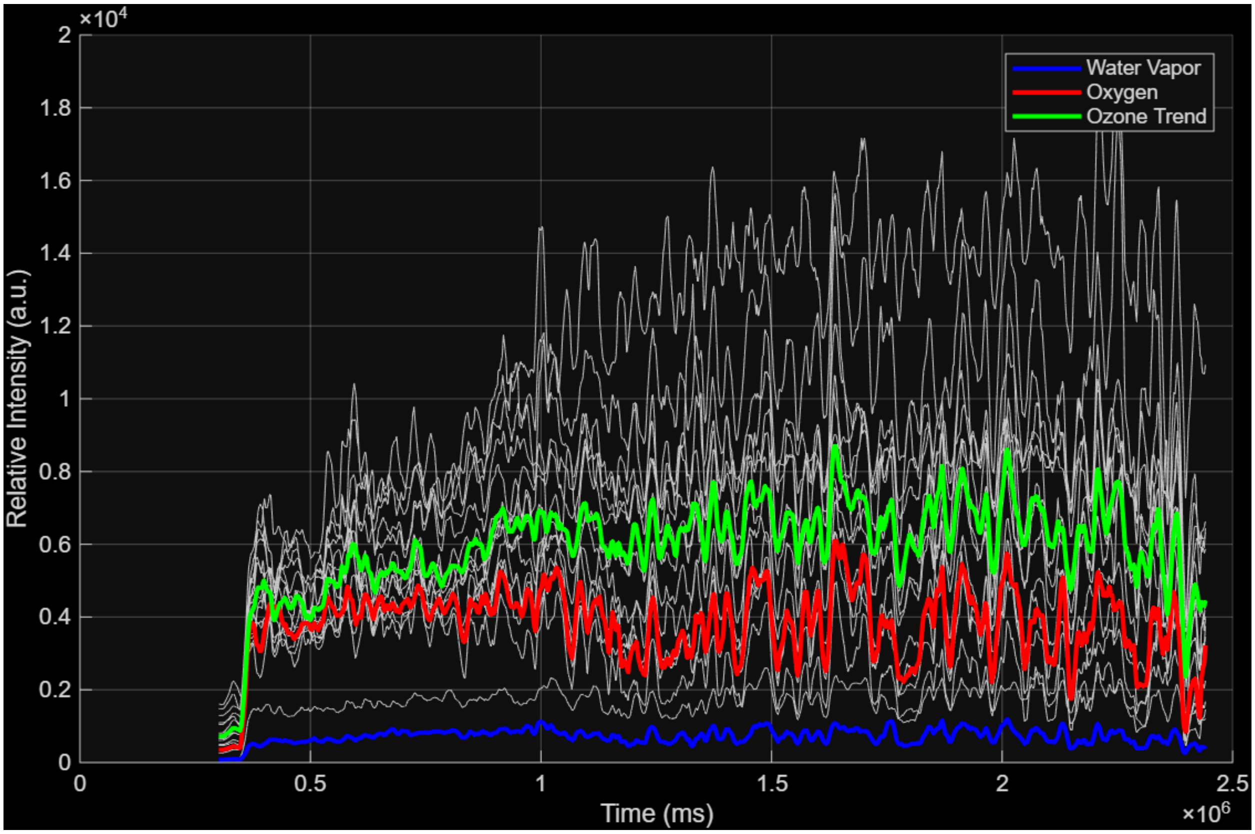

Figure 1. Relative intensity (unitless) against time (milliseconds). Each line represents a different wavelength. The wavelengths of interest to us are colored according to the legend.

Difference From Water Vapor

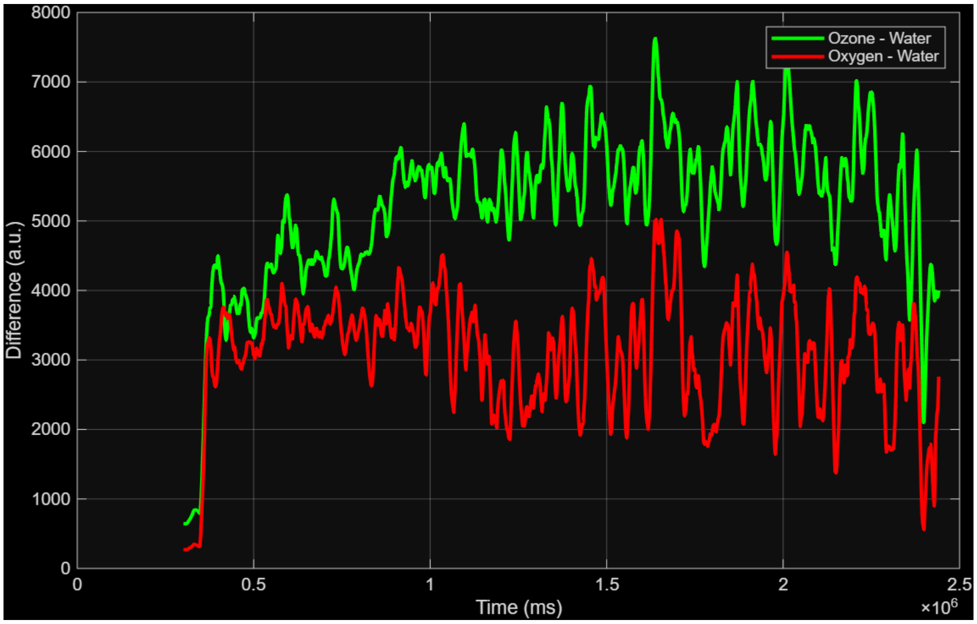

Figure 2. Difference between the change in intensity of water and the atmospheric gas over time for both Ozone and Oxygen.

Normalized Gas Comparison

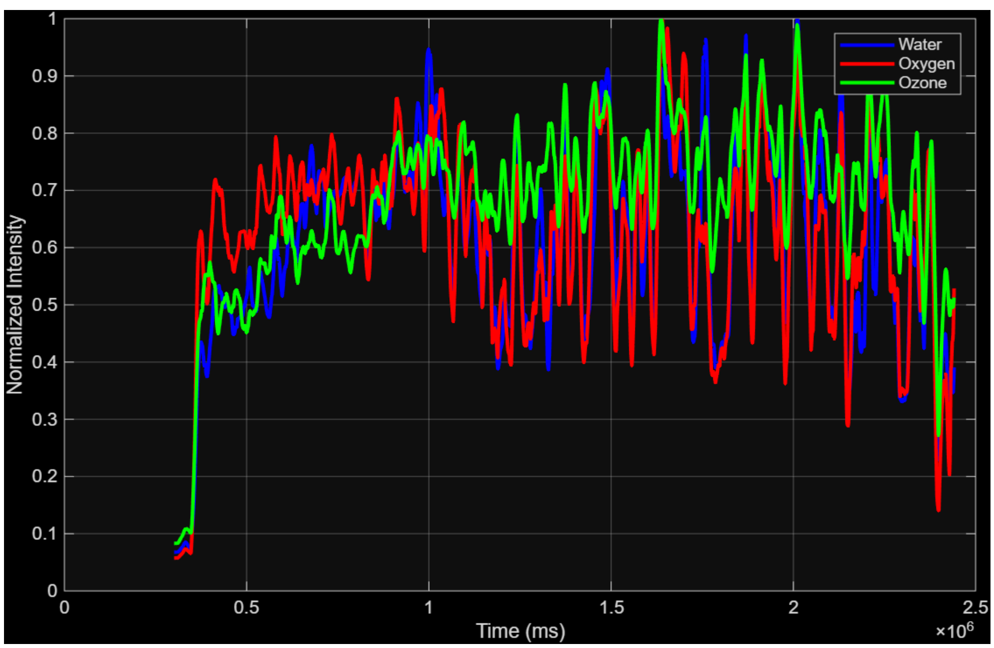

Figure 3. Normalized intensity of each wavelength of focus over time. The mean value of Water vs Oxygen correlation is 0.87491 and Water vs Ozone correlation is 0.78909.

Wavelength	Water	Oxygen	Ozone
A_410nm	0.4689	0.5431	0.8019
B_435nm	0.5030	0.5823	0.8002
C_460nm	0.2726	0.3300	0.6892
D_485nm	0.3760	0.4295	0.7313
E_510nm	0.4006	0.4331	0.8255
F_535nm	0.2876	0.3065	0.7772
G_560nm	0.4444	0.4119	0.8312
H_585nm	0.6587	0.6334	0.8026
R_610nm	0.5094	0.6750	0.6214
S_680nm	0.4461	0.5089	0.7940
T_730nm	0.5771	0.8466	0.4929
U_760nm	0.6218	1.0000	0.6156
V_810nm	0.4984	0.7113	0.6210
W_860nm	0.4940	0.7002	0.7093
K_900nm	0.5141	0.6009	0.6201
L_940nm	1.0000	0.6218	0.5688

Table 1. Correlation Values for Each Wavelength to Relevant Atmospheric Gases

Conclusions

The results of the SpectroSat experiment show a clear relationship between water vapor and both oxygen and ozone based on the collected spectral data. In Figure 1, the relative intensity of each wavelength changes over time, with the water vapor, oxygen, and ozone signals following similar overall patterns. This suggests that all three are being influenced by the same atmospheric conditions during flight and so have trends similar to each other.

In Figure 2, the difference between water vapor and the oxygen and ozone signals remains fairly consistent while still following similar trends. This indicates that although the magnitude of each signal is different, their behavior over time is closely related.

The strongest evidence is shown in Figure 3, where the data is normalized. After removing differences in scale, the signals align much more closely, with strong correlations between the bands corresponding to water vapor and oxygen (0.87491) and water vapor and ozone (0.78909). This shows that changes in water vapor are closely linked to changes in both oxygen and ozone measurements.

In conclusion, by focusing on the trends found in other atmospheric gases (such as Ozone and Oxygen Gas) it is possible to approximate the trends in water vapor. While the results found in this experiment included high levels of noise, the methods used were cost effective and required minimal personnel to achieve. Should the method of using spectroscopy measurements for other atmospheric gases to predict water vapor trends, a higher degree of accuracy in weather forecasting models may be achieved.

References

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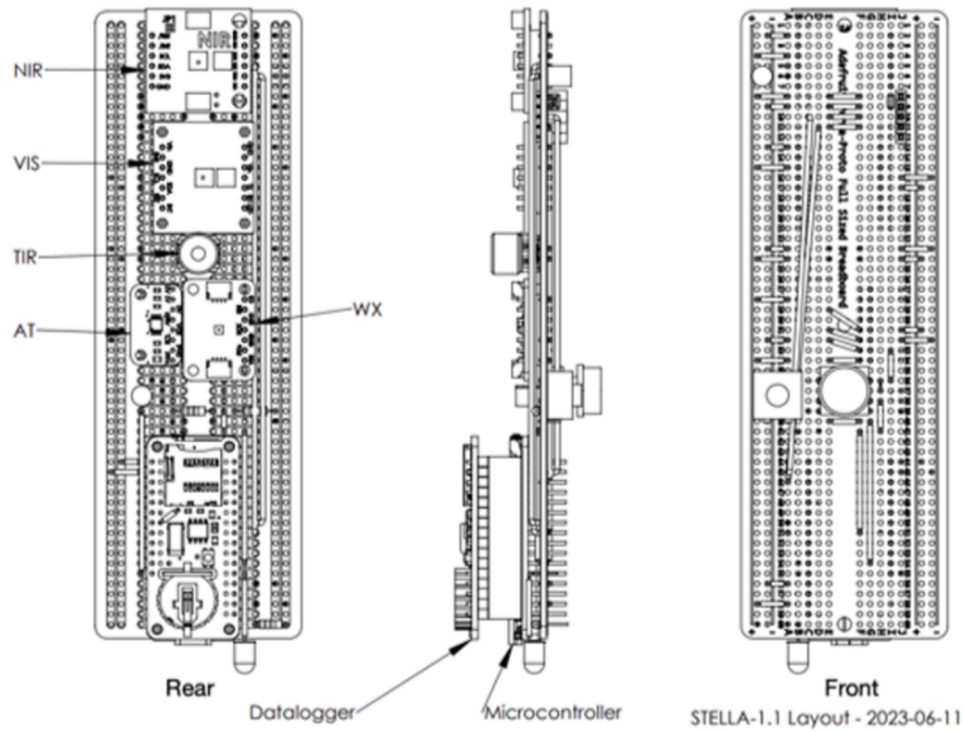
Appendix

Qty	$ ea	$ line	Item	Description	Part Number	Vendor
1	7	7	Protoboard	Adafruit Full Sized Perma Proto	1606	Adafruit
1	12	12	Microprocessor	Feather RP2040	4884	Adafruit
1	9	9	Data Logger	Adalogger Featherwing	2922	Adafruit
1	28	28	NIR Spectral Sensor	AS7263 NIR Spectral Sensor	SEN-14351	SparkFun
1	20	20	VIS Spectral Sensor	AS7262 VIS Spectral Sensor	3779	Adafruit
1	25	25	Thermal Infrared Sensor	MLX90614 3V Infra Red Thermometer - TO-39	MLX90614ESF-BCC-000-SP	DigiKey
1	5	5	Air Temperature Sensor	MCP9808 Air Temperature Sensor	1782	Adafruit
1	15	15	Ambient Weather Sensor	BME280 Ambient Weather Sensor	2652	Adafruit
1	0.17	0.17	Header pins	Header pins	392	Adafruit
1	0.4	0.4	Pushbutton Switch	Color Round Tactile Button Switch	1009	Adafruit
1	1.8	1.8	Push-On Push-Off Switch	SWITCH PUSHBUTTON SPST 1A 30V	GPTS203211B	
2	0.25	0.5	Capacitor, 10uF	CAP ALUM 10UF 20% 25V RADIAL	10-ECE-A1CKS100ICT-ND	
1	0.32	0.32	Capacitor, 0.1uF	CAP CER 0.1UF 50V Z5U RADIAL	1C10Z5U104M050B	
1	0.32	0.32	Red LED, super bright	Red LED, super bright	297	Adafruit
1	0.03	0.03	100 Ω Resistor	100 Ω Resistor	4293	Adafruit
2	0.03	0.06	10k Ω Resistor	10k Ω Resistor	2784	Adafruit
1	1.25	1.25	Stacking Headers	Stacking Headers for Feather	2830	Adafruit
1	3	3	Protoboard for display	DFRobot 3.08" L x 2.28" W pad per hole	FIT0203	
1	30	30	Display, TFT, capacitive touch, 2.8”	Display, TFT, capacitive touch, 2.8”	2090	Adafruit
2	1.5	3	Short Female Headers	Short Female Headers for Feather	2940	Adafruit
1	0.09	0.09	Nut, Tripod Mount	1/4-20 Hex Nut 7/16 wide x 7/32 thick	95462A029	McMaster Carr
1	10	10	Micro SD Card	8 GB Micro SD Card w/ SD adapter	1294	Adafruit
1	1	1	Clock Battery	CR1220 Coin Cell Battery	380	Adafruit
1	10	10	Main Battery	Lithium Ion Cylindrical Battery — 2200 mAh	1781	Adafruit
1	7	7	Micro SD Card Reader	USB-C Micro SD Card Reader	5212	Adafruit
1	10	10	USB Cable	USB-C cable, power and data	4199	Adafruit

Table 2. Budget

Material/Component	**Weight (g)**
3V Button Battery	1.5
3.7V Cylindrical battery	46
VIS sensor	2.6
NIR sensor	5g
Temperature sensor	0.9
Pressure/Humidity/Temp sensor	1.7
Adalogger	5.1
Feather	5
Breadboard PCB	23
SD card	0.26
Take measurement button	1.5
On/Off button	2.4
Header pins	7.35
Other misc. Components (wires, solder, resistors, capacitors)	4.19
3D printed frame	42.9
housing	111.6
Flight tube	23.4
Total	284.4

Table 3. Weight



NIR: AS7263 Near Infrared Spectrum Sensor on SparkFun Breakout Board

VIS: AS7262 Visible Spectrum Sensor on Adafruit Breakout Board

TIR:: MLX90614ESF-BCC-000 Thermal Infrared Remote Surface Thermometer

AT: MCP9808 Ambient Temperature Sensor on Adafruit Breakout Board

WX: BME280 Barometric Pressure and Humidity Sensor on Adafruit Breakout Board

Datalogger: PCF8523 Real Time Clock and SD Card Reader on Adafruit Adalogger Board

Microcontroller: RP2040 Microprocessor on Adafruit Feather Board

Figure 3. Board Layout. Source: National Aeronautics and Space Administration. STELLA-1.1. Greenbelt (MD): NASA Goddard Space Flight Center; [cited 2026 Apr 10]. Available from: https://science.gsfc.nasa.gov/stella/instruments/spectral/stella-1-1/

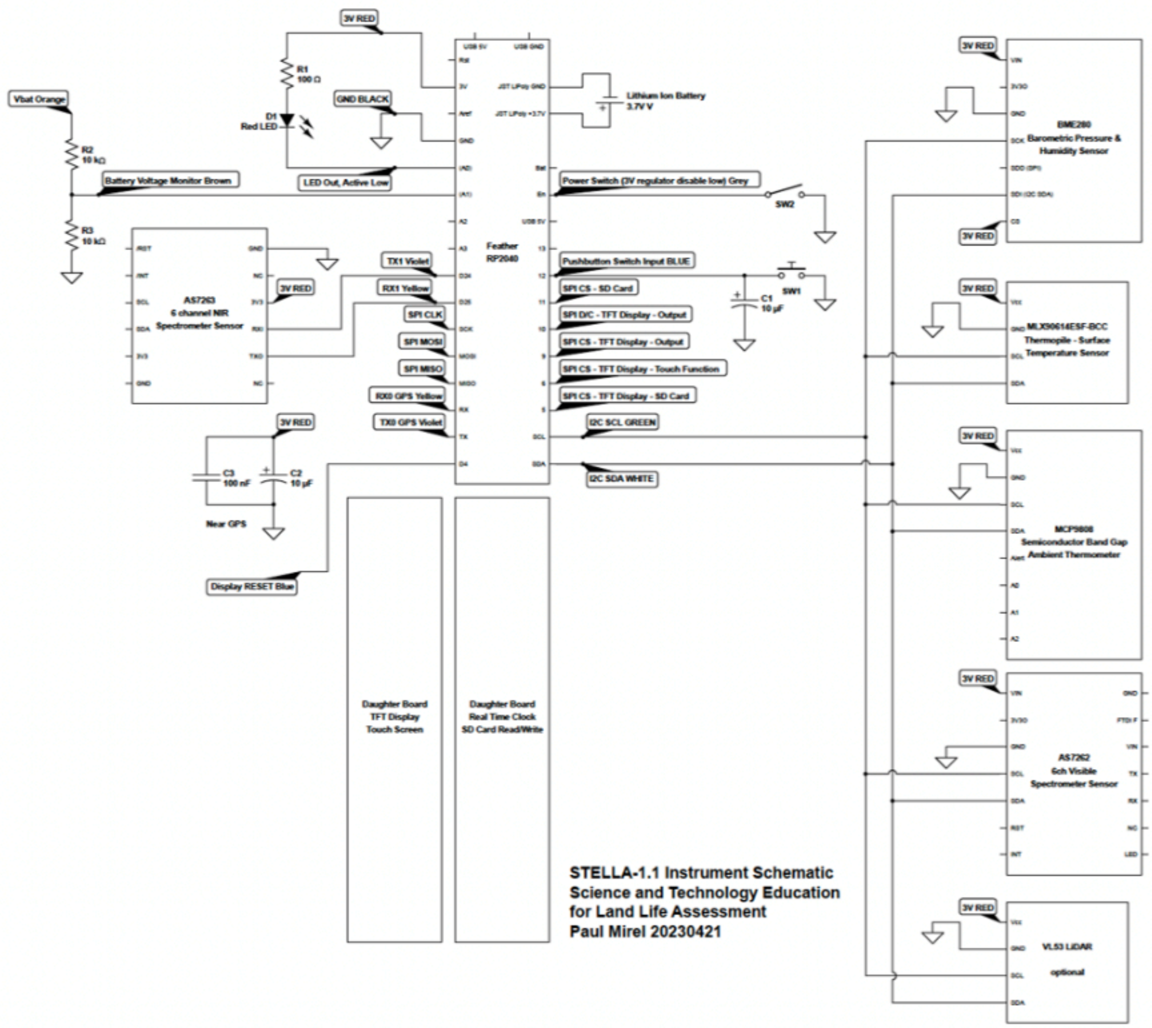


Figure 4. Electrical schematic. Source: National Aeronautics and Space Administration. STELLA-1.1. Greenbelt (MD): NASA Goddard Space Flight Center; [cited 2026 Apr 10]. Available from: https://science.gsfc.nasa.gov/stella/instruments/spectral/stella-1-1/