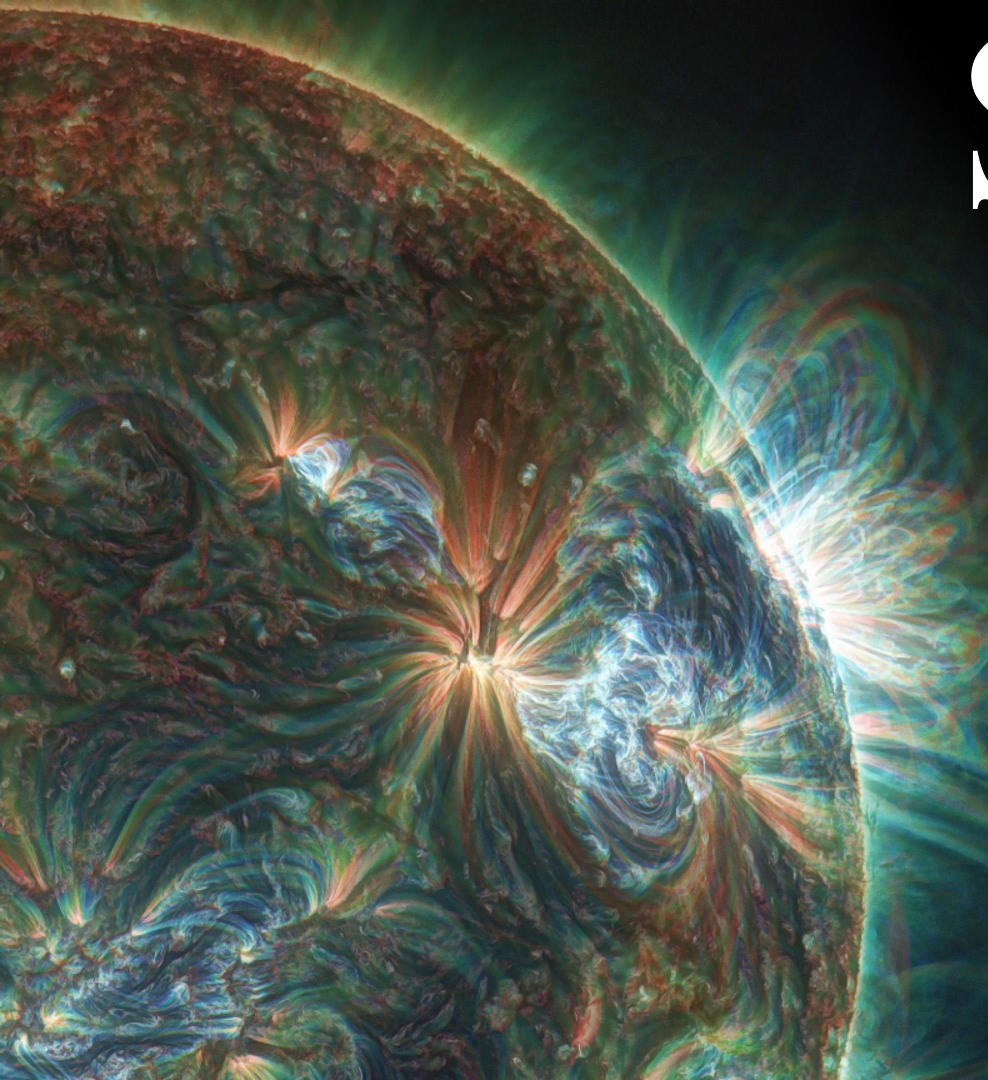


STOUT

Spectropolarimeter
Telescope
Observatory for
Ultraviolet
Transmissions

Presenters:

1. Andrew Arnold
2. Caleb Beavers
3. Matt Funk
4. Ian Geraghty
5. Dawson Stokley

Team Members:

1. Zach Allen
2. Darin Brock
3. Joshua Bruski-Hyland
4. Andrew Lux
5. Ryan Lynch
6. Matthew Normile

Customer:
NCAR High Altitude Observatory

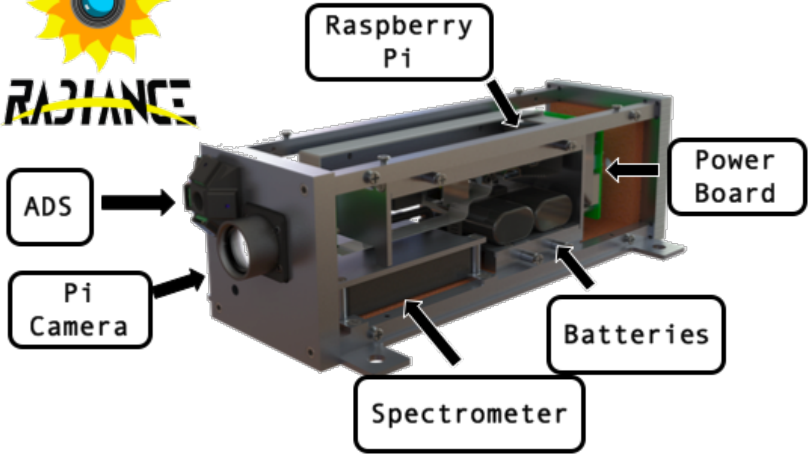
1. Phil Oakley
2. Scott Sewell

Advisor:
Francisco López Jiménez

Motivation

- Solar phenomena present catastrophic risks to ground and space based systems
- Models can be used to determine preconditions in the magnetic structure that lead to solar phenomena
- Solar photosphere and transition region (solar atmosphere) emit UV light
- UV light passes through the sun's magnetic field and is polarized to align with the field vector
- Measurements of UV spectra at varying polarization angles can be used to model solar magnetic field structure

RADIANCE Module



Project objective: 3U CubeSat-style payload to collect solar irradiance data

Systems to be Modified and Integrated with STOUT

- Environmental Monitoring and Control
- Raspberry Pi (pointing control and data acquisition)
- Spectrometer (spectra measurements)
- Attitude Determination (pointing feedback)
- Data Storage
- Electric Power System
- Structure

Mission Statement

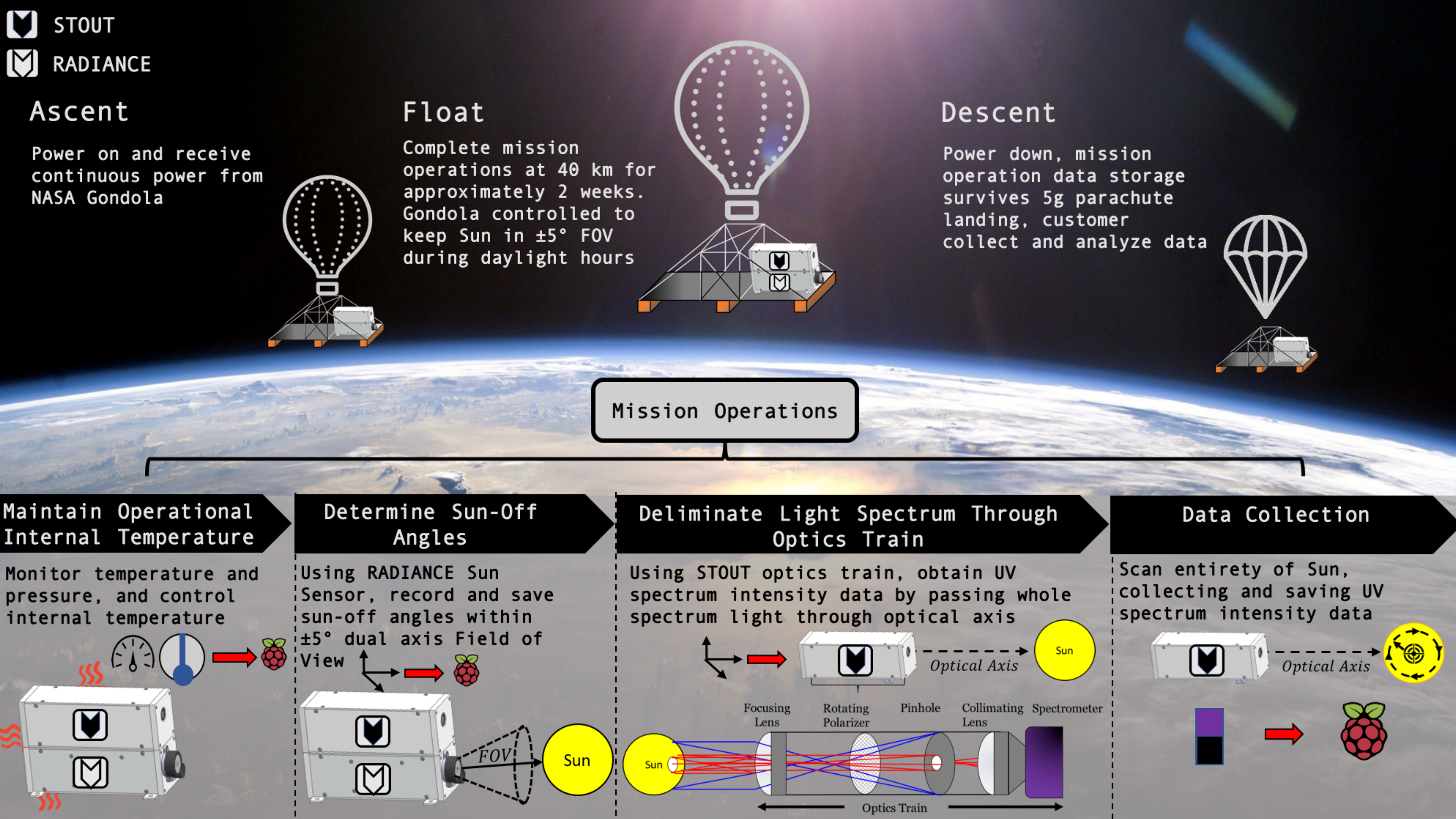
STOUT will design and manufacture a 3U CubeSat-style payload capable of high-altitude balloon flight, which integrates with last year's RADIANCE project. The module will scan the body of the sun to measure sunlight intensity as a function of position on the sun, polarization angle, and wavelength. Ambient atmospheric data, pointing attitude information, and images will be recorded as well. The team will utilize a variety of ground tests that simulate the expected high altitude environment in order to calibrate the module's data collection systems and verify the payload's flight readiness.

Project Objectives

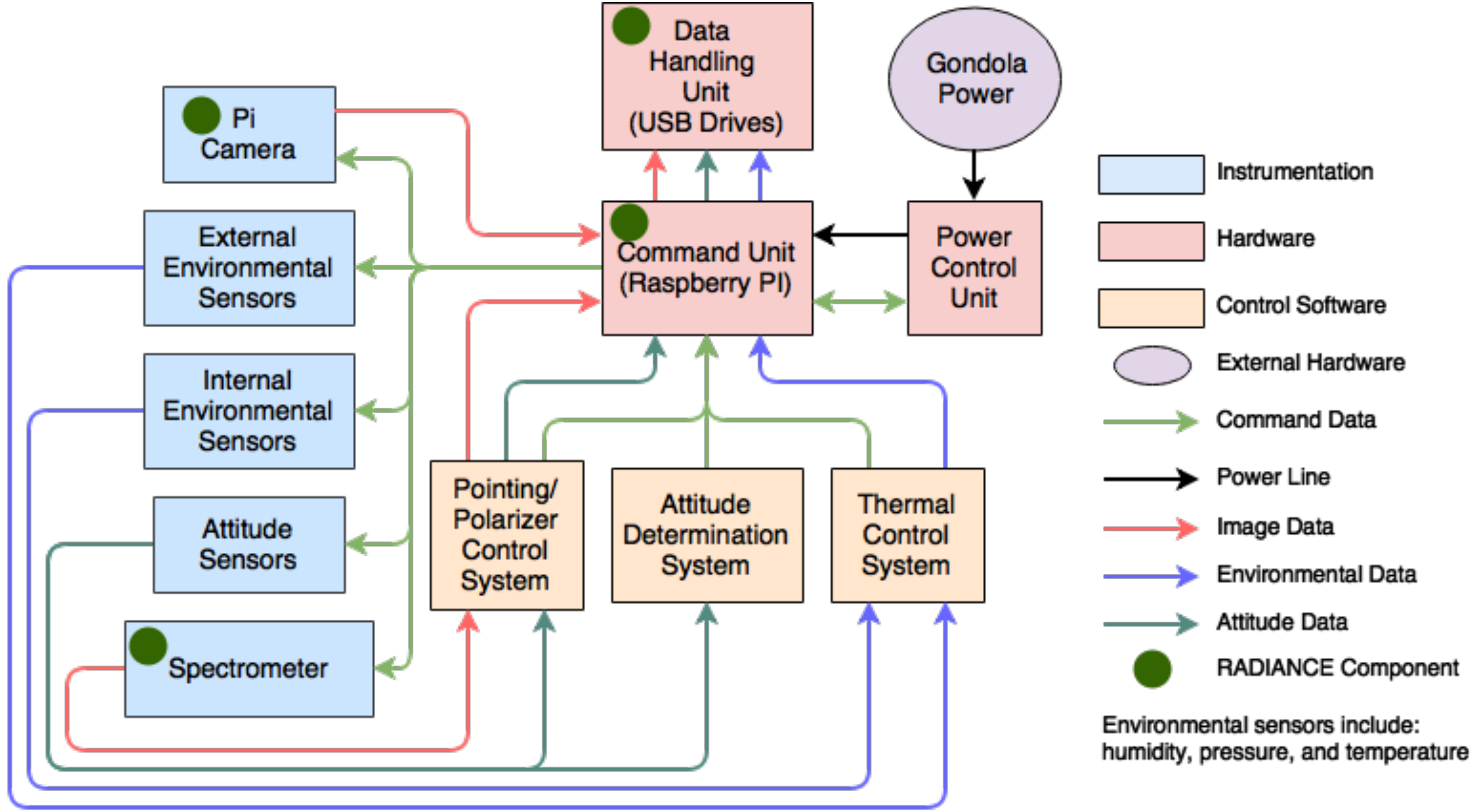
STOUT shall be capable of…

1. Integrating with RADIANCE module and NASA high altitude balloon gondola
2. Enduring and collecting data during the conditions of a 40 km high-altitude balloon flight
3. Determining its attitude relative to the sun
4. Collecting variable polarization UV spectra at various points on the sun's surface
5. Capturing images of the sun in the visible spectrum
6. Surviving a descent under parachute and impact with the ground so data is retrievable by customer

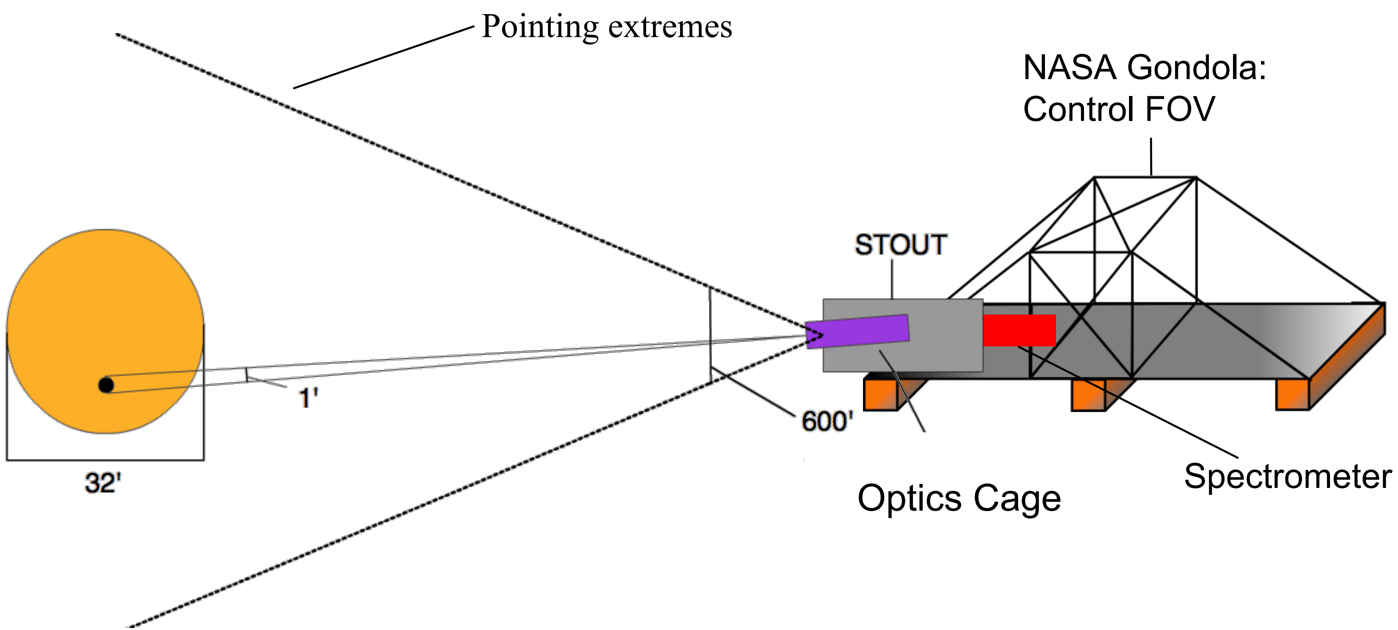
Concept of Operation: Mission CONOPS


STOUT
RADIANCE
Ascent
Power on and receive continuous power from NASA Gondola
Float
Complete mission operations at 40 km for approximately 2 weeks. Gondola controlled to keep Sun in ±5° FOV during daylight hours
Descent
Power down, mission operation data storage survives 5g parachute landing, customer collect and analyze data
Mission Operations
Maintain Operational Internal Temperature
Monitor temperature and pressure, and control internal temperature
Determine Sun-Off Angles
Using RADIANCE Sun Sensor, record and save sun-off angles within ±5° dual axis Field of View
FOV
Sun
Deliminate Light Spectrum Through Optics Train
Using STOUT optics train, obtain UV spectrum intensity data by passing whole spectrum light through optical axis
Optical Axis
Sun
Focusing Lens
Rotating Polarizer
Pinhole
Collimating Lens
Spectrometer
Sun
Optics Train
Data Collection
Scan entirety of Sun, collecting and saving UV spectrum intensity data
Optical Axis

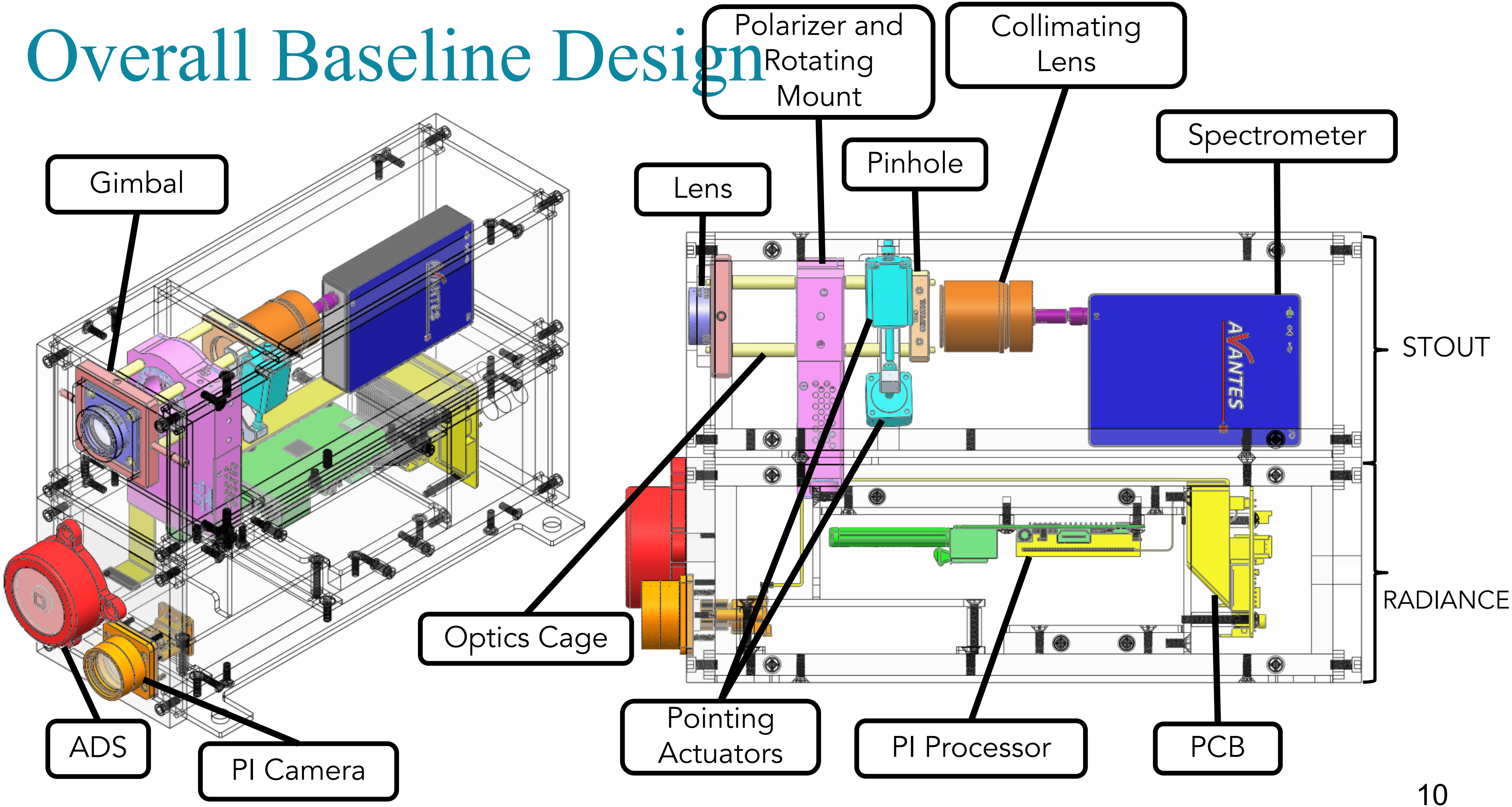
Functional Block Diagram



Pointing Explanation



Overall Baseline Design



Identification of Critical Project Elements

Baseline Design Topics

- **Instrumentation & Control**
  - Lenses
  - Polarize Mount
  - Pointing Actuators
  - Optics Mount
- **Environmental Monitoring & Control**
  - Active Control
- **Attitude Determination**
  - Sun Sensor
- **Data Acquisition**
  - Software
- **Structure**
  - Gondola Integration

Legend

- Subsystem
- Sub-Subsystem
- Controlled Sub-Subsystem

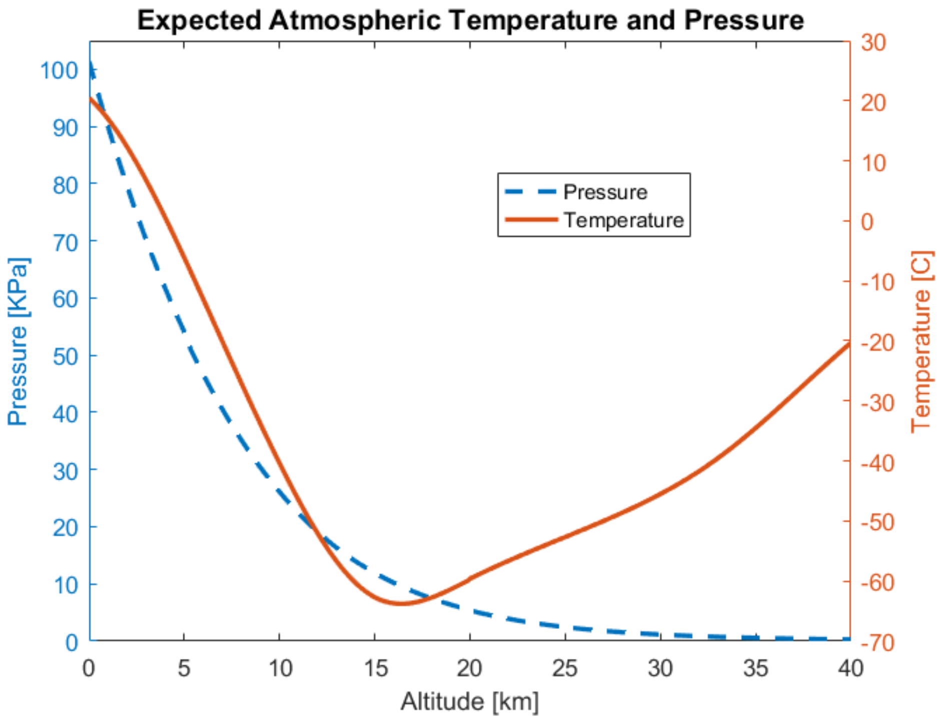
EMCS Requirements

FR5: The system shall survive the conditions of a high altitude balloon flight up to 40km

Requirement	Description
5.1	During ascent and descent the system shall survive external temperatures ranging from -70°C to 20°C
5.2	During cruise the system shall operate under external temperatures ranging from -25°C to -15°C
5.3	The system shall operate at pressure values of 100 kPa to 10 Pa

Atmospheric Model

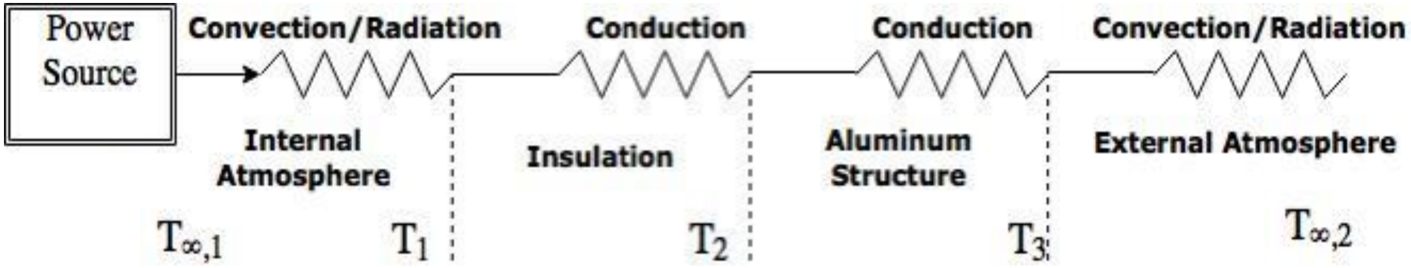
- Flight conditions for Fort Sumner, NM launch
- Based on 2001 US Navy Model (temperature) & COESA Model (Pressure)



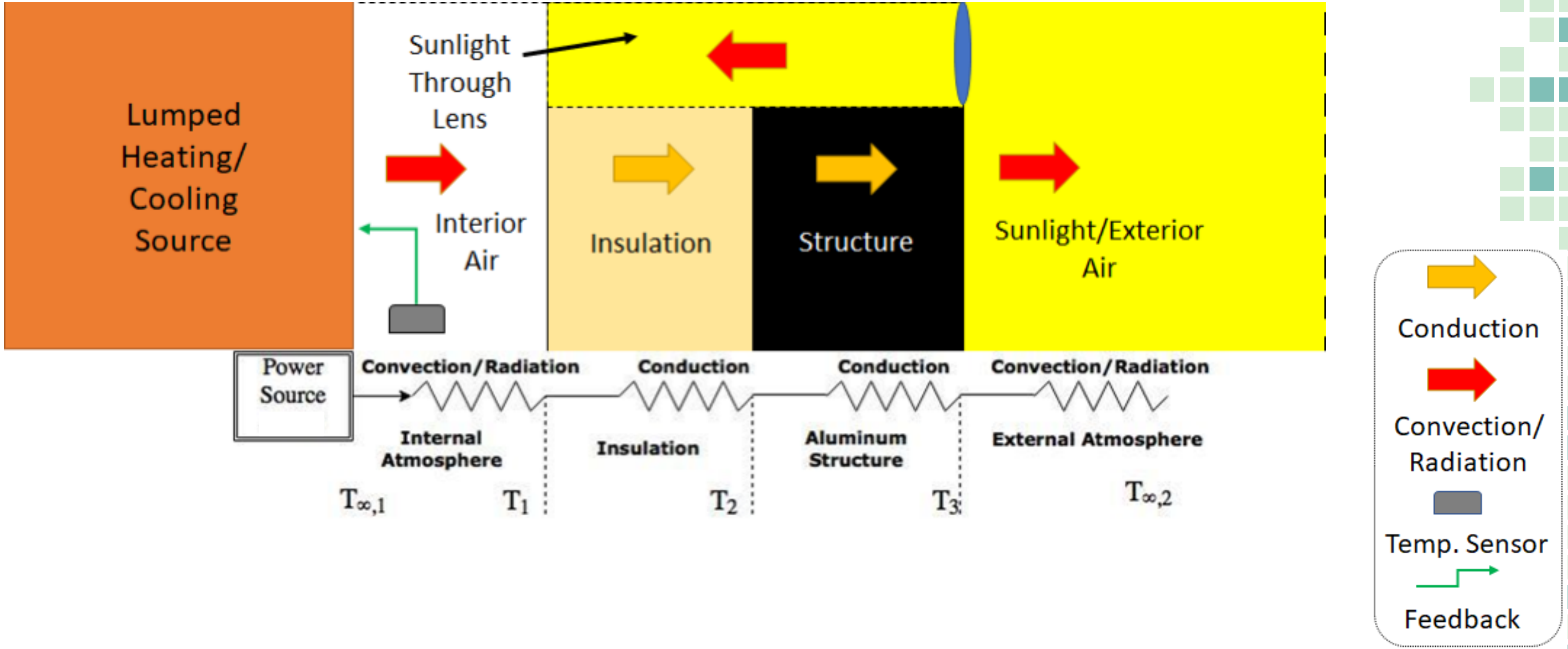
Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

EMCS Baseline Design

- Assumptions:
  - Bulk temperatures (no variation within components)
  - No forced convection (wind)
  - Thermal conductivity of air varies linearly with respect to pressure



EMCS Baseline Design



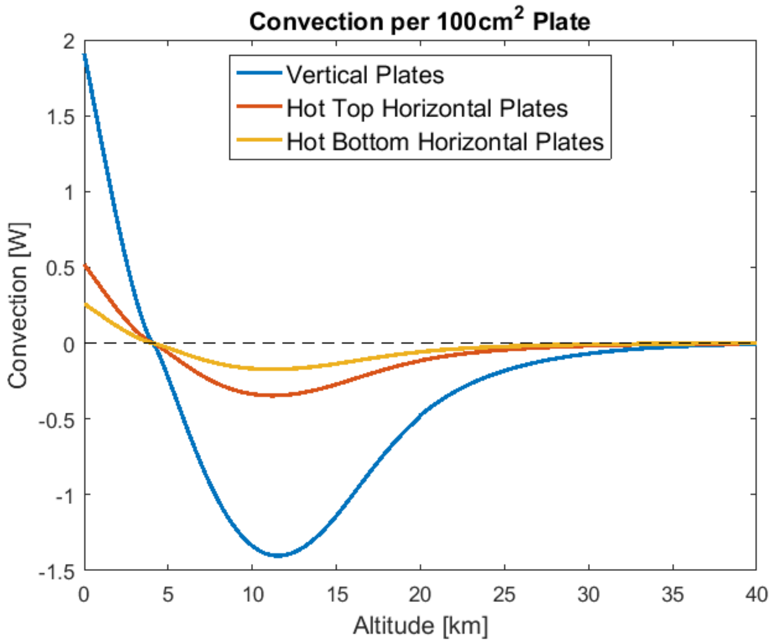
Convection

Relevant Equations

$$\dot{Q} = hA\Delta T$$

$$h = \frac{k}{L_c} Nu$$

$$Nu(Ra,Pr) = \frac{gC_p\rho(T_s - T_\infty)L_c^3}{\kappa\nu}$$



Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

Radiation

Radiated Heat

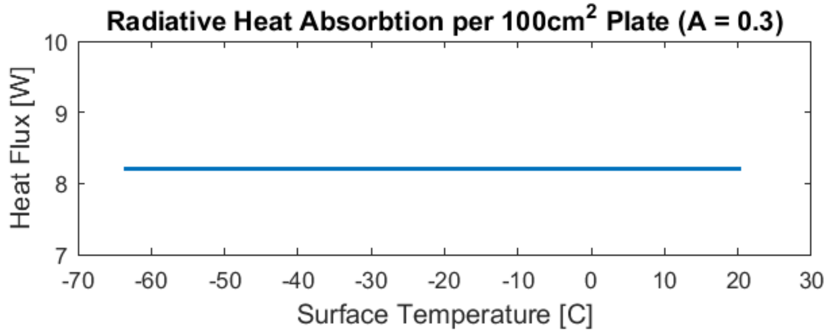
$$\dot{Q} = \sigma A T^4 \epsilon$$

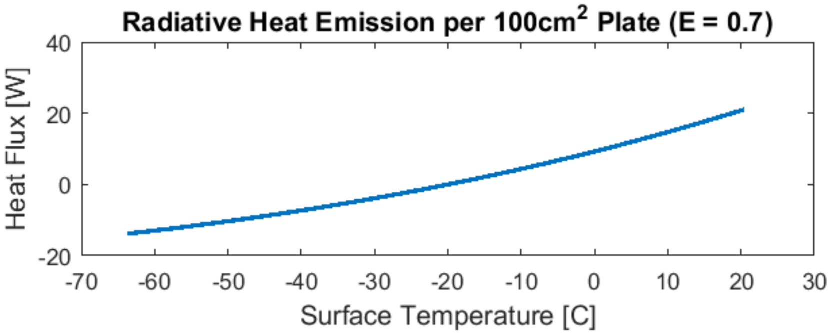
$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$$

Absorbed Heat

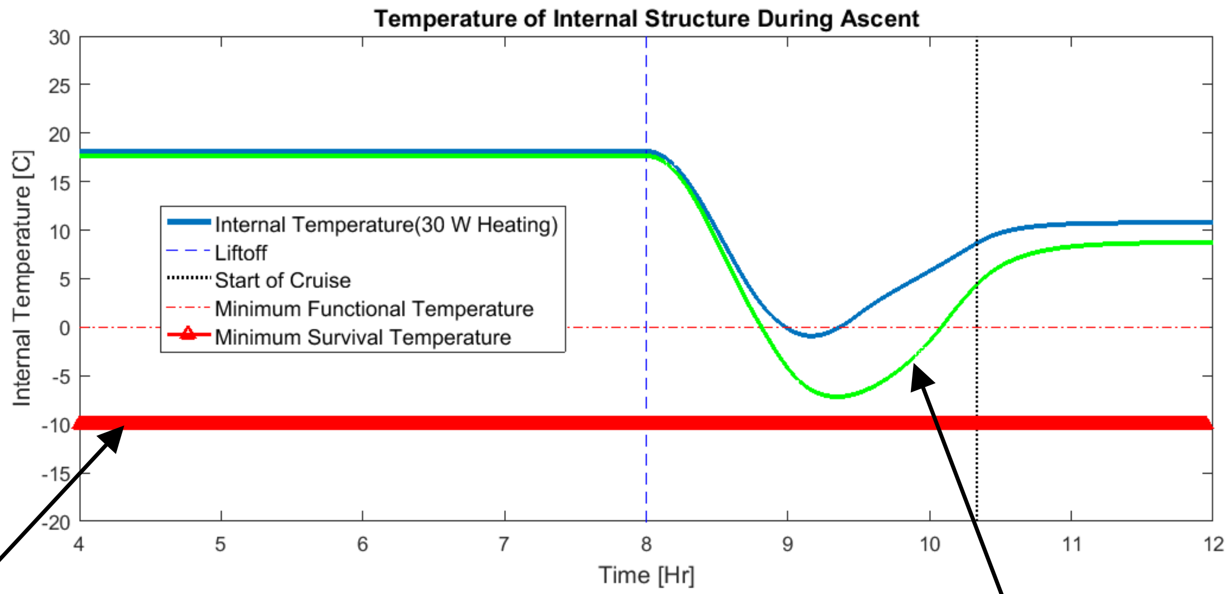
$$\dot{Q}_{in} = \dot{Q}_{Source} A \alpha$$

$$\dot{Q}_{Vacuum} \approx 1367 [W/m^2]$$





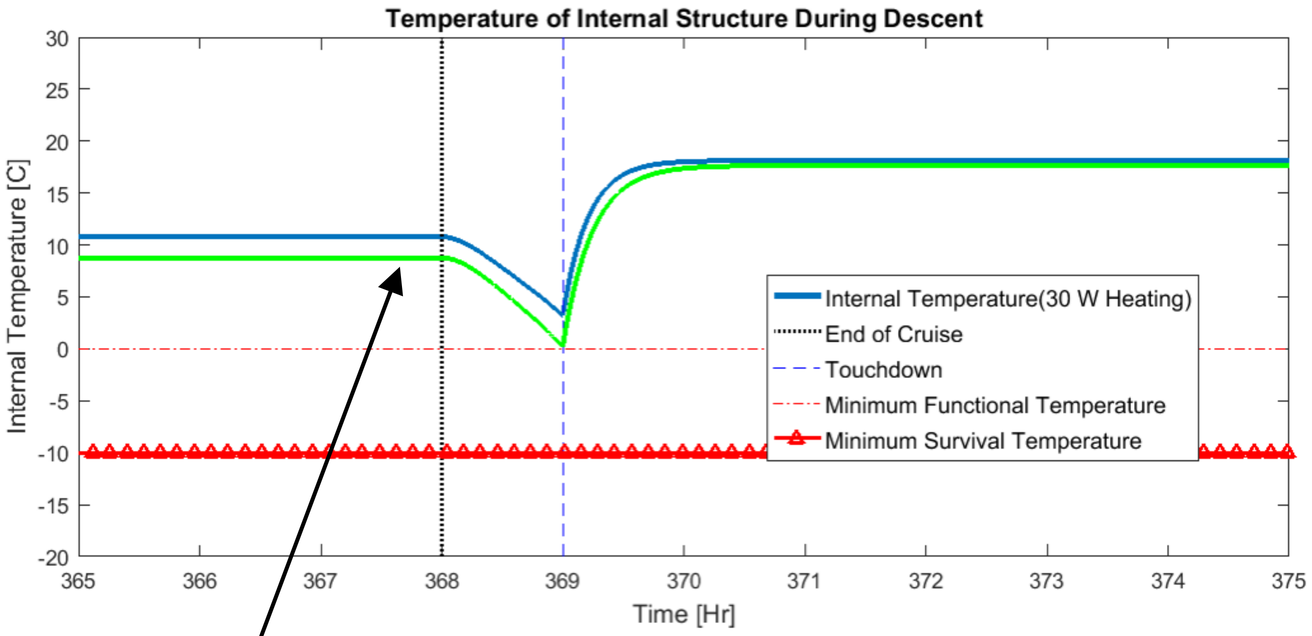
Thermal Profiles: Ascent



Survival temperature determined by spectrometer survivability temperature

Internal Temperature (20 W Heating)

Thermal Profiles: Descent



Internal Temperature (20 W Heating)

✔ **Feasible**

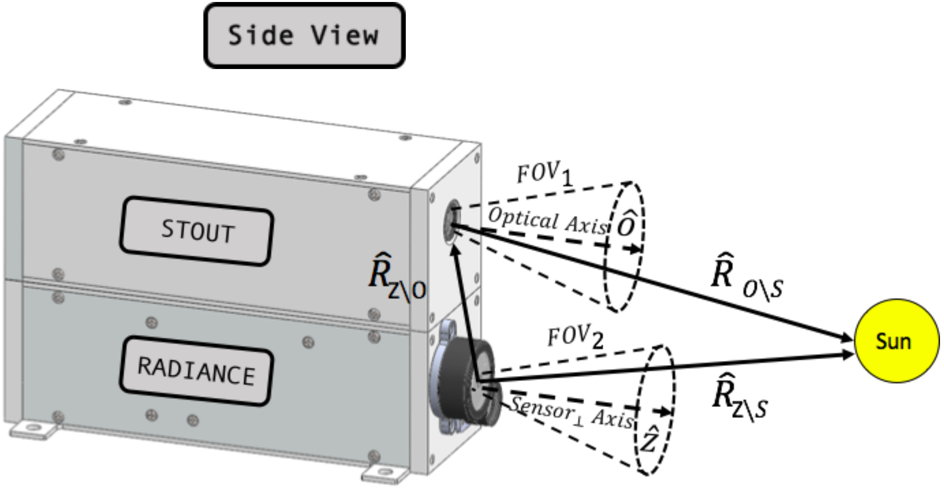
Attitude Determination Requirements

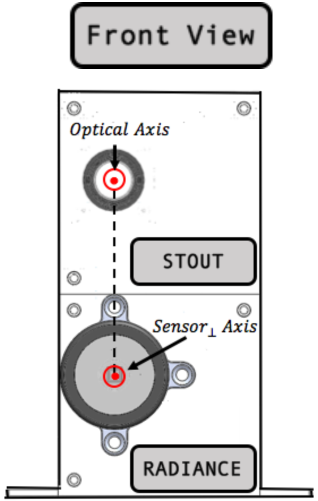
FR3: The system shall determine its attitude relative to the sun center

Requirement	Description
3.1	The off-light source angle attitude shall be determined to within 3′ (0.05°) of light source center
3.2	Attitude data shall be recorded synchronously with instrument data
3.3	Attitude data shall be interfaced with instrumentation pointing control

Statement

Purpose: Solve Off-Sun Angles





Assumptions

Sun within ± 5° of optical axis (given by customer)

Given

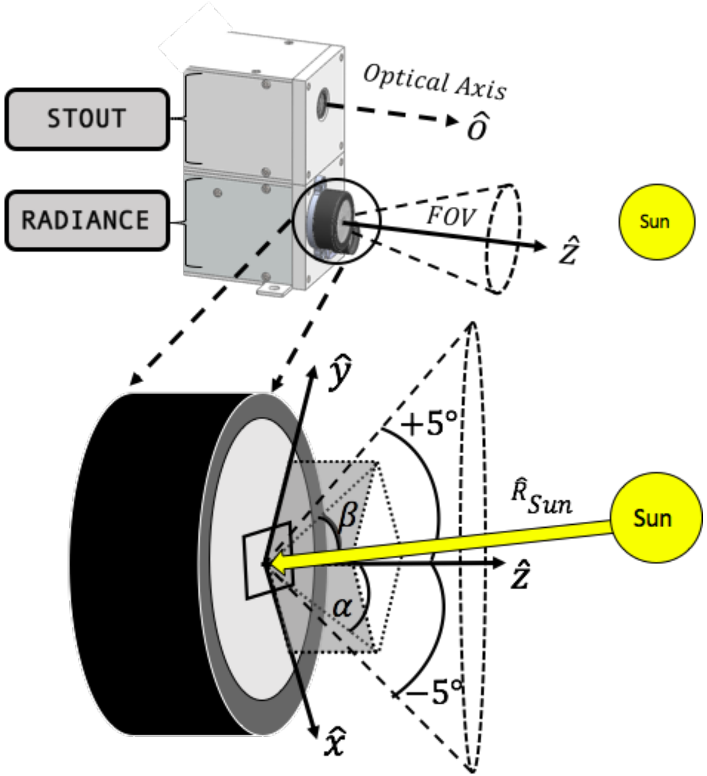
$\hat{o} = \hat{z}, \; \hat{R}_{O\backslash S}, \hat{R}_{Z\backslash S} >> \hat{R}_{S\backslash O}$

- $\hat{R}_{O\backslash S} = \hat{R}_{Z\backslash S}$

Conclusion

Sun off-angles relative to sun sensor axis is equal to that of the optical axis

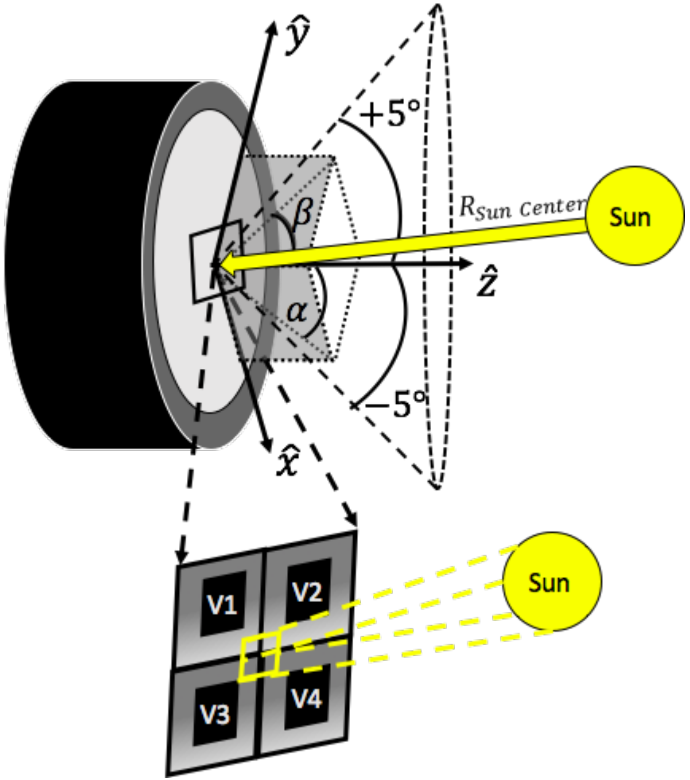
Attitude Determination Baseline Design



Sun Sensor

- Used to solve off-sun angles
- Used for optics pointing control
- Mounted on RADIANCE sun facing panel
- Replace existing RADIANCE ADS (deemed infeasible)
- Normal vector in same direction as optical axis
- Uses quadrant photodetector to measure incident angle from generated photocurrents
- Field of View: dual axes ± 5°
- Accuracy: ± 0.02°
- Compatible with Raspberry Pi

Attitude Determination Baseline Design



Relevant Equations

$$x_1 = V_3 + V_4 \qquad y_1 = V_1 + V_4$$

$$x_2 = V_1 + V_2 \qquad y_2 = V_2 + V_3$$

$$F_x = \frac{x_2 - x_1}{x_2 + x_1} \qquad F_y = \frac{y_2 - y_1}{y_2 + y_1}$$

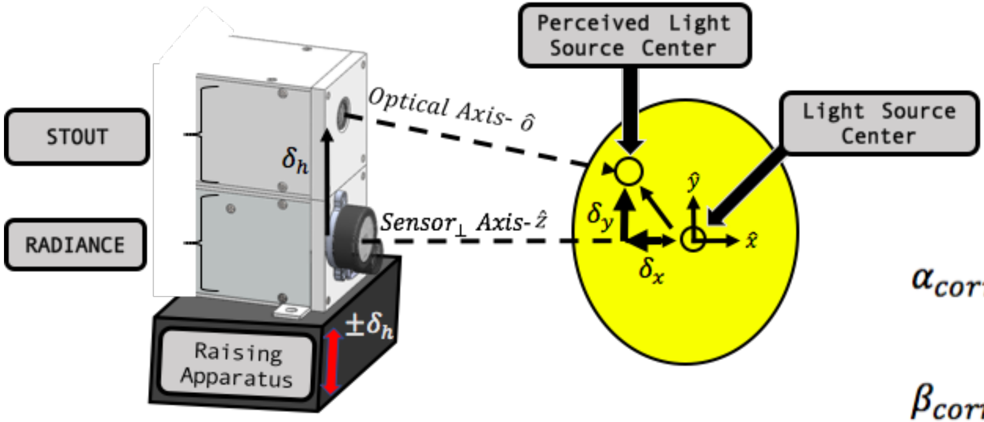
$$\alpha = \arctan(C * F_x) \qquad \beta = \arctan(C * F_y)$$

Parametric Value (C)
∗ Dependent on Sensor ∗

Sun Off-Angles (α & β)

- Communicates the sun's position relative to field of view to the system
- Data saved and used in optics controls

Attitude Determination Feasibility



Corrected Equations

$$\alpha_{corrected} = arctan(C * F_x) + \tan^{-1}\frac{\delta_x}{\delta_y}$$

$$\beta_{corrected} = arctan(C * F_y) + \tan^{-1}\frac{\delta_y}{\delta_x}$$

Calibration

- Sensor normal axis corresponds to max photocurrent generation
- Move system until max photocurrents generated
- Measure deviations of optical axis and sensor normal axis
  - Laser pointing down optical axis
  - Sun simulated light source
- Corrects manufacturing errors

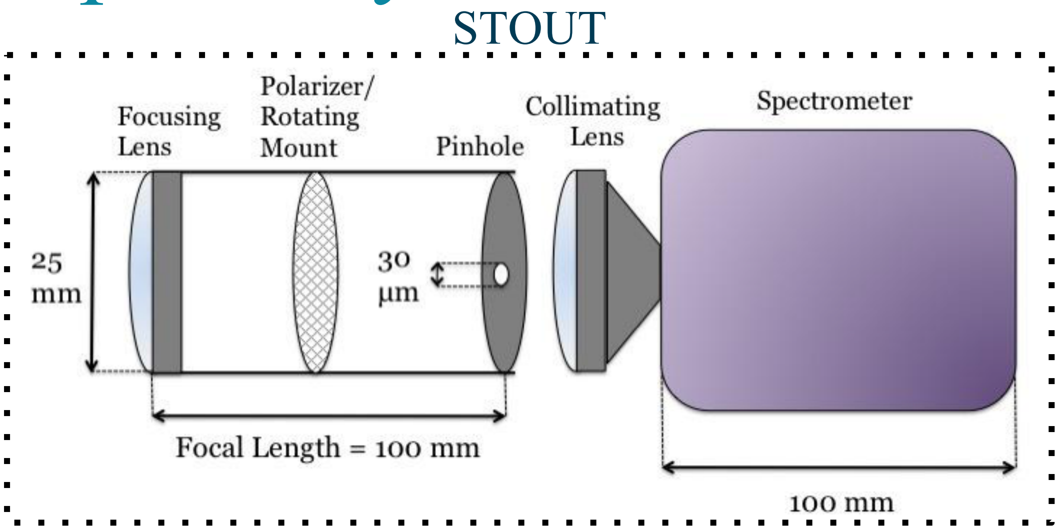
✓ **Feasible**

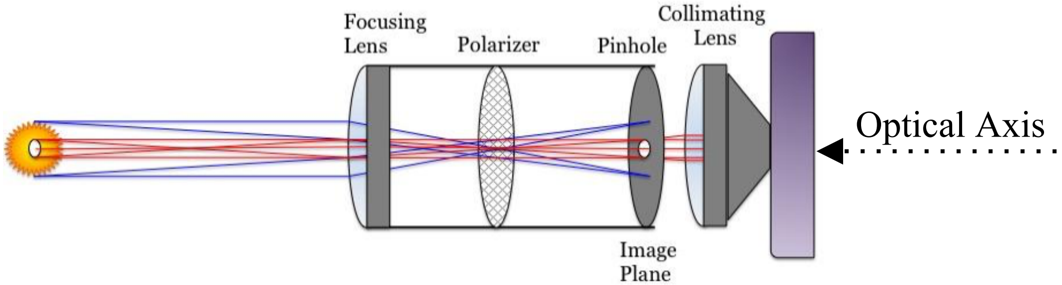
Optical System Requirements

FR2: Collect variable polarization UV spectra at various points on the sun’s surface

Requirement	Description
2.1	Isolation of <= 1′ (0.0167°) spot
2.2	Spectrum measurements in the 270 - 290 nm range

Optical System Baseline Design

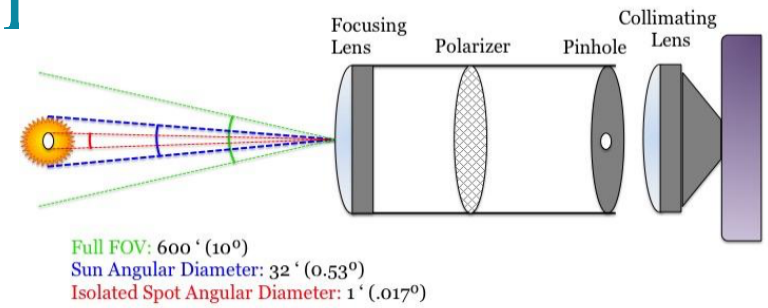


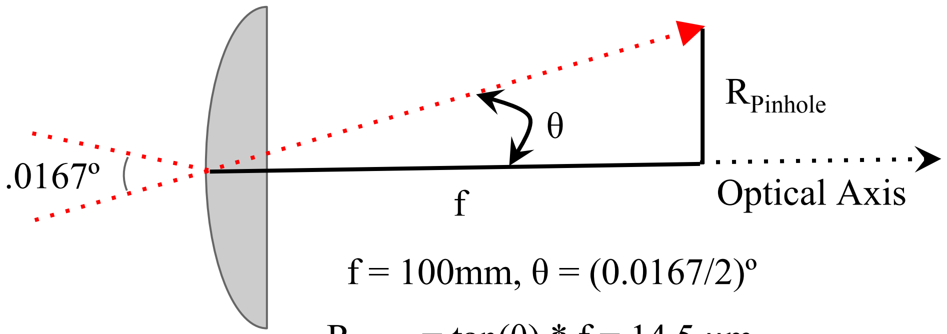


- Focusing lens bends incoming light such that an image of the FOV forms at the focal length
- Polarizer reflects incoming light that isn't propagating at the same angle as its mounted
- Pinhole blocks light outside of 60'' spot in FOV
- Collimating lens directs light into the spectrometer
- Spectrometer records intensity as a function of wavelength

Optical System Feasibi

- Isolation of a 60'' spot in the FOV can be accomplished with a 30 μm diameter pinhole in image plane
- Zemax modeling of Thorlabs ACA254 - UV lens shows that sufficient focusing occurs at the focal length when the target is aligned with the optics

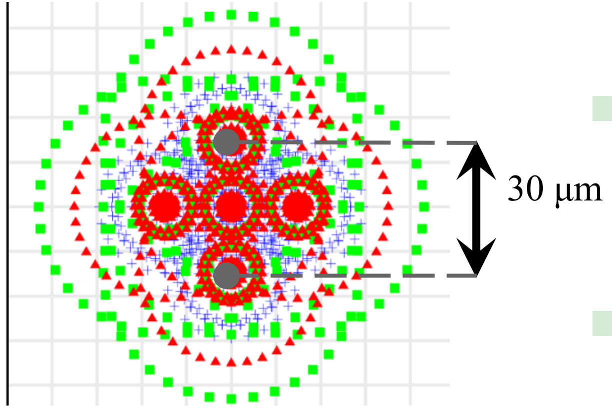




$f = 100mm$, $\theta = (0.0167/2)^o$

$R_{Pinhole} = \tan(\theta) * f = 14.5\ \mu m$

Spot Diagram of Centered 60' Spot in FOV



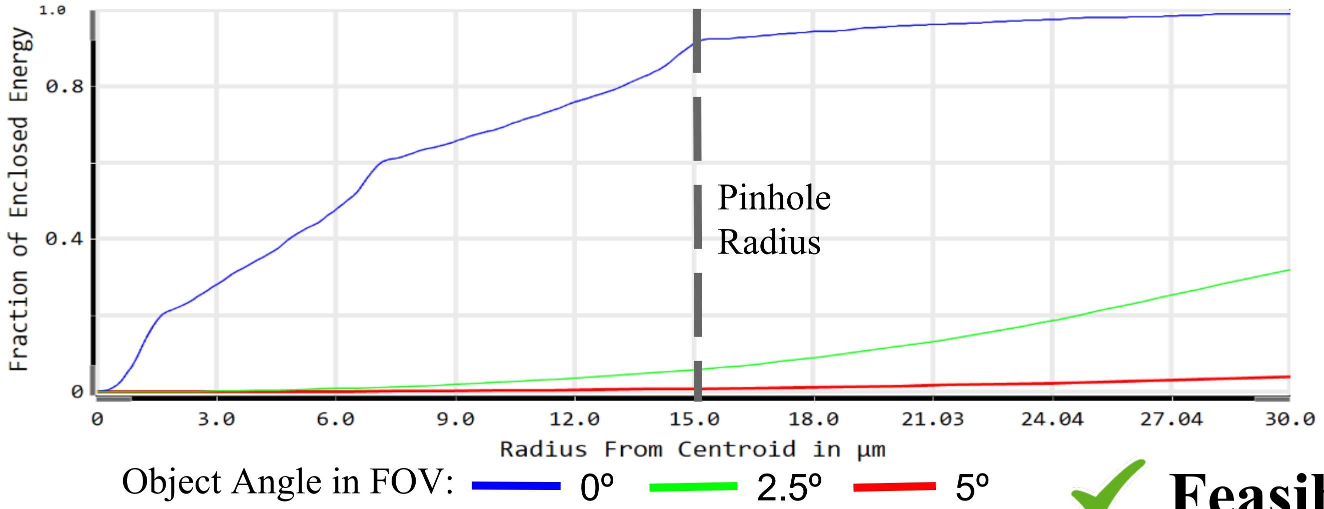
- 270 nm - 280 nm - 290 nm

Optical System Feasibility

- Spherical and chromatic aberrations cause poor focusing when object is not at center of FOV
- At center of FOV ~92% of energy is enclosed in pinhole area

Must point the optics components to collect valuable data

Geometric Enclosed Energy of Spot Diagram



✓ **Feasible**

Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

Instrument Feasibility

Flux Budget

Stage	Total Power Over 270 - 290 nm range
Before lens	3.7 mW
After lens	3.4 mW
After polarizer	2 .0 mW
After pinhole	2 μW
After Collimator	1.8 μW

- Need to set exposure time/averaging of Avantes Mini 2048L Spectrometer to reach goal SNR of 200:1
- Avantes engineers expect ~3 second integration time for predicted input power of 1.8 μW

✓ **Feasible**

Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

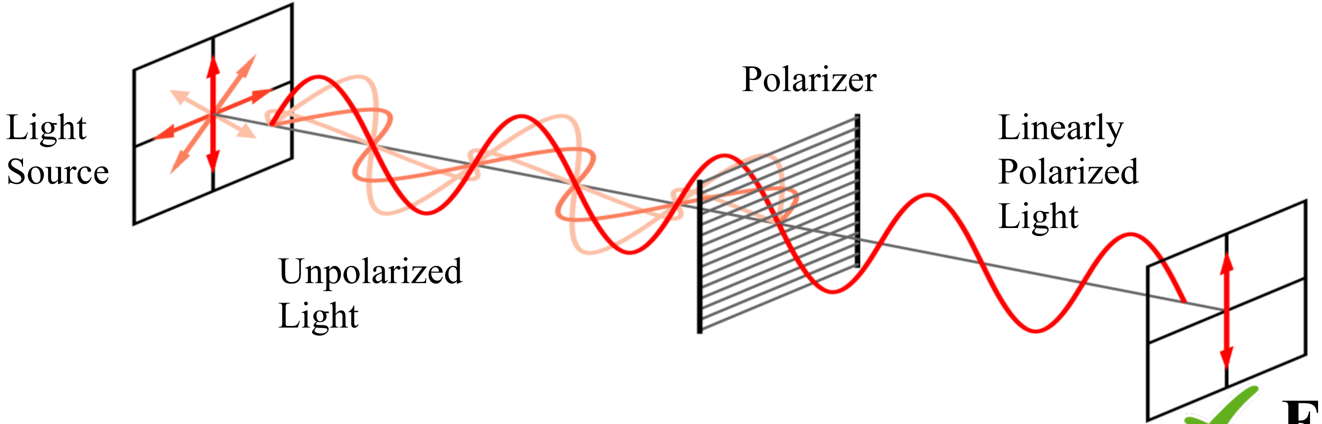
Pointing Control Requirements

FR2: Collect variable polarization UV spectra at various points on the sun's surface

Requirement	Description
2.3	Rotate polarizer with <=1º accuracy
2.4	Altitude pointing of +/- 1º in azimuth and +/- 5º in elevation

Feasibility

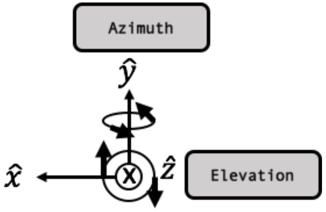
- ➢ By rotating the polarizer we can control the polarization of the collected light
- ➢ Thorlabs Ultra Broadband Wire Grid Polarizer is provided by our customer
- ➢ Thorlabs Stepper Motor Rotation Mount provides 0.03° of incremental rotation of the polarizer

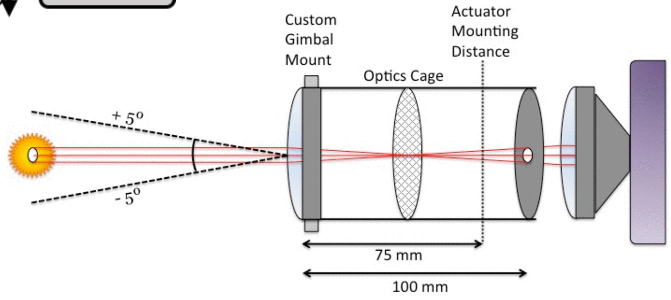


Feasible

Pointing Control Baseline Design

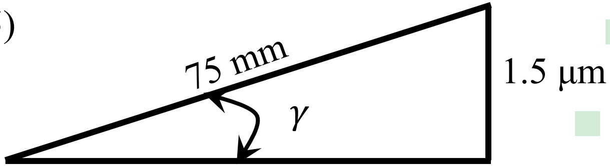
- ➢ Optics cage mounted so azimuth/elevation pointing can be achieved using linear stepper motors
  - ○ Gimbal on front
  - ○ Stepper motors mounted to the optics cage with ball joints
- ➢ Avantes 25mm Diameter Collimating Lens: allows optics cage to pivot by +/- 5º while spectrometer/collimating lens remain stationary
- ➢ Haydon Kerk Hybrid Stepper Motors provide incremental movement of 1.5 μm which corresponds to a change in pointing angle of γ





γ = arcsin(0.0015/75)

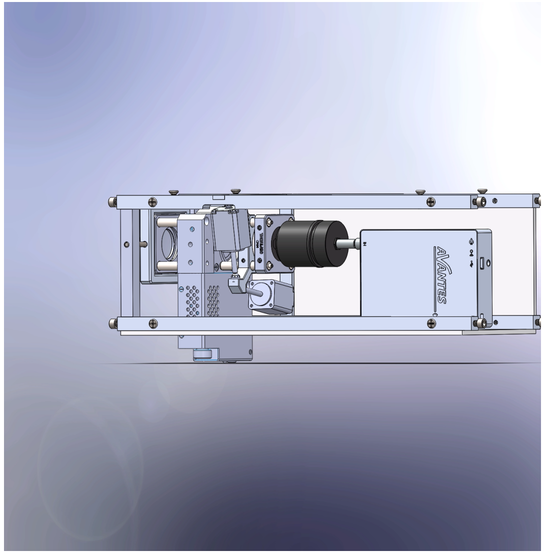
γ = 0.0015º = ~0.1'



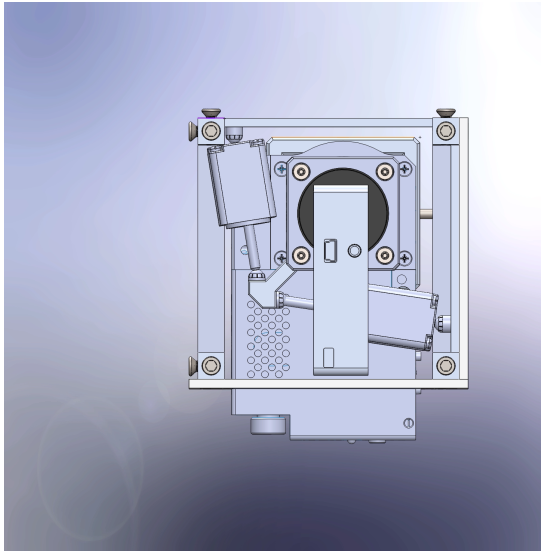
*movement along an arc approximated by linear displacement

Pointing Control Feasibility

- ➢ Pointing position determined by taking into account the extension of each motor head and the constraints (no rotation about optical axis) of the gimbal mount



Side View

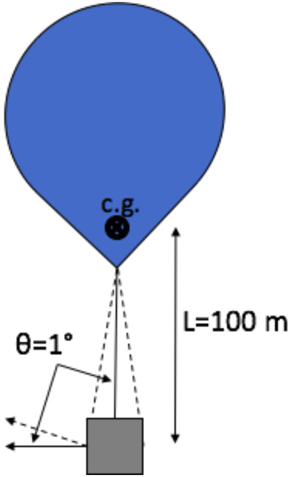


Front View

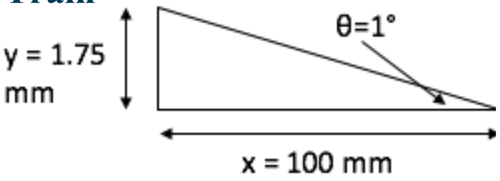
Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

Pointing Control Feasibility

Diagram



Linear Disp. of Optics Train

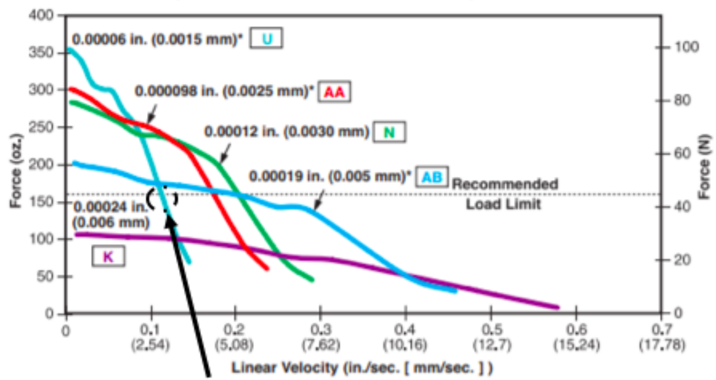


Relevant Equations

$$T = 2\pi\sqrt{\frac{L}{g}}$$

$$v_{req} = \frac{4y}{T}$$

Haydon Linear Actuator Speed



Speed of U Series at Force of 42 N:

$$v_{act} = 3.175\ mm/s$$

Assumptions

- ➢ Length of pendulum: 100 m
- ➢ Max deflection angle 1 deg
- ➢ For $v_{act} > v_{req}$ pointing req. met

Conclusion

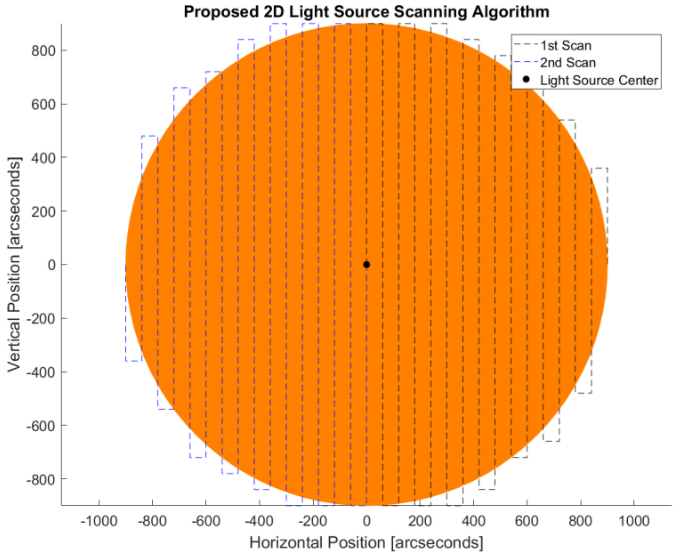
$$v_{req} = 0.35\frac{mm}{s} < v_{act}$$

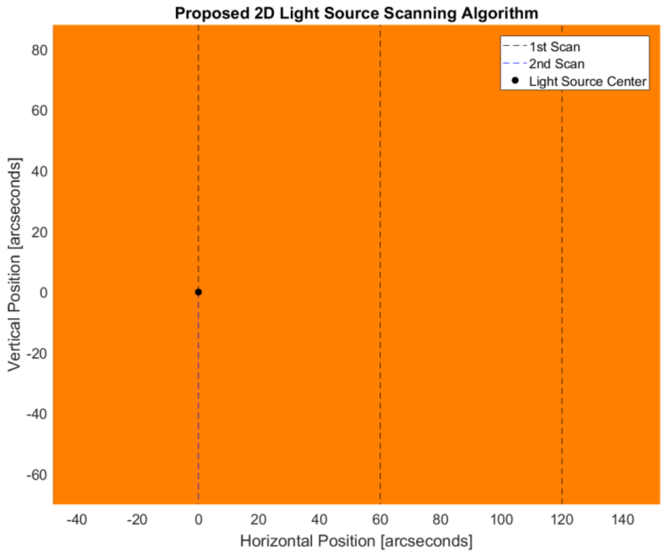
As pendulum swings, linear actuators move quick enough to maintain same pointing position

✔ **Feasible**

Light Source Scanning Algorithm

- 1' between scan points
- Currently 788 scan points: 19.7 days to scan entire surface at all polarization angles
- To decrease scan time
  - Larger lens/ more input power/ decrease spectrometer exposure time to 1s

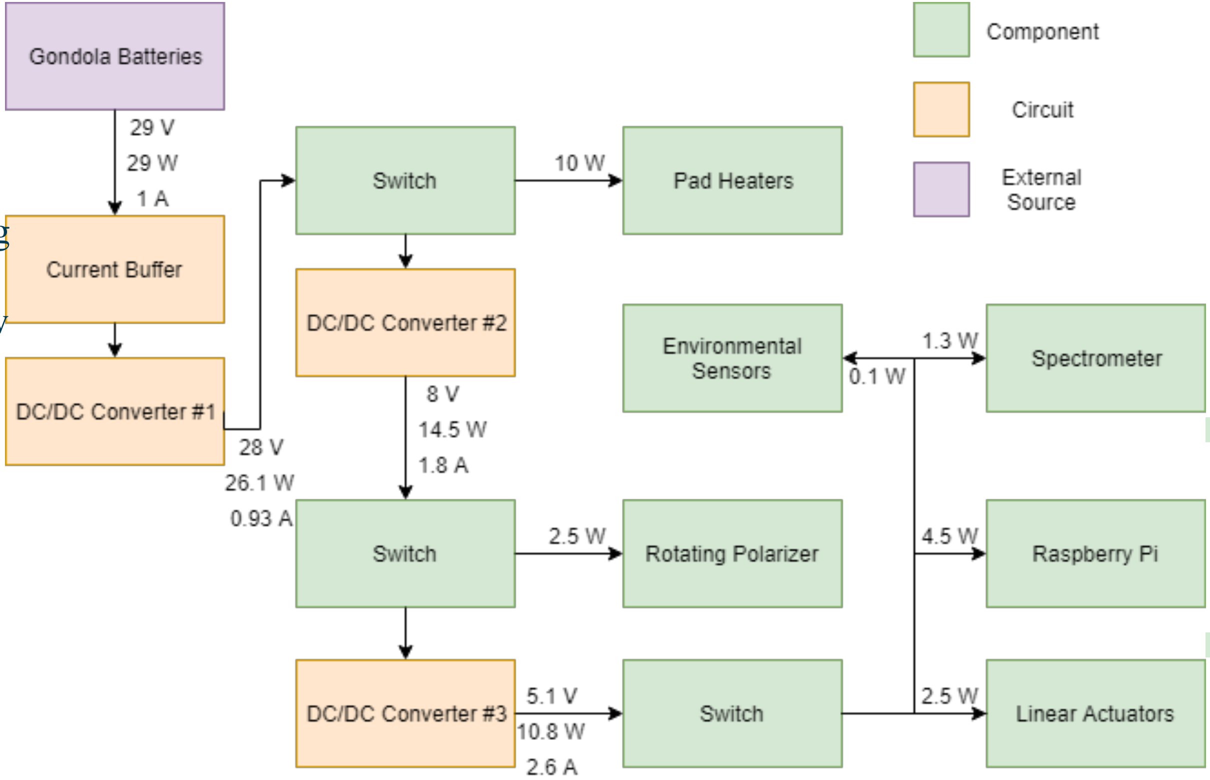




Power Baseline Design

Assumptions:

- ➢ Converter efficiency: ~90%
- ➢ No losses in wiring
- ➢ Steady power draw from gondola batteries
- ➢ Converter load is sufficient for operation



Power Budget

Component	Wattage (W)	Voltage(V)
Raspberry Pi(DAQ)	4.25	5.25
Spectrometer	1.25	5.0-15.0
Rotating Polarizer	2.50	8.0
Linear Actuators	2.45	5.0
Pad Heaters	20.0	28.0
Sun Sensor	0.045	5.0
Total	30.5	-
Supply	29.00	29.0
Difference	-1.50	-

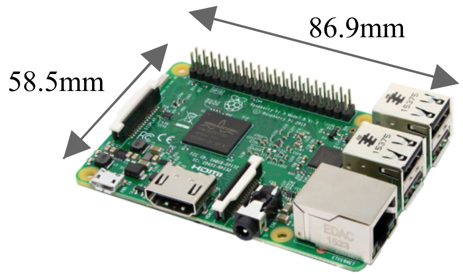
DAQ and Microprocessor Requirements

Requirement	Description	Frequency
1.1	System shall interface with RADIANCE's Raspberry Pi	N/A
6.1	System shall record temperature data	1 Hz
6.2	System shall record pressure data	1 Hz
6.3	System shall record attitude data	1 Hz
6.4	System shall record Raspberry Pi camera images	0.1 Hz
6.5	System shall record attitude data at same rate as spectrometer readings during measurement	Determined by Spectrometer
6.6	System shall time-stamp all measured data	1 Hz

DAQ Baseline Design

Single Processor: Raspberry Pi 3 Model B

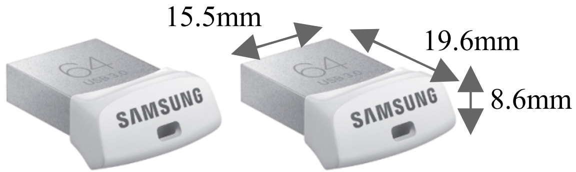
Specifications	
CPU	1.2 GHz quad-core
Interfaces	4 USB, 40 GPIO
OS Storage	1 microSD Slot
OS	Raspbian



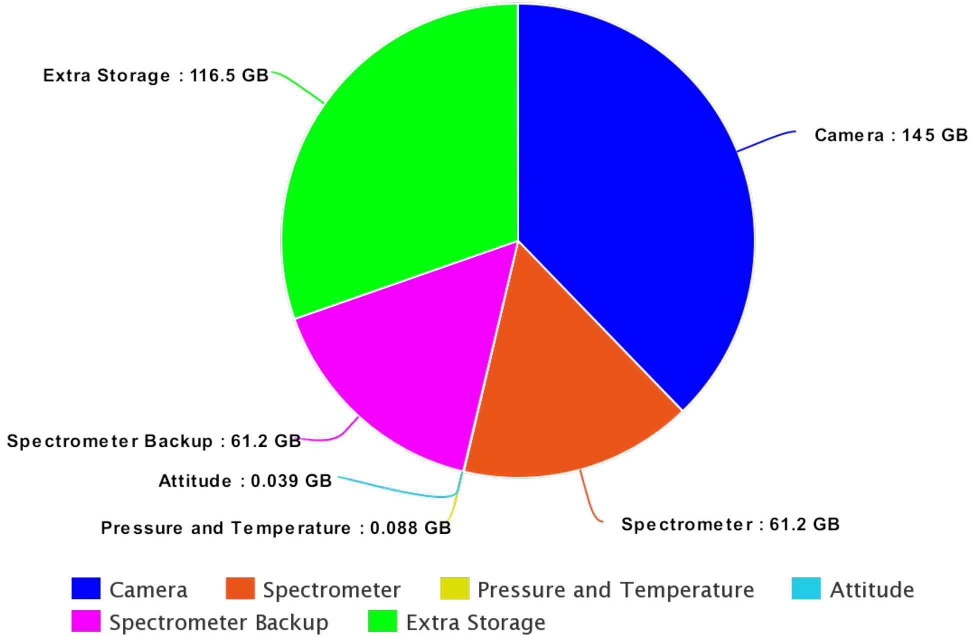
*From RADIANCE

Data Storage: USB Flash Drives

Specifications	
MX-ES SLC 64GB	Shock resistant, SLC format protects against radiation
Two Samsung Fit 128GB	Shock resistant
One Samsung Fit 64GB	Shock resistant, inherited from RADIANCE



Data Storage Feasibility



- Storage Needed:
  - 267 GB
- Available Storage:
  - 384 GB

✓ **Feasible**

Structural Requirements

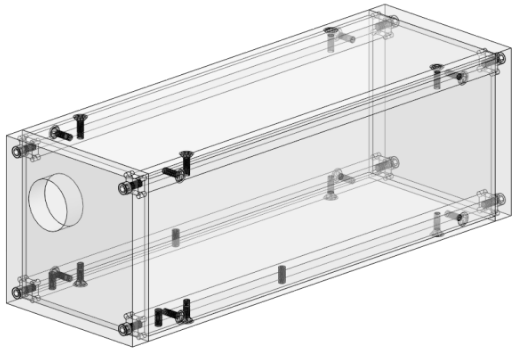
FR7: STOUT shall Integrate with RADIANCE module and NASA balloon gondola

Requirement	Description
7.2	The mass of STOUT shall not exceed 6kg
7.5	The structure linkages shall comply with all requirements and provisions of "Structural Requirements and Recommendations for Balloon Gondola Design"
7.6	STOUT structure shall preserve structural integrity up to a 5g shock force

*** For Level 1 Requirement, only concerned with structure and data storage survivability***

Structure Baseline Design & Feasibility

- Front and back plates
- Interior support struts
- Exterior surface panels
- Mounts on top of RADIANCE module
- Constructed from Aluminum 6061

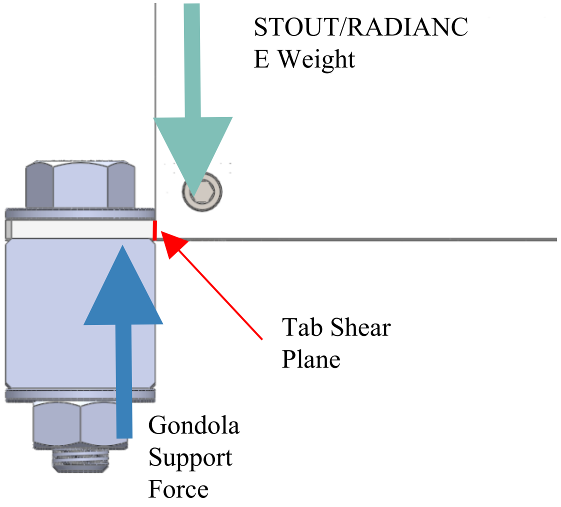


Mass Budget

Component	Mass (kg)
Structure	2.00
Thermal	0.05
Instrumentation	0.70
Actuation	0.70
C&DH	0.05
Total System	3.50

✔ **Feasible**

Structural Feasibility



- Each bolt subjected to tensile stress
  - For 5g shock = 34.1psi
- SAE J429 Grade 1 bolt tensile strength = 60,000psi
  - FOS = 1760
- Each tab (4 total) subjected to shear stress
  - For 5g shock = 120.5psi
- Al 6061 Shear strength = 30,000psi, FOS = 249

✔ **Feasible**

Status Summary

Feasibility Recap and Next Steps

All Level 1 Requirements Feasible

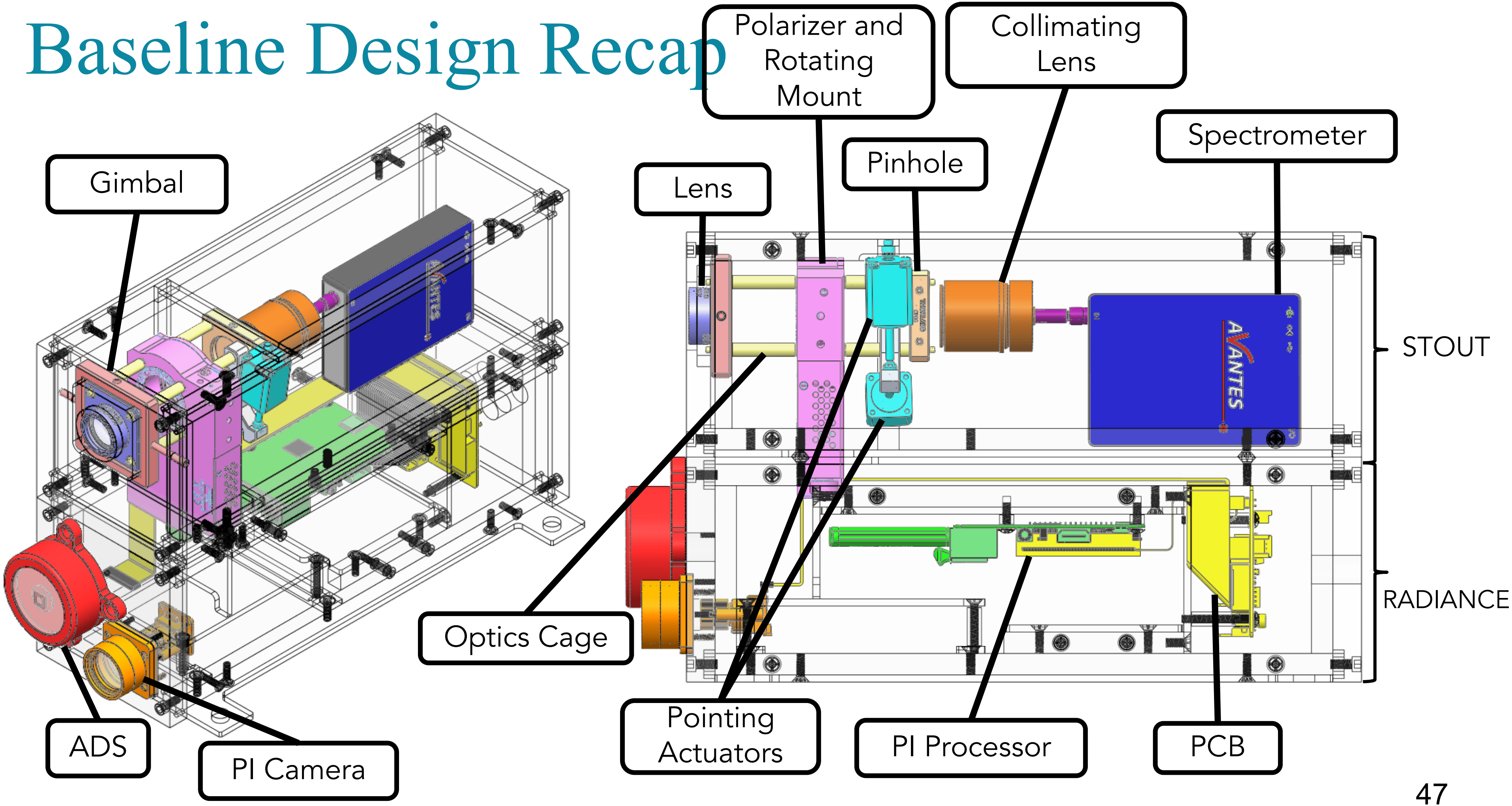
Fully Feasible

1. Instrument Data Collection
2. Structures
3. Environmental Monitoring & Control
4. Attitude Determination
5. Electric Power
6. Data Acquisition
7. Software
8. RADIANCE Integration

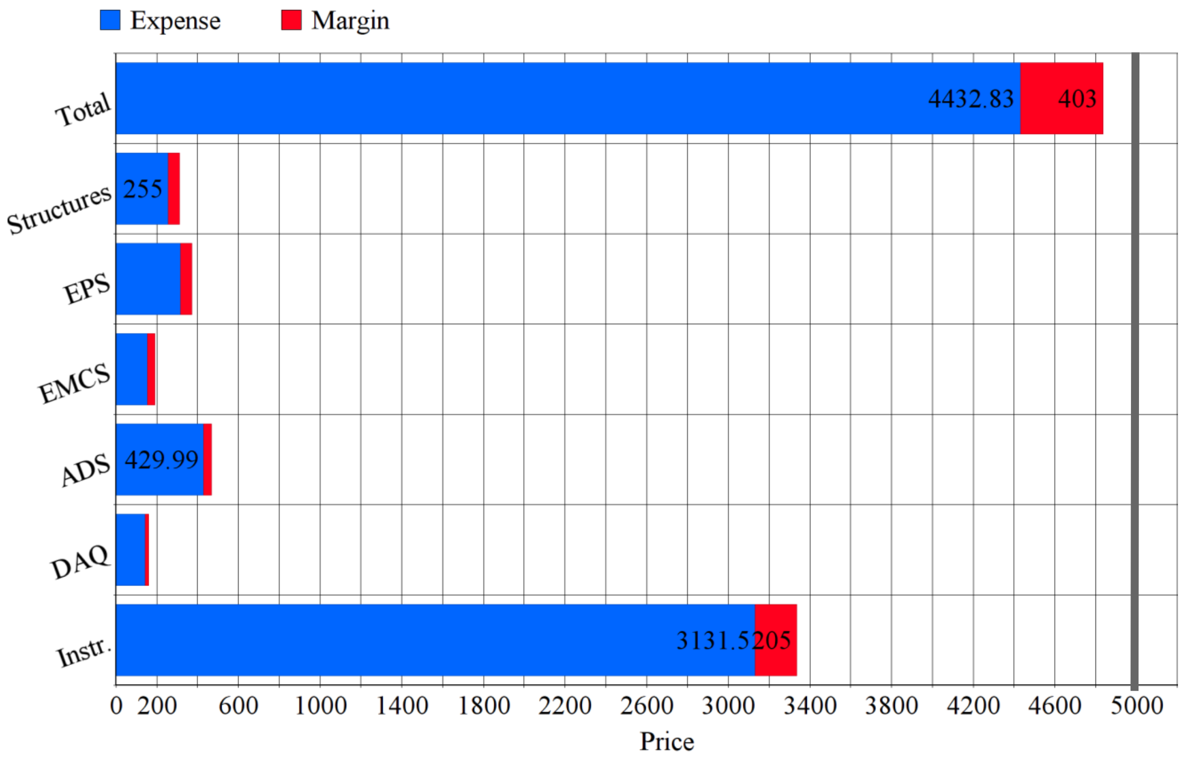
Needs Further Analysis:

1. Control Software Response Speed
2. Instrument Pointing Capabilities

Baseline Design Recap



STOUT Expenses

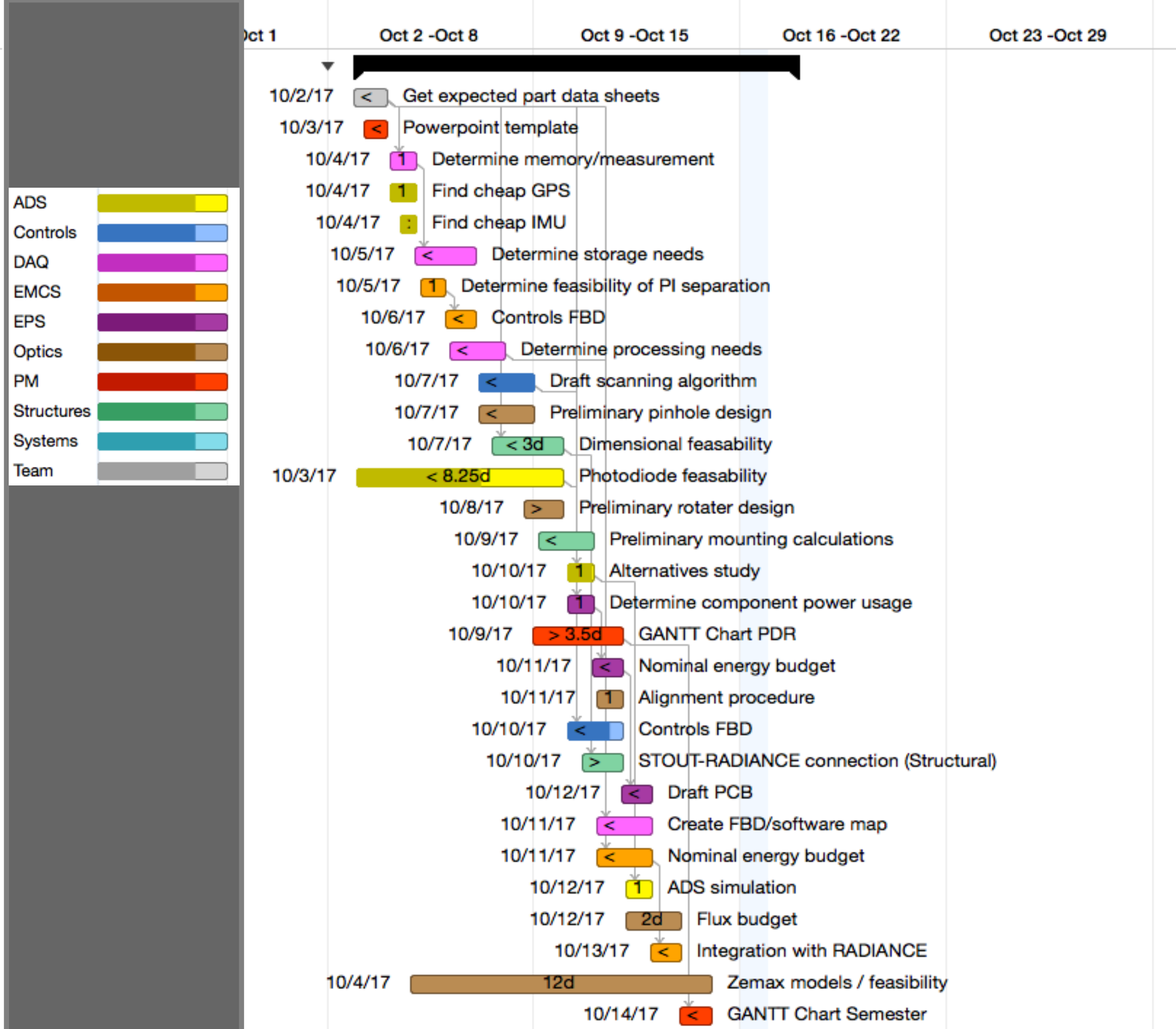


Budget: $5000

Total expenses: $4432.83

Total expenses with ~10% margin: $4835.83

Title	Planned Start	Planned End
▼ PDR	10/2/17	10/17/17
• Get expected part data sheets	10/2/17	10/3/17
• Powerpoint template	10/3/17	10/3/17
• Determine memory/measurement	10/4/17	10/4/17
• Find cheap GPS	10/4/17	10/4/17
• Find cheap IMU	10/4/17	10/4/17
• Determine storage needs	10/5/17	10/6/17
• Determine feasibility of PI separation	10/5/17	10/5/17
• Controls FBD	10/6/17	10/6/17
• Determine processing needs	10/6/17	10/7/17
• Draft scanning algorithm	10/7/17	10/8/17
• Preliminary pinhole design	10/7/17	10/8/17
• Dimensional feasability	10/7/17	10/9/17
• Photodiode feasability	10/3/17	10/9/17
• Preliminary rotater design	10/8/17	10/9/17
• Preliminary mounting calculations	10/9/17	10/10/17
• Alternatives study	10/10/17	10/10/17
• Determine component power usage	10/10/17	10/10/17
• GANTT Chart PDR	10/9/17	10/11/17
• Nominal energy budget	10/11/17	10/11/17
• Alignment procedure	10/11/17	10/11/17
• Controls FBD	10/10/17	10/11/17
• STOUT-RADIANCE connection (Structural)	10/10/17	10/11/17
• Draft PCB	10/12/17	10/12/17
• Create FBD/software map	10/11/17	10/12/17
• Nominal energy budget	10/11/17	10/12/17
• ADS simulation	10/12/17	10/12/17
• Flux budget	10/12/17	10/13/17
• Integration with RADIANCE	10/13/17	10/13/17
• Zemax models / feasibility	10/4/17	10/14/17
• GANTT Chart Semester	10/14/17	10/14/17



STOUT

Thank you for listening! We appreciate your feedback.

Are there any questions?

References

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- ADS Sun Sensor - http://www.solar-mems.com/
- Polarizer Mount - https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=8750
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- Battery Configuration Characteristics - ftp://apollo.ssl.berkeley.edu/pub/jolson/COSI_final_report/Final_report/CSBFGondolaDesignRecommendations%20newer%20version.pdf
- Ext Temp Sensor - https://www.sparkfun.com/products/13314
- Int Temp Sensor - https://www.sparkfun.com/products/245
- Pressure Sensor - https://sensing.honeywell.com/honeywell-sensing-trustability-ssc-series-standard-accuracy-board-mount-pressure-sensors-50099533-a-en.pdf
- Actuator Supplier - http://www.haydonkerkpittman.com

Table of Contents

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Project Overview CONOPS Critical Project Elements EMCS ADS Optical System Pointing Control Remaining Systems Conclusion	Thermal Model Pressure Feasibility Thermal Components ADS Feasibility ADS Thermal Expansion RADIANCE ADS Infeasibility Optical Parts Optics Mount Polarizer Mount Actuators Power Software Microcontroller Data Storage Structures/Materials

Backups

Customer

HAO

High Altitude Observatory

NCAR

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Flight Feasibility Testing Methodology

- Temperature feasibility
  - Tested through transient, one dimensional thermal model inherited from RADIANCE mission
    - Proven to be a valid baseline test through rigorous investigation and comparison to basic thermal concepts
  - Thermal model modified to include combined STOUT/RADIANCE module, accounting for increase in volume, area, and added heat output of all onboard instrumentation
  - Baseline thermal design implemented in combined module (i.e. resistive heat pads, peltier devices, polyiso)
- Pressure feasibility
  - Dictated by most sensitive instrument
    - In this case the ADS sensor is rated down to 5 Pa
  - If most sensitive instrument can survive pressure range of flight, system is feasible
    - Also keeps from increasing complexity of system (i.e. pressurized model)

Parameters

- Assumptions:
  - Average internal temperature taken between all instruments
  - System in thermal equilibrium before flight
  - Latitude or longitude of balloon/gondola does not change during flight
  - Two week flight time
  - Forced convection not accounted for (wind speed data challenge)

- Parameters:
  - One dimensional, Transient model
  - Radiation, convection, conduction accounted for
  - STIFF equation solved through ODE15S
  - Fort Sumner, NM Sept. flight location chosen (proven to be very rigorous)
  - No night flight accounted for in terms of temp variations

Thermal Model Inputs

- Mass of Structure: 5.25 kg (c=900 J/(kg•K))
- External Structure Thickness: 3.175 mm
- Insulation Thickness: 1 cm
- Emissivity/Absorptivity: 0.7/0.3
- Ascent Time: 2.33 hrs
- Descent Time: 1 hr
- Flight Conditions for New Mexico launch

Thermal Budget

Components Thermal Budget		
Component	**Operating Range**	**Dissipation**
Pi	-25 to 85 C	~0.6 W
Optics	N/A	0.63 W
Spectrometer	0 to 55 C, -10 survival	~1.27 W
Actuators	-10 to 85 C	~1.7 W
Power Board	-50 to 100 C	6 W
Sensors	-50 to 100 C	~0.1 W
Flash Drives (USB 2.0)	0 to 60 C, -10 survival	0.25 W
Total	**Min op temp = 0 C, Min survival temp = -10 C**	**10.55 W**
Active Control Devices		
Heater	-200 to 120 C	10 W max each
Peltier	-100 to 80 C	-13 W max each

Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

Thermal Radiation Equations

Radiated Heat

$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$$

$$\dot{Q} = \sigma A T^4 \epsilon$$

Absorbed Heat

$$\dot{Q}_{in} = \dot{Q}_{Source} A \alpha$$

$$\dot{Q}_{Ground} \approx 1050[W/m^2]$$

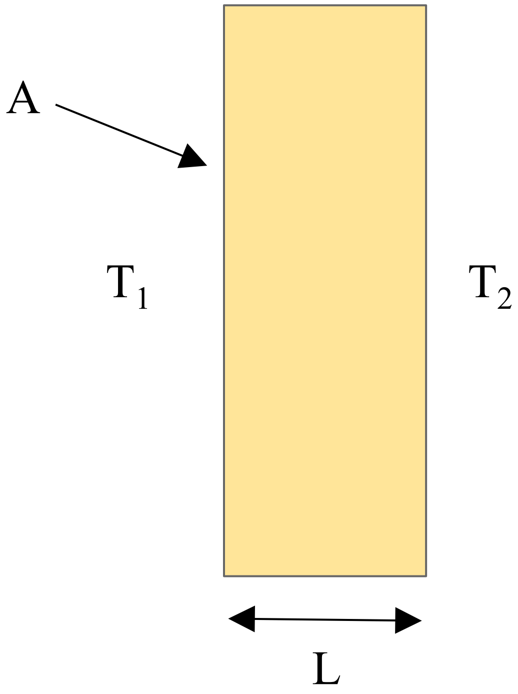
$$\dot{Q}_{Ground+Albedo} \approx 1120[W/m^2]$$

$$\dot{Q}_{Vacuum} \approx 1367[W/m^2]$$

Insulation Equations

$$R = \frac{L}{KA}$$

$$\dot{Q} = \frac{T_1 - T_2}{R}$$

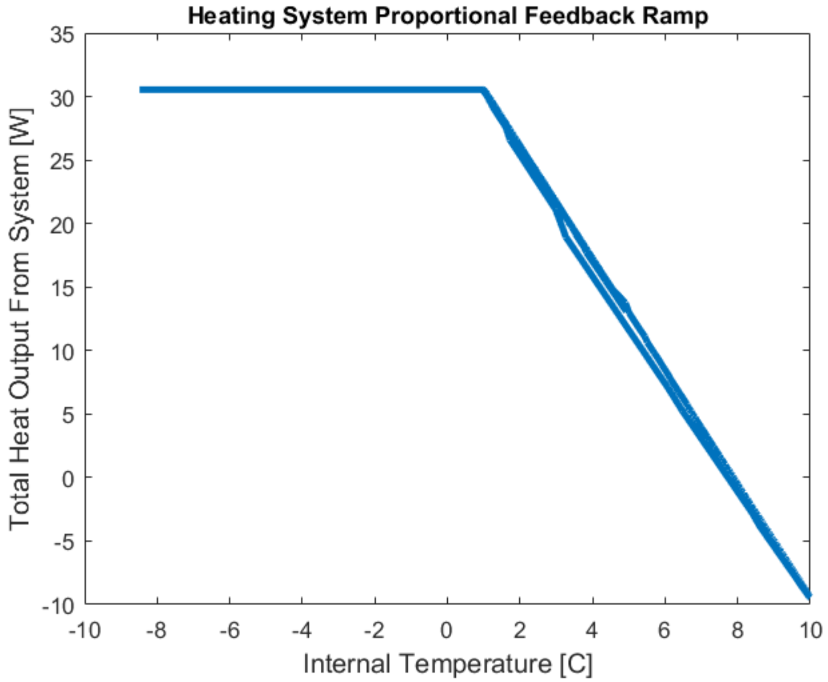


EMCS Feasibility: Pressure

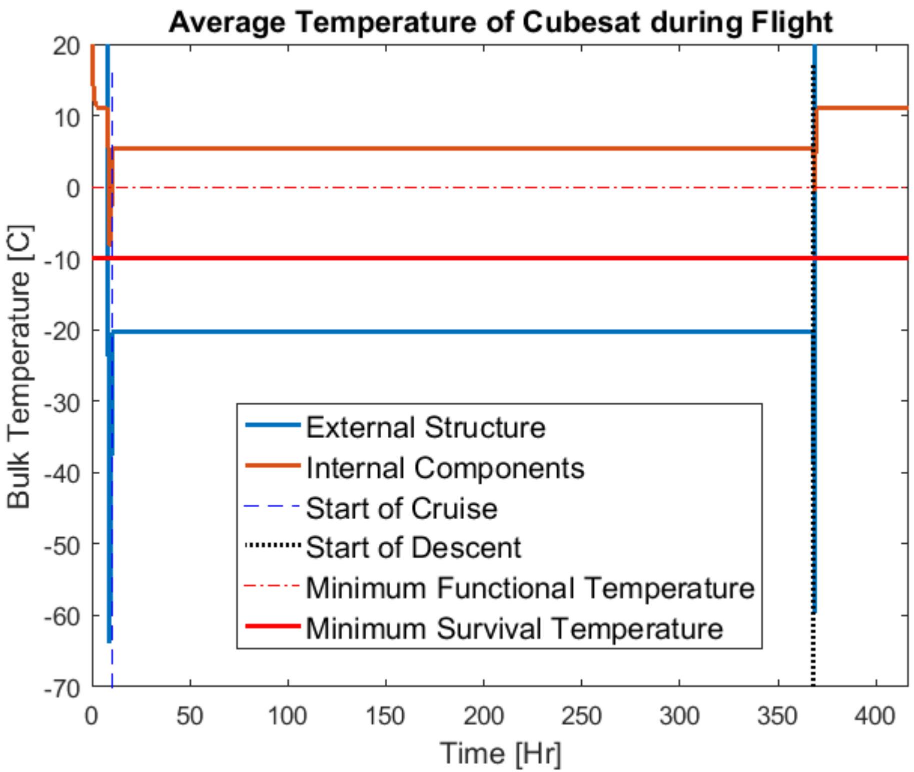
Component	Minimum Pressure Rating (Pa)
Actuators	0.1
Polarizer Mount	0.133
ADS Sensor	5
Pressure Sensor	0

Active Control Heating Ramp

- Estimate 10.55 W heat output from electrical components
- Cruise temperature is ~5°C



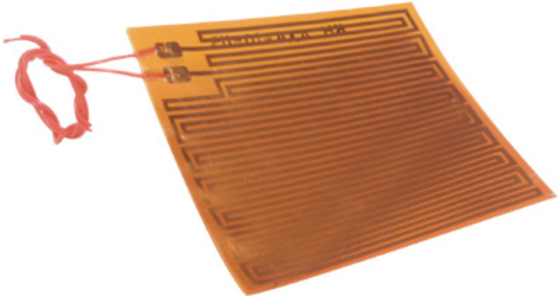
Full Thermal Simulation



Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

EMCS Feasibility: Pad Heaters

- **Omega Polyimide Film Insulated Flexible Heaters**
  - 28 V supply voltage, 0.357 A max supply current
  - 10 x 2.5 x 0.025 cm dimensions
  - 0-10 W evenly distributed heat output each



Coolers

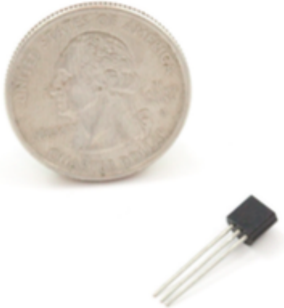
- **CUI Inc. CP60240 Peltier Modules**
  - 3.9 V max supply voltage
  - 20x20x4 cm dimensions
  - Pumps 10 W at 3.6 A supply current ($\Delta T=0$)
  - Place near critical thermal areas (Raspberry Pi processor, actuators, power board)

EMCS Feasibility: Temperature Sensors

- ➢ External Temperature: 2x TMP102 Digital Temperature Sensor (Same as RADIANCE)

- ➢ Internal Temperature:

  7x DS18B20 One Wire Digital Temperature Sensors (Same as RADIANCE)



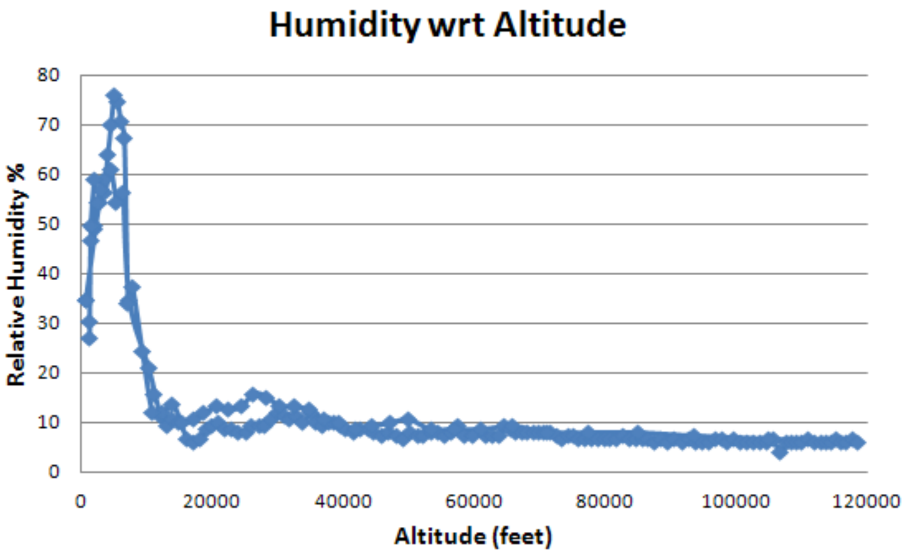
EMCS Feasibility: Pressure Sensor

- Honeywell SSC Series - 1.6BA
  - 0 to 160 kPa operating pressure
  - 5 V input voltage, 2 mA supply current
  - -20 to 85°C operating temperature

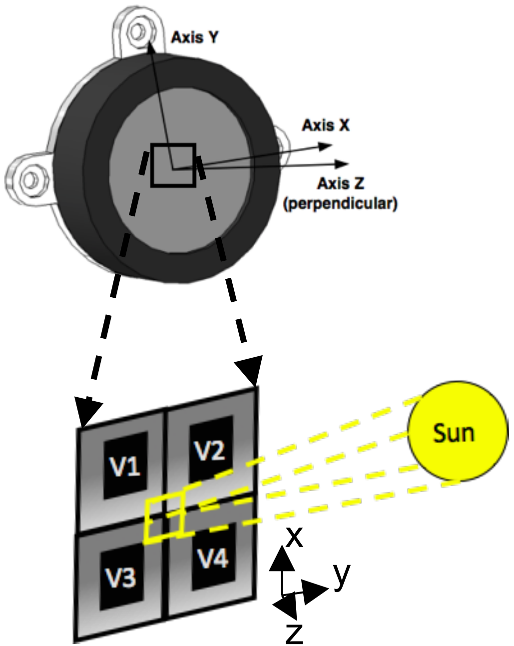
Project Overview → Critical Project Elements → EMCS → ADS → Optical System → Pointing Control → Remaining Systems → Conclusion

Atmospheric Humidity

- Expected relative humidity varies from 5% to 75%
- Could result in condensation during ascent and descent



Attitude Determination Feasibility



Solar Mems Sun Sensor

Fully Feasible ✓

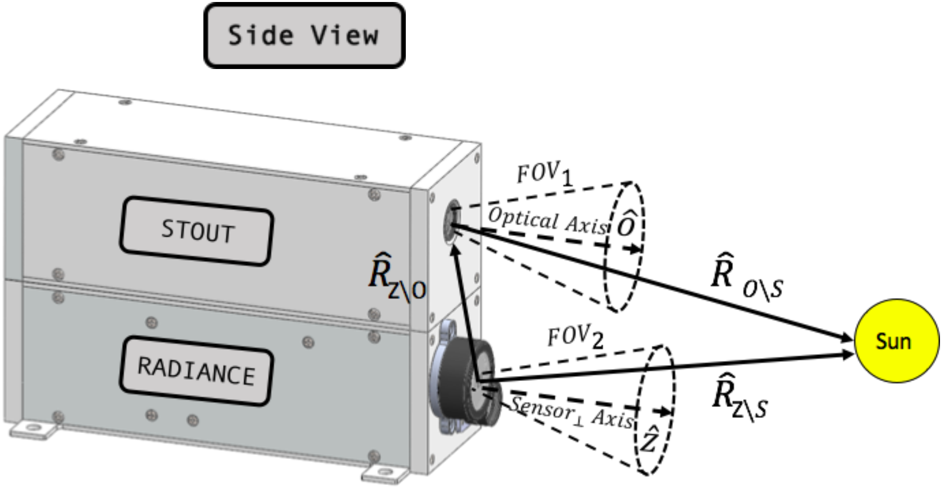
- Measures Incident Angle
- Uses Quadrant photodetector
- Photocurrents generated
- Field of View: Dual Axes ± 15°
- Accuracy: ± 0.02°

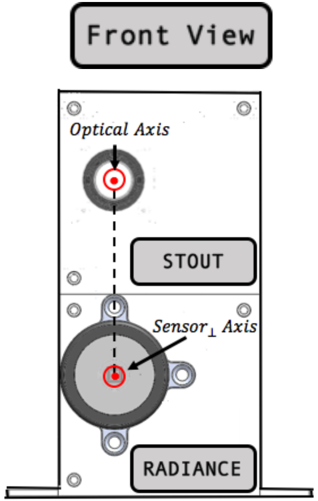
Calibration

- Telescope w/ High-Precision sidereal tracking
- Control telescope to get max power generation
- Determine off sun angle, program as zero degree position

Expansion

Purpose: Solve Off-Sun Angles





Assumptions

Sun within ± 5° of Optical Axis (Given by Customer)

Given

$\hat{o} = \hat{z}, \quad \hat{R}_{O\backslash S}, \hat{R}_{Z\backslash S} >> \hat{R}_{S\backslash O}$

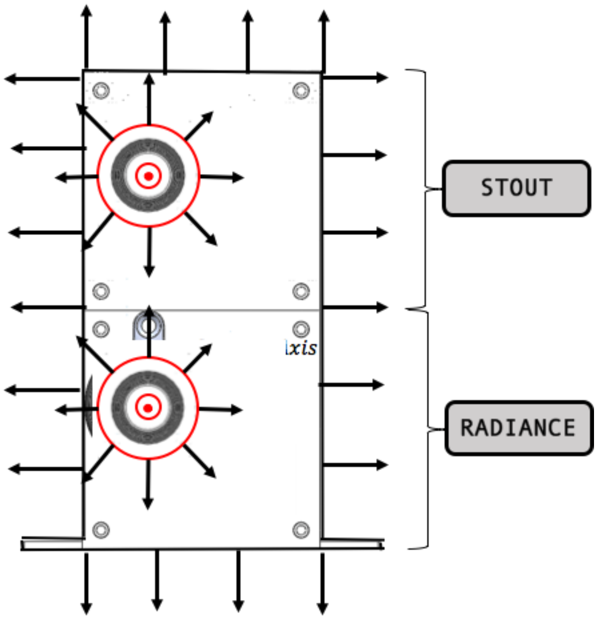
- $\hat{R}_{O\backslash S} = \hat{R}_{Z\backslash S}$

Conclusion

Sun off-angles relative to Sun Sensor axis is equal to that of the optical axis

Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

Expansion



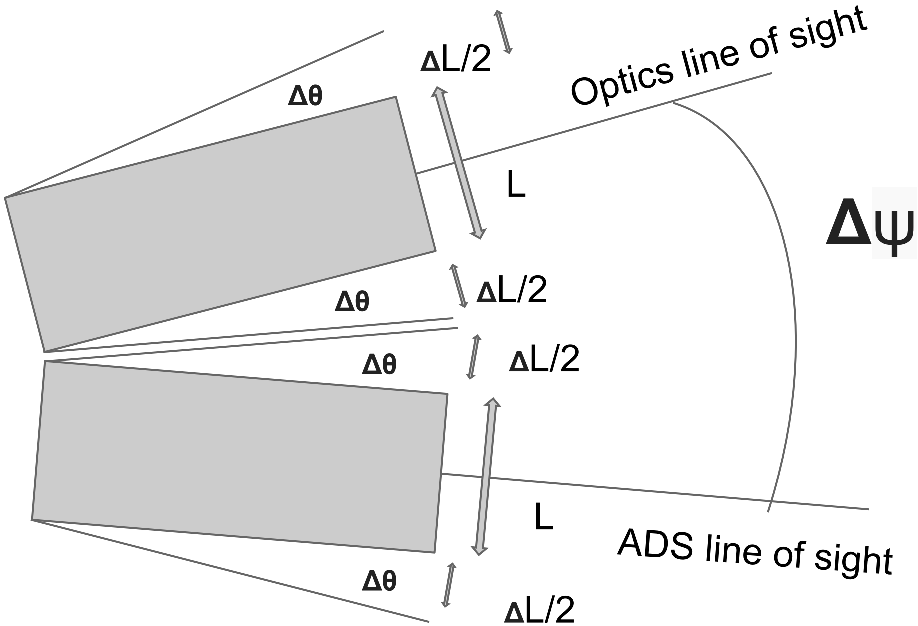
Thermal Expansion

- Expanding material assumed uniform
- Sun Face is assumed as flat plate
- Every linear dimension increases by the same percentage with a change in temperature, including holes.

Conclusion

- Expansions assumed negligible so long as linear expansion and no bending (Explained on next slide)

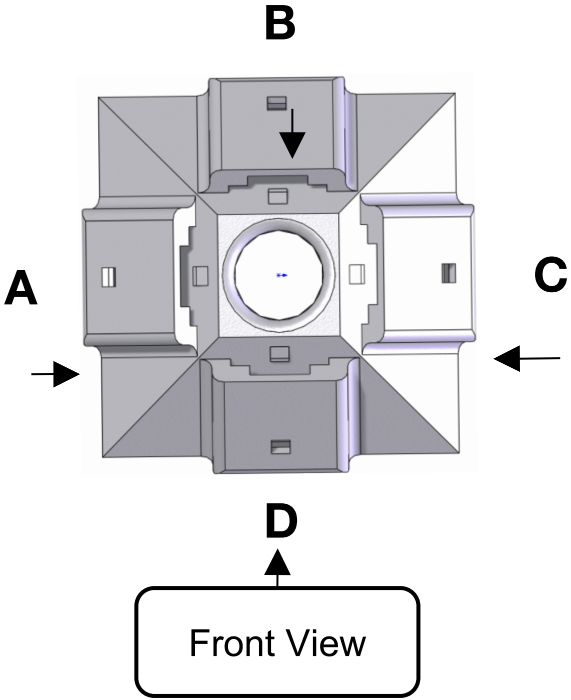
Attitude Determination Thermal Expansion

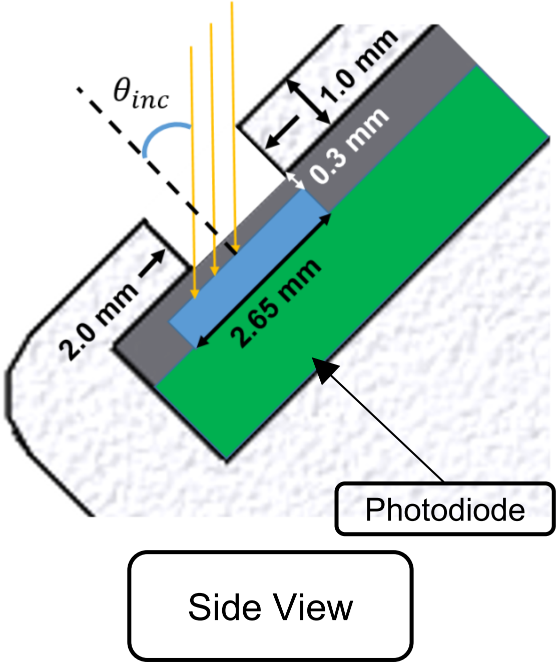


At an extreme variation in temperature where the front sun facing side is 20º K warmer than back side, the difference in optics and ADS line of sight will only be Δψ =0.00886º

Attitude Determination Feasibility

RADIANCE ADS: Infeasible

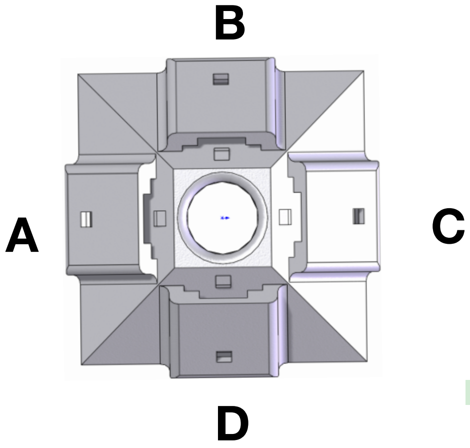




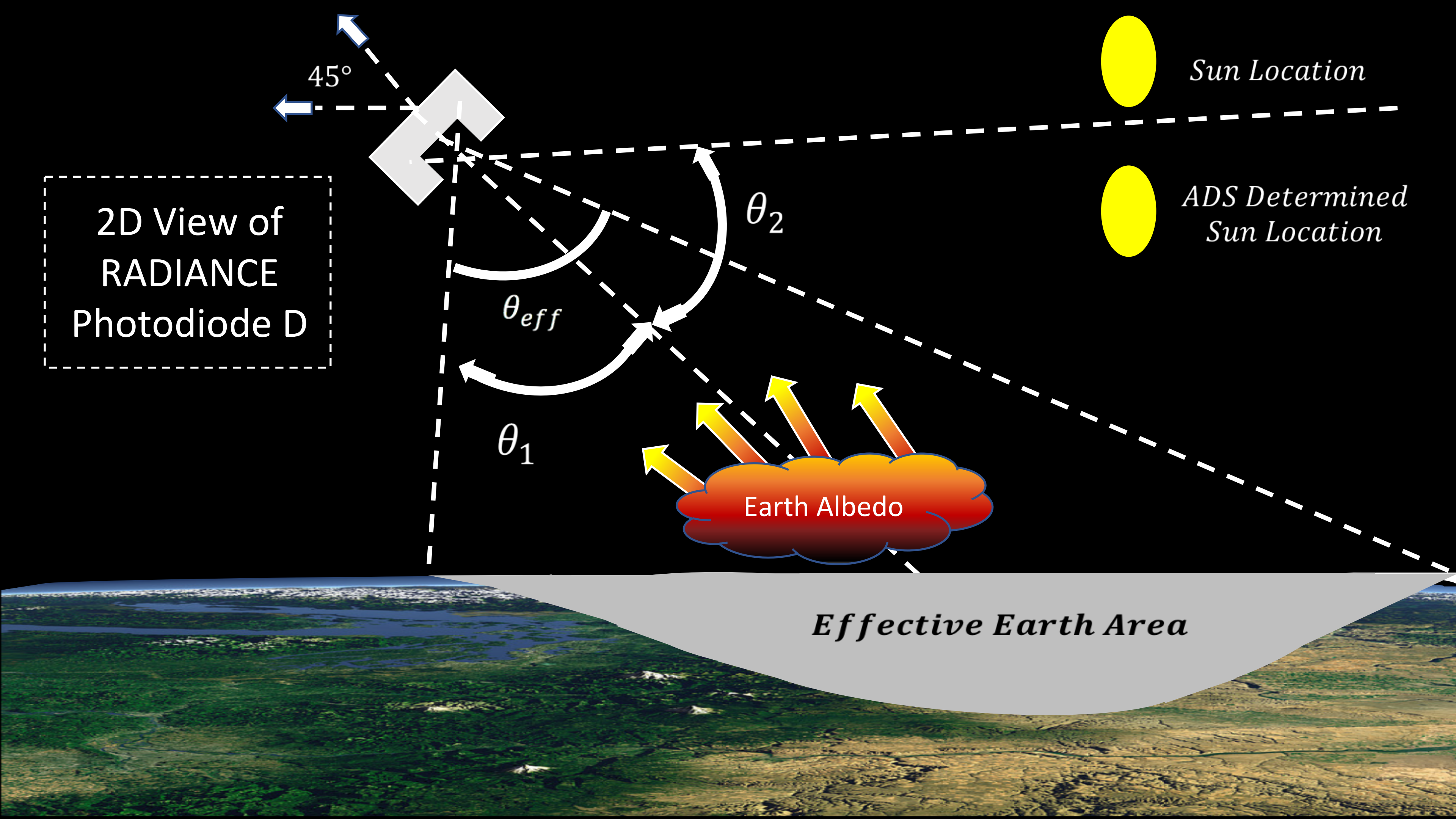
Attitude Determination Feasibility

RADIANCE ADS

- 4 Photodiode Array inclined 45°
- Based on LASP MinXSS-1 CubeSat
  - Discrepancies:
    - RADIANCE larger FOV
    - MinXSS included Star Tracker
- Accuracy Discrepancies
  - RADIANCE PFR Report's ±1° accuracy but never confirmed
- Photodiode Array with ±0.1° accuracy incorporates slit design not inclined array
- Summary: RADIANCE ADS Infeasible
  - Large FOV induces Earth's Albedo Error
  - Accuracy doesn't meet Requirements

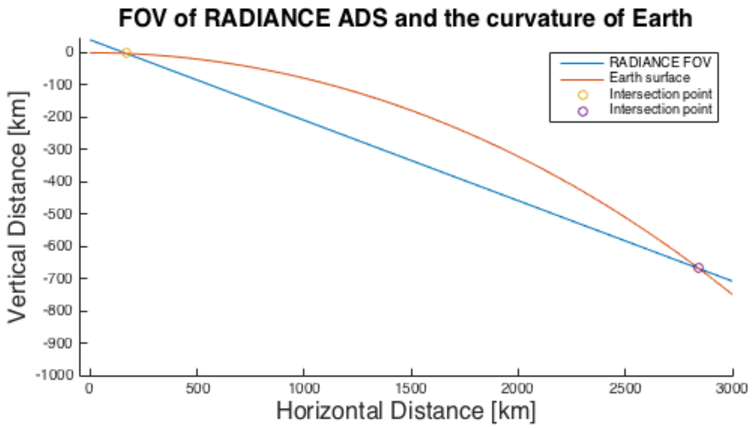


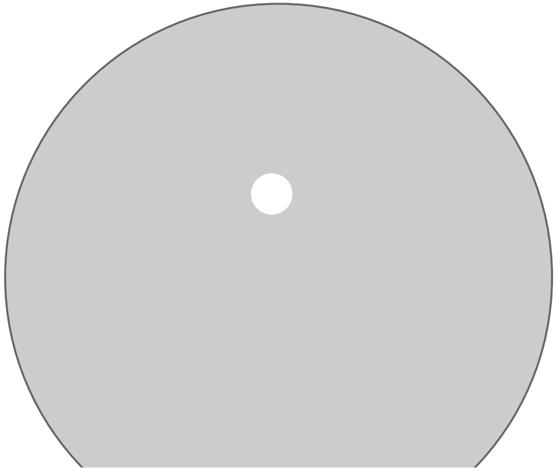
Front View



45°
Sun Location
ADS Determined
Sun Location
2D View of
RADIANCE
Photodiode D
θ_2
θ_{eff}
θ_1
Earth Albedo
Effective Earth Area

RADIANCE ADS Infeasibility



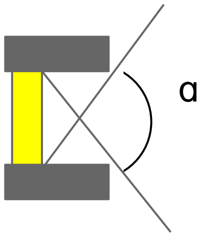


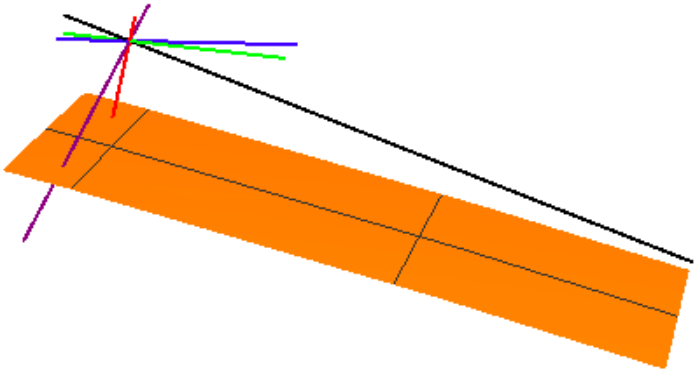
+/- 14 degree field of view cuts through Earth with a max chunk height of 150.6 km

Percentage of FOV that is the Sun -> 0.1434%
Percentage of FOV that is the Earth -> 6.137%
In terms of area FOV "sees", Earth takes up 42.8 times more than the Sun

RADIANCE ADS Infeasibility

Look at just the bottom photodiode...





Bottom photodiode gets light from 32,485 square kilometers on Earth

RADIANCE ADS Infeasibility

(1) $$x = f\frac{I_C - I_A}{I_A + I_B + I_C + I_D}$$

(2) $$y = f\frac{I_B - I_D}{I_A + I_B + I_C + I_D}$$

(3) $$\theta = \sqrt{x^2 + y^2} = \frac{f\sqrt{(I_C - I_A)^2 + (I_B - I_D)^2}}{I_A + I_B + I_C + I_D}$$

(4) $$\frac{\partial\theta}{\partial I_D} = -\frac{f(I_B - I_D)}{\sqrt{(I_C - I_A)^2 + (I_B - I_D)^2}(I_A + I_B + I_C + I_D)} - \frac{f\sqrt{(I_C - I_A)^2 + (I_B - I_D)^2}}{I_A + I_B + I_C + I_D}$$

(5) $$\theta_{error} = 0.05 = \frac{\partial\theta}{\partial I_D}\Delta I_D$$

(6) $$\Delta I_D = \frac{1}{20\left(-\frac{f(I_B - I_D)}{\sqrt{(I_C - I_A)^2 + (I_B - I_D)^2}(I_A + I_B + I_C + I_D)} - \frac{f\sqrt{(I_C - I_A)^2 + (I_B - I_D)^2}}{I_A + I_B + I_C + I_D}\right)}$$

Plug in dummy variables

- I_{Total}=1000, I_A=200, I_B=350, I_C=300, and I_D = 150
- f = I_{Total}/28=35.71428
- Allowable current change in bottom photodiode is -0.0062
- Watts from Earth, W_E=1,000*32,485*cos(45)*α
- α = [0.04 to 0.9] -> W_E = [918,814 to 20,673,327]
- Current varies proportionally -> P=IV

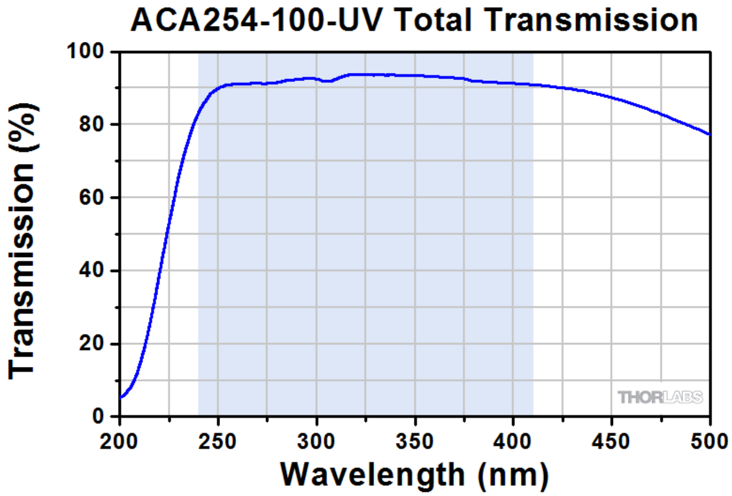
Lens Baseline Design

Thorlabs ACA254-UV-100

- Air-Spaced Doublet to correct for chromatic aberrations

ACA254-100-UV

Price	$969
Focal Length	100mm
Clear Aperture	18mm

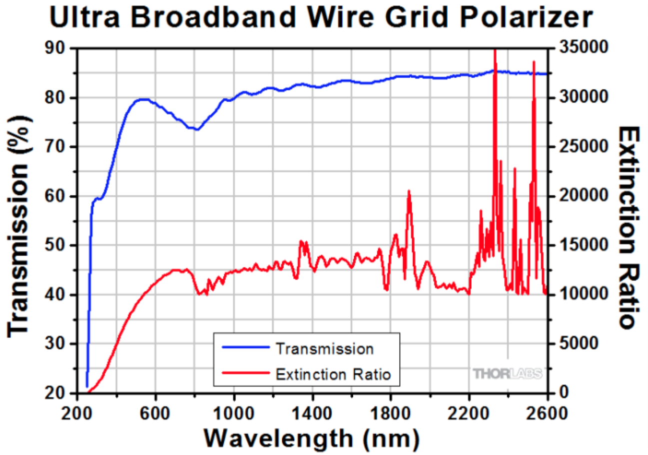


Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

Polarizer Baseline Design

Thorlabs 25 mm Diameter Mounted Wire Grid Polarizer

- Provided by Customer



Project Overview | Critical Project Elements | EMCS | ADS | Optical System | Pointing Control | Remaining Systems | Conclusion

Spectrometer Baseline Design

Avantes Mini 2048-L

- Inherited From RADIANCE

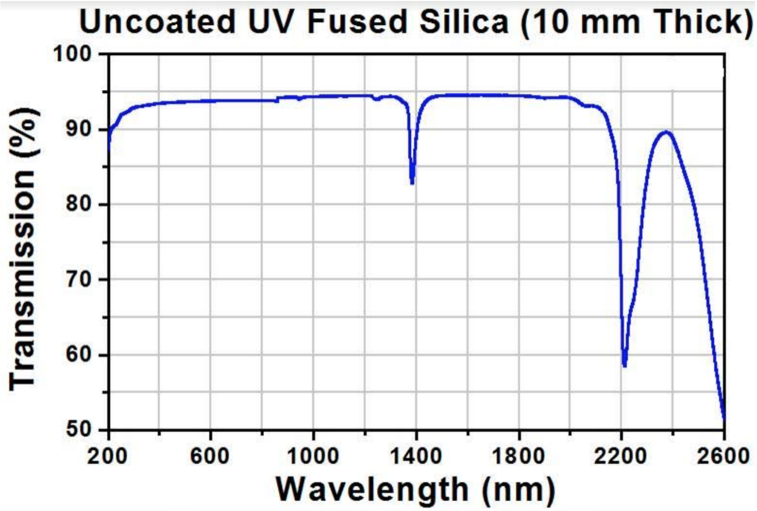
Avantes AvaSpec-Mini 2048L-UVI25	
Optics	200-1100nm, 1.4 nm resolution
Grating	300 lines/mm
Slit Size	25µm
Price	$2946.25

Spectrometer Coupling Design

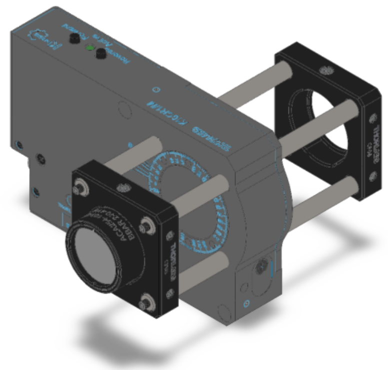
Avantes COL-UV/VIS-25

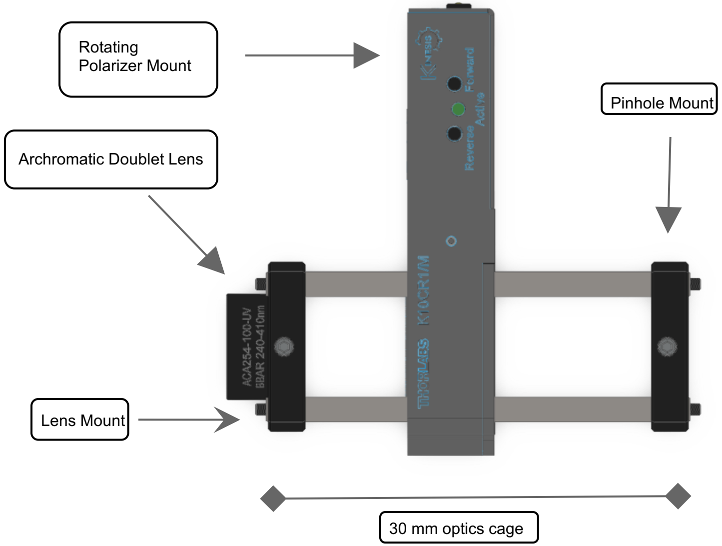
- Collimating lens attached to spectrometer delivers light from image plane to the spectrometer aperture

Price	$600
Diameter	25 mm
FOV	~25°

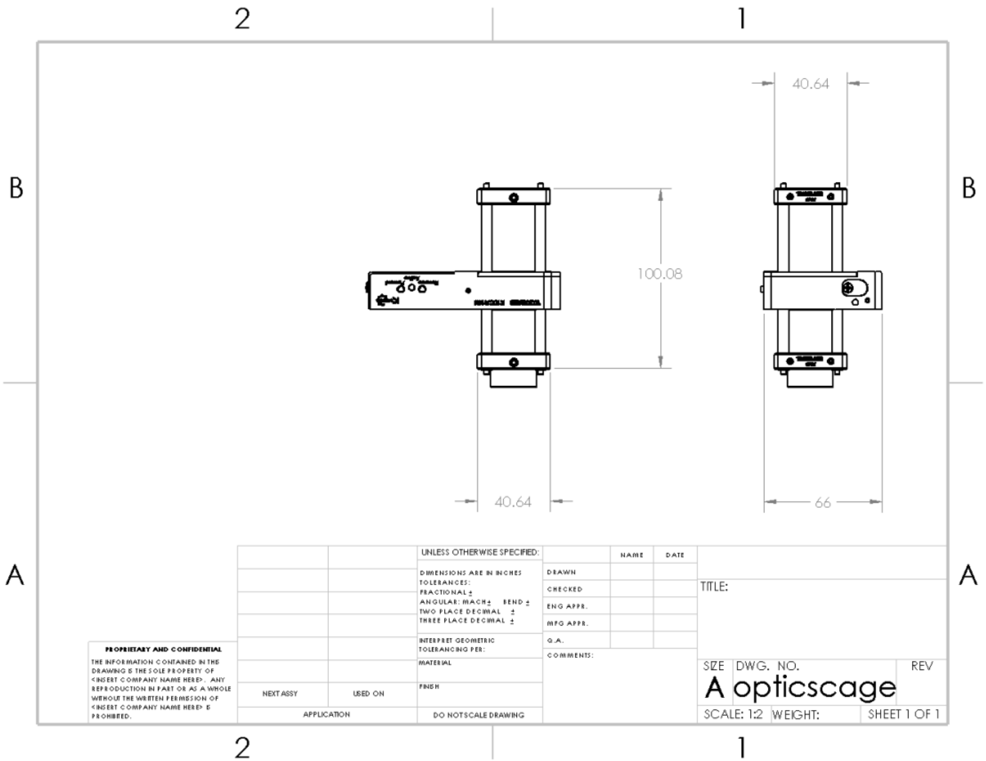


Optics Mount





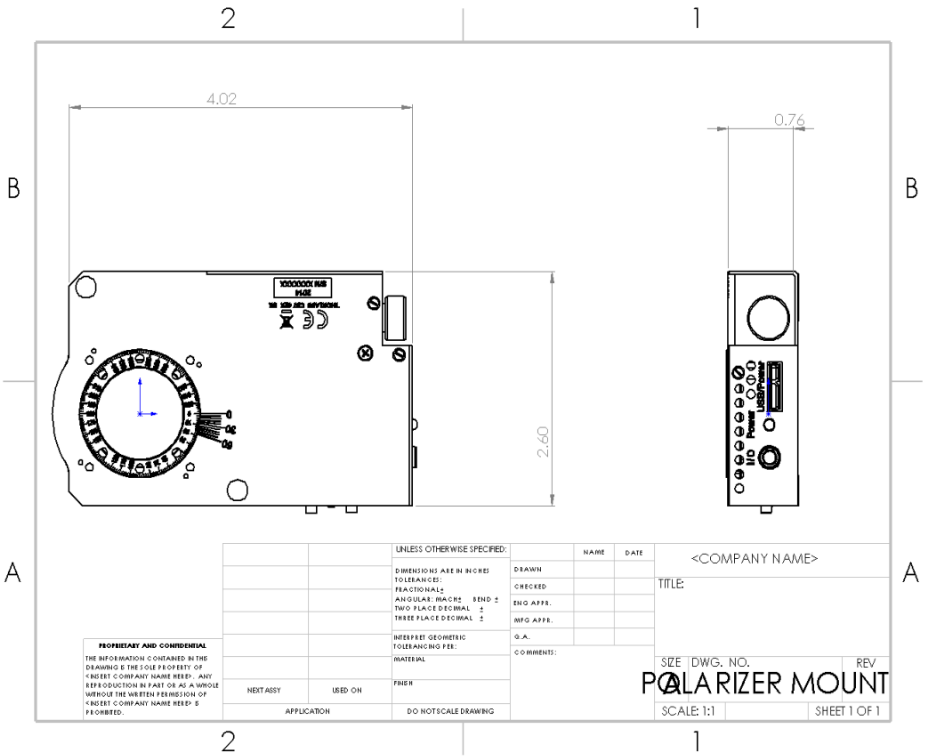
Optics Mount



Polarizer Mount

Key Specifications	
Maximum Speed	10 deg/sec
Minimum Speed	0.005 deg/sec
Repeatable Incremental Movement	0.03 deg
Absolute Accuracy	+/- 0.14 deg

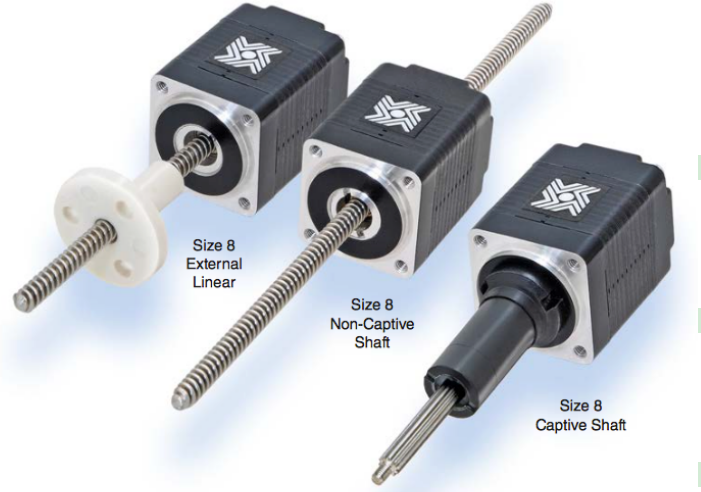
Polarizer Mount



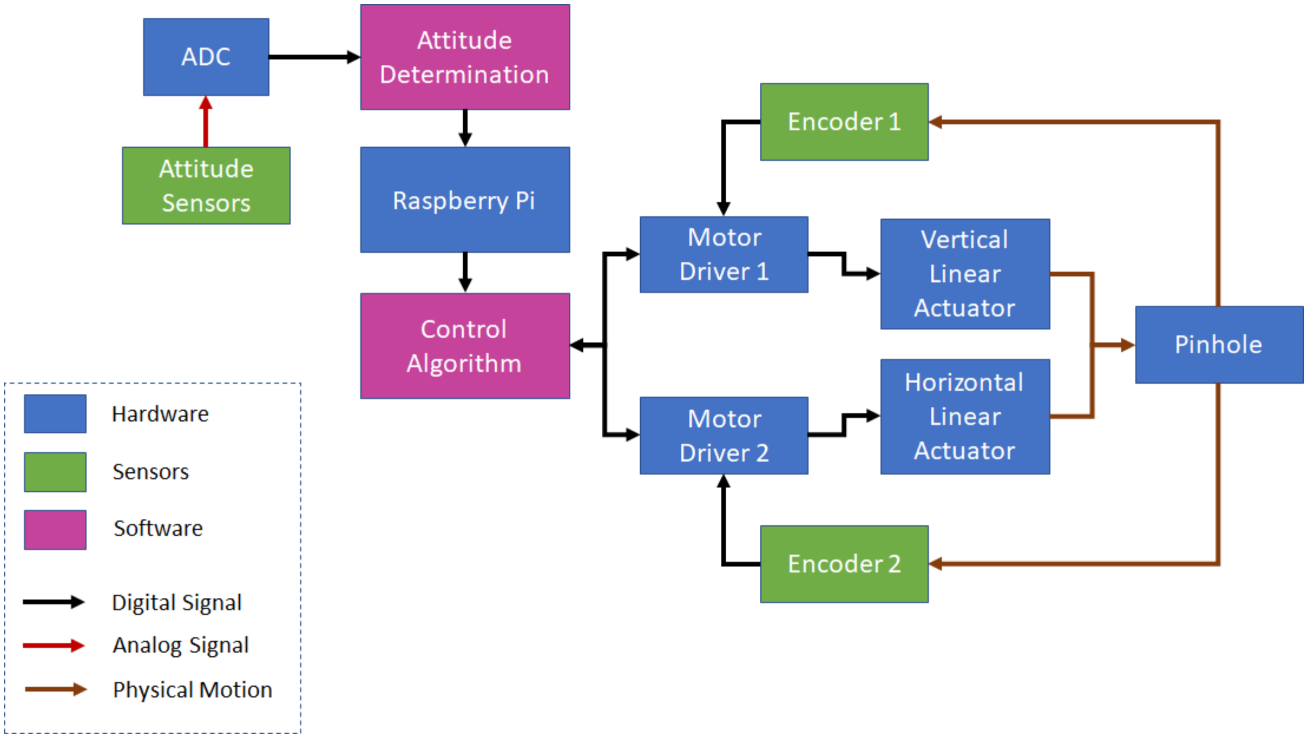
Instrument Actuators

Haydon Kerk 21 mm Linear Actuators

- Non-captive for horizontal movement
- Captive for vertical movement



Functional Block Diagram - Controls



Battery Trade Study

Criteria (ranked by weight)		Primary	Secondary	G62 Gondola
Cost	0.45	4 1.80	2 0.90	5 2.25
Weight	0.30	2 0.60	1 0.30	5 1.50
Voltage Consistency	0.15	1 0.15	4 0.60	5 0.75
Configuration Flexibility	0.10	4 0.40	4 0.40	2 0.20
Total	1.00	2.95	2.20	4.70

Table 68: Battery Trade Study

Battery Baseline Design

Table 3 Battery Types

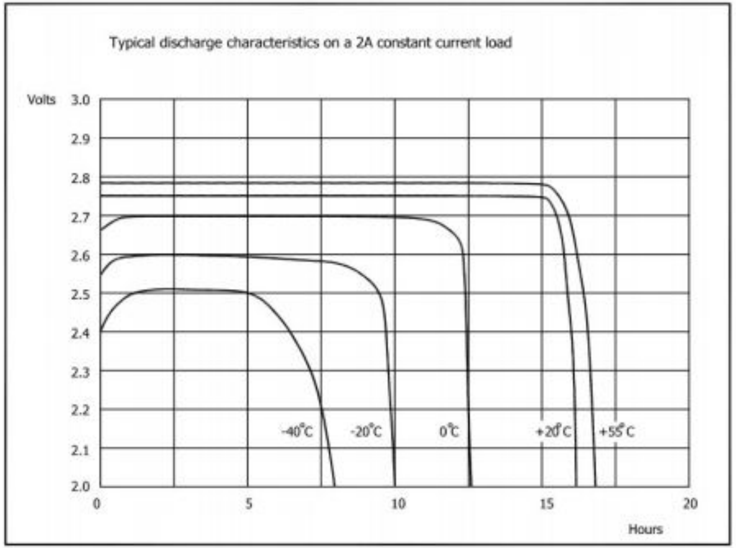
Battery	Cells per Pack	Loaded Voltage	Ampere Hour*
B7901-10	10	26	30
B7901-11	11	29	30
B7901-12	12	32	30
B9660	10	26	7
B9525	5	14	7
B9808	4	11.2	1
G20-12	1	2.6	7
G62-12	1	2.6	30

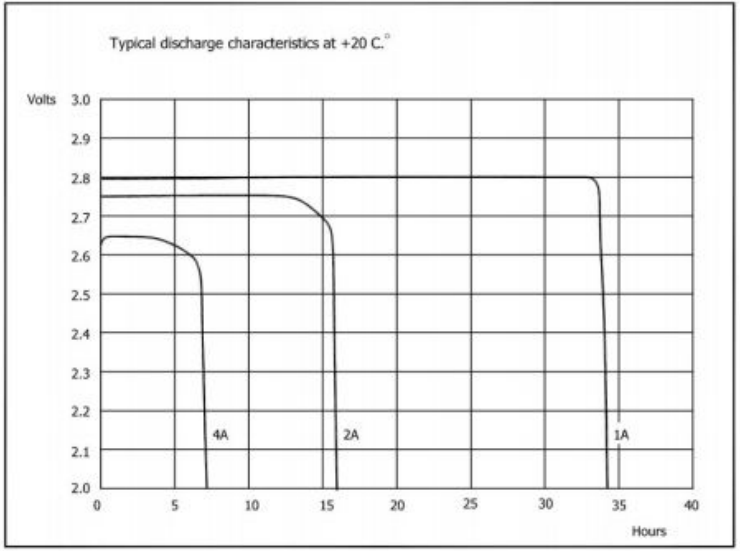
* De-rate ampere hour ratings for temperatures below -20°C.

Size (ASA Designation) .. N/A
Length........................ 141.0mm
Diameter 41.7mm
Weight 300g
Construction .... Hermetically sealed, all welded steel casing, incorporating a safety vent and a glass to metal seal

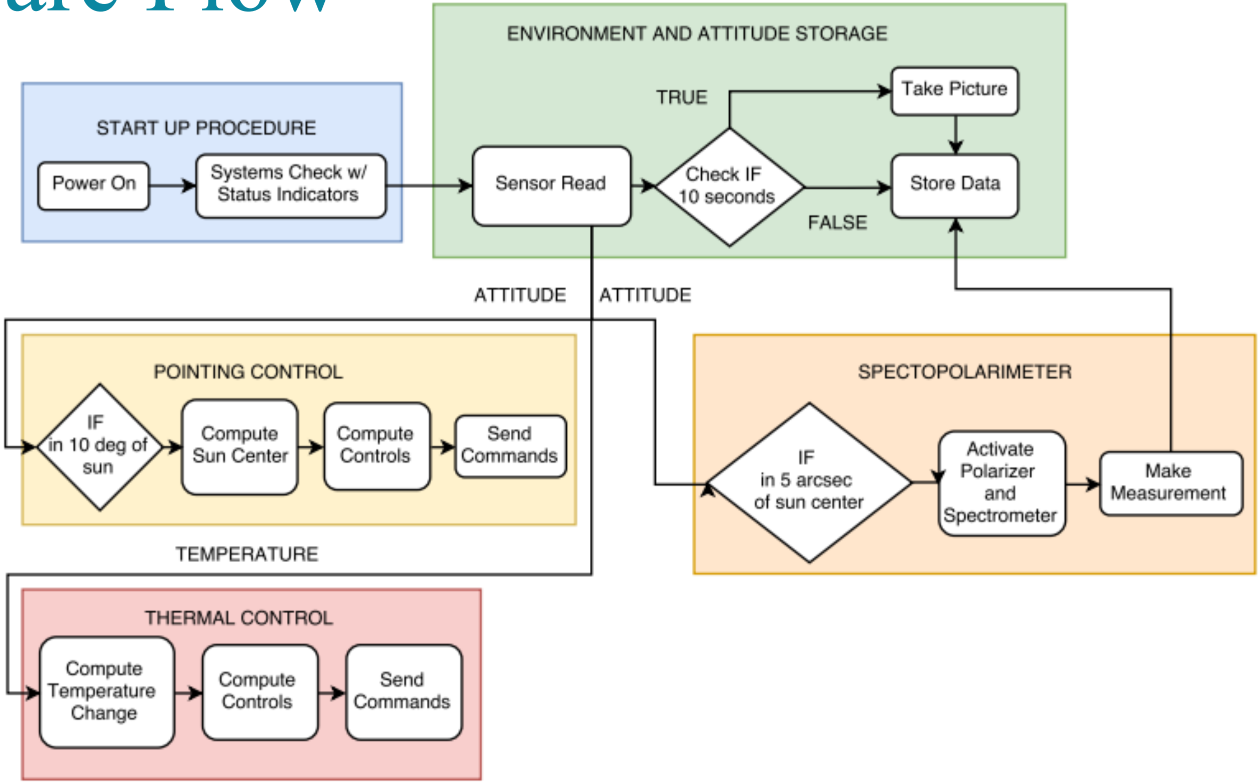
Voltage .... Nominal 3.0 volts
Typical operating Voltage .... 2.65 - 2.80 volts
Capacity (1000mA - 2.0v) 34Ah
50% capacity achieved at 8000mA
Temperature range .... -50˚C + 70 ˚C
Shelf life at ambient temperature ... 10 years
Self discharge .... Typical 2% p.a.

Power Feasibility: Batteries

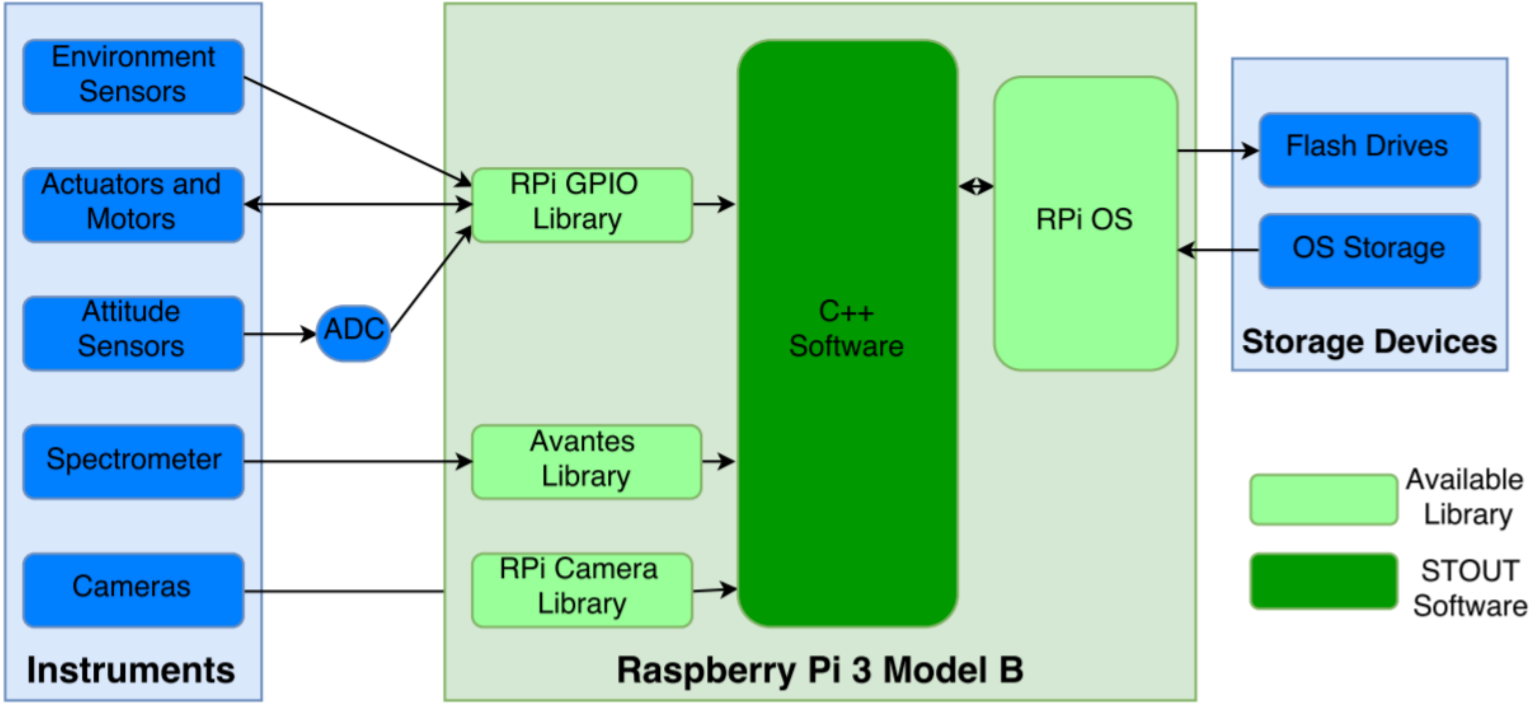




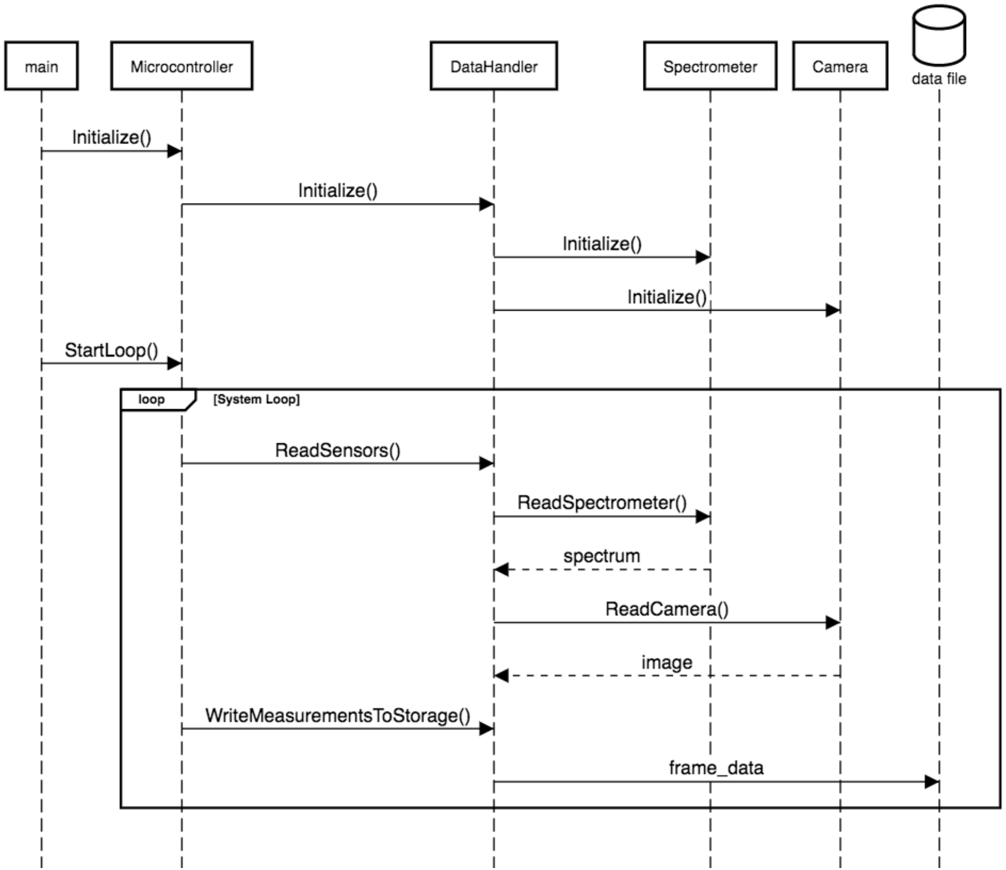
Software Flow



Software Interfaces



RADIANCE Software Sequence

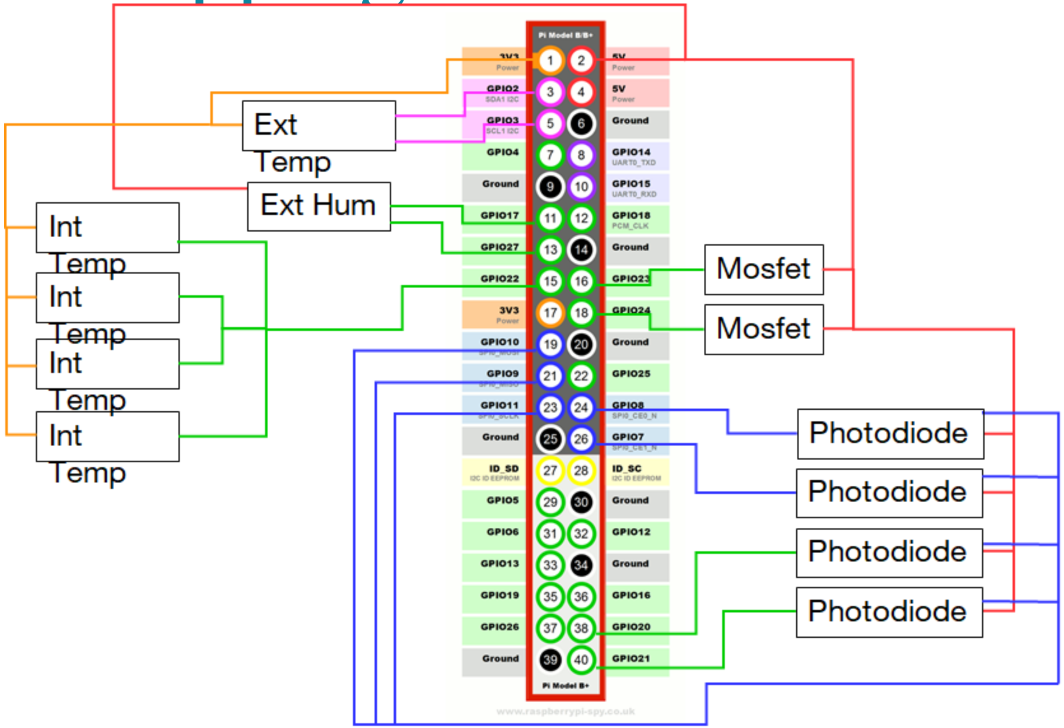


Controls Software Next Steps

Raspberry Pi 3 Model B

- From analysis of RADIANCE's CDR:
  - Software sequence doesn't show significant use of threading
- Solution: Give pointing system read priority when controlling

Port Mapping



Rates

Raspberry Pi 3 Model B

- Time required for measurement and read:
  - Approximated at .501 seconds

- Time required for write of data:
  - 2.41 MB @ 60 MB/s = .04 sec

- Total Time Required
  - .671 sec < 1 sec (Req 6.1-6.6)

- This satisfies the customer required rates

Rates

Quantity	Component	Time Per Measurement	Data Transfer Time	Total
1	Camera	Typical Exposure Time: 0.25 s	2.4MB @ 30MB/s (USB2.0) = .08 s	0.33s
1	Spectrometer	Typical Integration Time: 0.17 s	10 kB @ 30MB/s (USB2.0) = 3.33e-4 s	0.17s
7	Environment and Pressure	I2C Bus Speed: 2.5e-6 s	8B @ 100kB/s (I2C) = 0.8e-4 s	5.78e-4s
4	Attitude Sensor	ADC Sampling Rate: 1.33e-5 s	8B @ 100kB/s (I2C) = 8e-5 s	3.73e-4s
			TOTAL:	.501s

This analysis was used by RADIANCE. We adjusted the amounts of data for our system.

Required

- ➢ Customer requires Raspberry Pi 3 Model B (Req 1.1)
- ➢ Has input capability for all required data:

Requirement	Data Type	Time Per Measurement
6.1	Temperature	GPIO
6.2	Pressure	GPIO
6.3	Attitude	ADC to GPIO
6.4	Camera	Camera Serial Interface
6.5	Spectrometer	USB

- ➢ Software capable of recording timestamps from computer clock (Req 6.6)

Medium

Component	Number of Meas.	Size of Meas	Frequency	Total Data Over Flight
Temperature	7	8B	1Hz	67.8MB
Pressure	1	8B	1Hz	9.67MB
Accelerometer	1	8B	1Hz	9.67MB
Camera	1	2.4MB	.1Hz	145GB
Time Stamp	1	8B	1Hz	9.67MB
Sun Sensor Angle	4	8B	1Hz	38.68MB

Assumptions:

- Time of flight is two weeks=1,209,600s
- Pictures will only be taken during daytime
- Each single number measurement will be stored as a C++ double; 8 bytes

Data Storage Feasibility

Spectrometer Data Approximation:

- 788 scan points on sun * 360 polarization angles per scan
  - 283680 measurements
- 10 kB per measurement
- 2.8 GB required for full sun scan
- MX-ES 64GB SLC Flash Drive
  - Has radiative protection

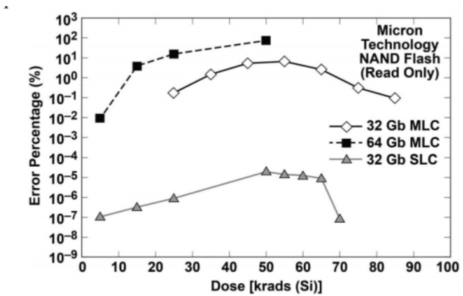
Data Storage Feasibility

- Write Speeds Required for data:
  - ADS, EMCS, and Timestamp:
    - 88 bytes @ 1Hz ⟶ minimum of 88B/s write speed required
  - Picture Data:
    - 2.4MB @ .1Hz ⟶ minimum of .24MB/s write speed required

- Write Speeds Available From Flash Drives:
  - Samsung Fit Flash Drives - 150MB/s
  - MX-ES SLC Drive - 180MB/s

Data Storage Radiation Effect Research

- Radiation events are common at altitude
  - Graph shows that number of detected radiation events grows with altitude
  - STOUT will fly at 40km
  - Hundreds of events detected at 35 km
- Radiation Events can affect flash memory
  - Single event upsets can cause bit flips in flash memory
  - Single layer cell flash memory has less chance of having a bit flip due to a Single event upset



Source: "Single Event Effect and Total Ionizing Dose Results of Highly Scaled Flash Memories" http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6658209

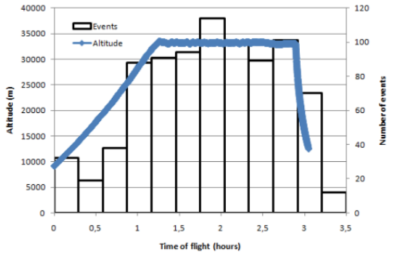


Figure 9 : Comparison between the evolution of the number of detected events as a function of time of flight and altitude profile.

Source: "Radiation Measurements in the Stratosphere" http://spaceflight.esa.int/pac-symposium_archives/files/papers/s7_10pantel.pdf

Materials Selection

- Aluminum 6061 - Inexpensive, lightweight, easy to machine
- Aluminum 7075- Strength comparable to steel, expensive
- Titanium 6al4v - Lightweight, very strong, very difficult to machine
- Stainless Steel 15-5ph - Very strong, highly corrosion resistant
- Nickel 718 - Ideal for high pressure/temp environments, very difficult to machine

Materials Trade Study

Criteria (ranked by weight)		Aluminum 6061	Aluminum 7075	Titanium 6al-4v	Stainless Steel 15-5PH	Nickel 718
Cost	0.35	5 1.75	4 1.40	1 0.35	2 0.70	1 0.35
Manufacturability	0.20	4 0.80	4 0.80	1 0.20	3 0.60	2 0.40
Tensile Strength	0.10	1 0.10	3 0.30	4 0.40	5 0.50	5 0.50
Shear Strength	0.10	1 0.10	2 0.20	3 0.30	4 0.40	4 0.40
Familiarity	0.10	5 0.50	4 0.40	1 0.10	3 0.30	2 0.20
Density	0.05	4 0.20	4 0.20	3 0.15	2 0.10	1 0.05
Thermal Conductivity	0.05	1 0.05	2 0.10	5 0.25	5 0.25	5 0.25
Corrosion Resistance	0.05	5 0.25	4 0.20	3 0.15	5 0.25	4 0.20
Total	1.00	3.75	3.60	1.90	3.10	2.35

Materials Trade Study

Value	Cost ($/lb)	Manufacturability	Tesnile Strength (MPa)	Shear Strength
1	< 6	Requires outsourcing to have component manufactured	< 300	< 200
2	6 to 10	Very difficult material to machine	300 to 500	200 to 400
3	10 to 30	Difficult material to machine	500 to 700	400 to 600
4	30 to 50	Moderately difficult material to machine	700 to 900	600 to 800
5	> 50	Easy material to machine	> 900	> 800

Value	Familiarity	Density (g/cm^3)	Thermal Conductivity (W/m/K)	Corrosion Resistance
1	No experience with material	> 8	> 150	Not corrosion resistant
2	Knowledge of material	8 to 6	150 to 100	Slightly corrosion resistant
3	Used material before	6 to 4	100 to 75	Moderately corrosion resistant
4	Very experienced with material	4 to 2	75 to 50	Highly corrosion resistant
5	Expert with material	< 2	< 50	Extremely corrosion resistant

Structural Material Feasibility

- Aluminum 6061-T6
  - Inexpensive - 2’x2’ sheet of 3/16” can be bought for less than $50
  - Easily machinable
  - Lightweight
  - Corrosion Resistant
  - Readily available