COE CST Sixth Annual Technical Meeting

Task 311: Fire and Hazard Detection for Space Vehicles Using LEDs

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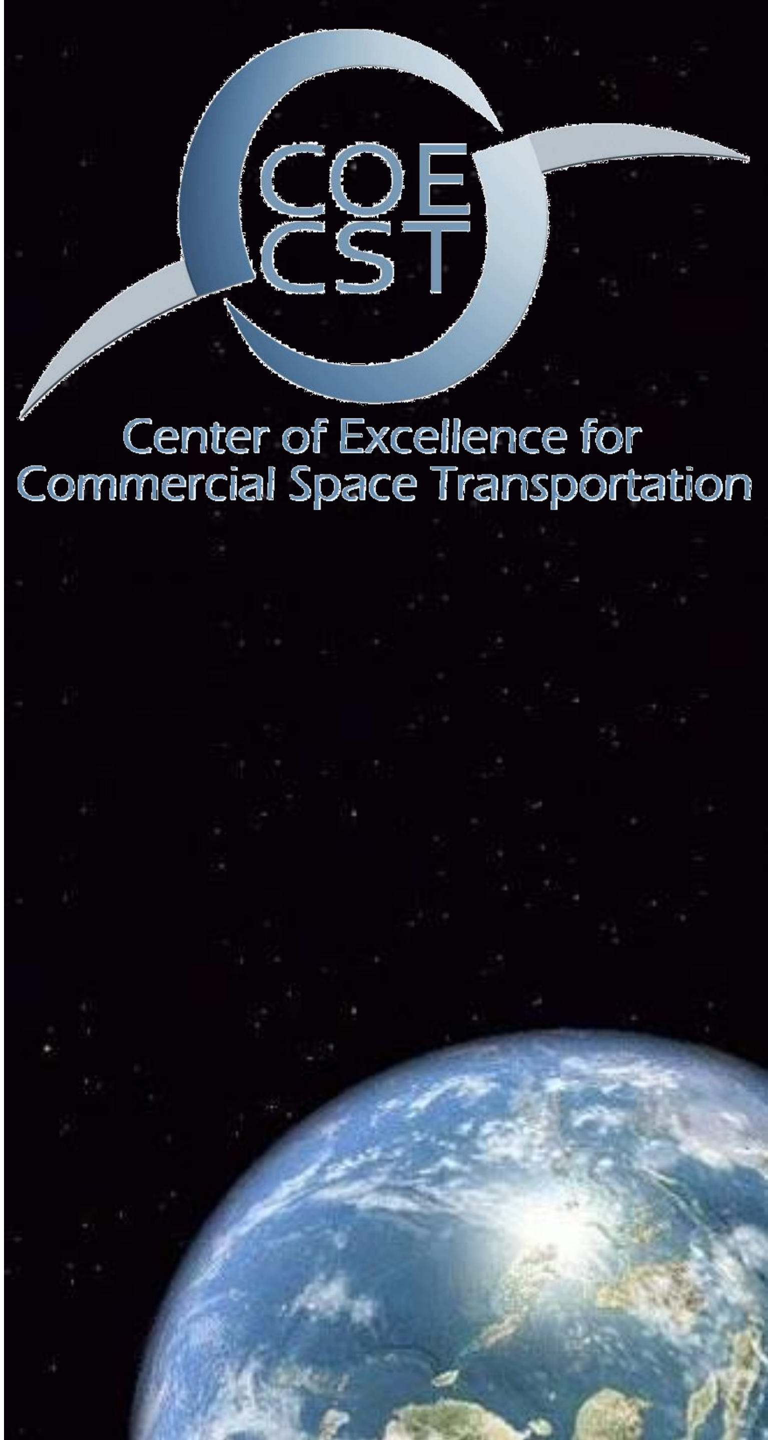
October 11, 2016
Las Cruces, NM



Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Applicability to the Industry
- Conclusions and Future Work

Team Members

Principal Investigators

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Collaborators

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Undergraduate Students

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Organizations

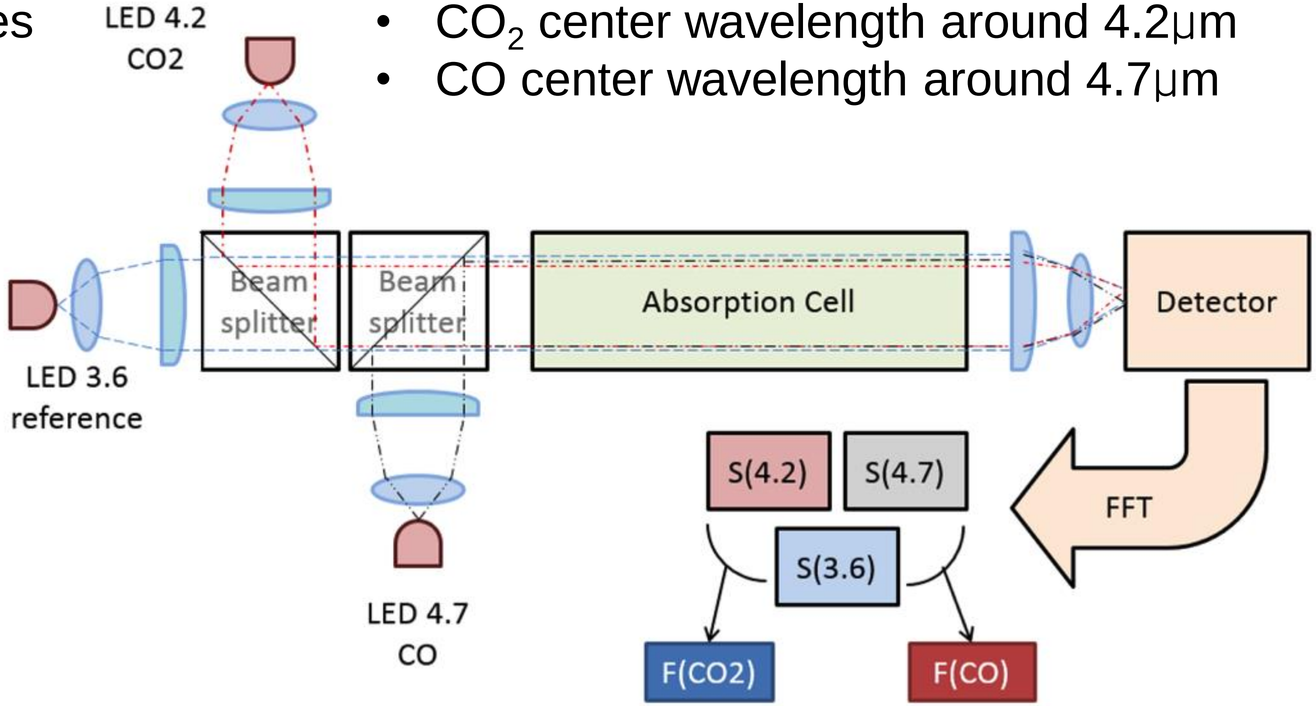
- Center for Advanced Turbomachinery and Energy Research (CATER), University of Central Florida
- Fuels, Engines, and Emissions Research Center, Oak Ridge National Laboratory

Matching Funds: Progress Energy Florida, UCF MAE Department & UCF Research and Commercialization. Support from ORAU and the Oak Ridge National Laboratory sponsored by US Department of Energy, Office of Energy Efficiency and Renewable Energy.

Sensor Design Using LEDs

Non-Dispersive Infrared (NDIR) absorption sensor using LEDs

- Three MIR LEDs centered at
  - 3.6µm (for reference)
  - 4.2µm (CO_2)
  - 4.7µm (CO)
- LEDs amplitude modulated at different frequencies
- Band pass filters
- Collimating lenses
- Pellicle beam splitters
- Thermo-electrically cooled photovoltaic detector
- Detects carbon monoxide and carbon dioxide
  - CO_2 center wavelength around 4.2µm
  - CO center wavelength around 4.7µm



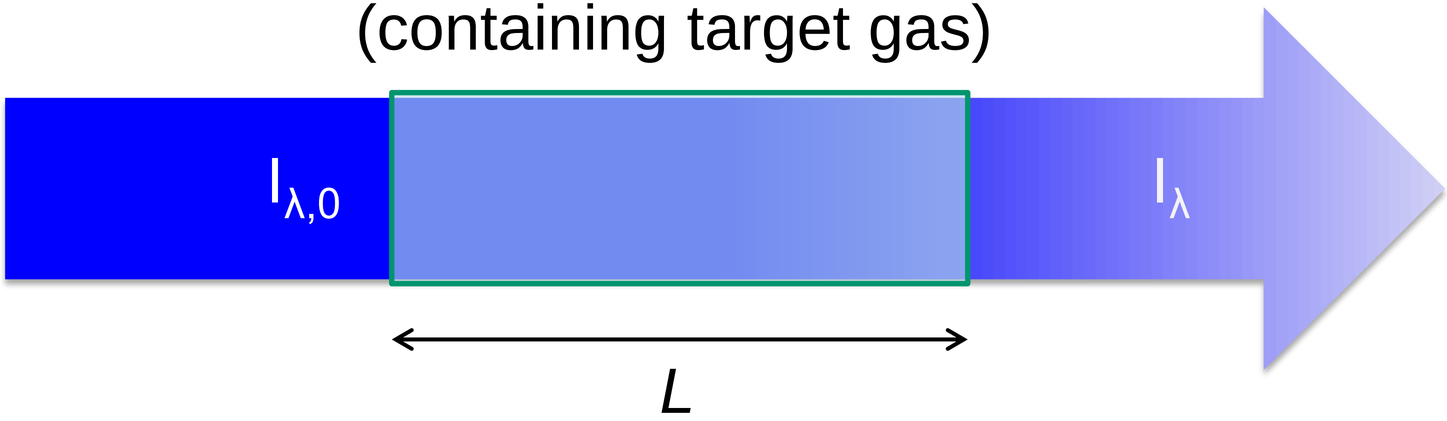
Absorption Spectroscopy and Beer's Law

Beer-Lambert Law of Absorption

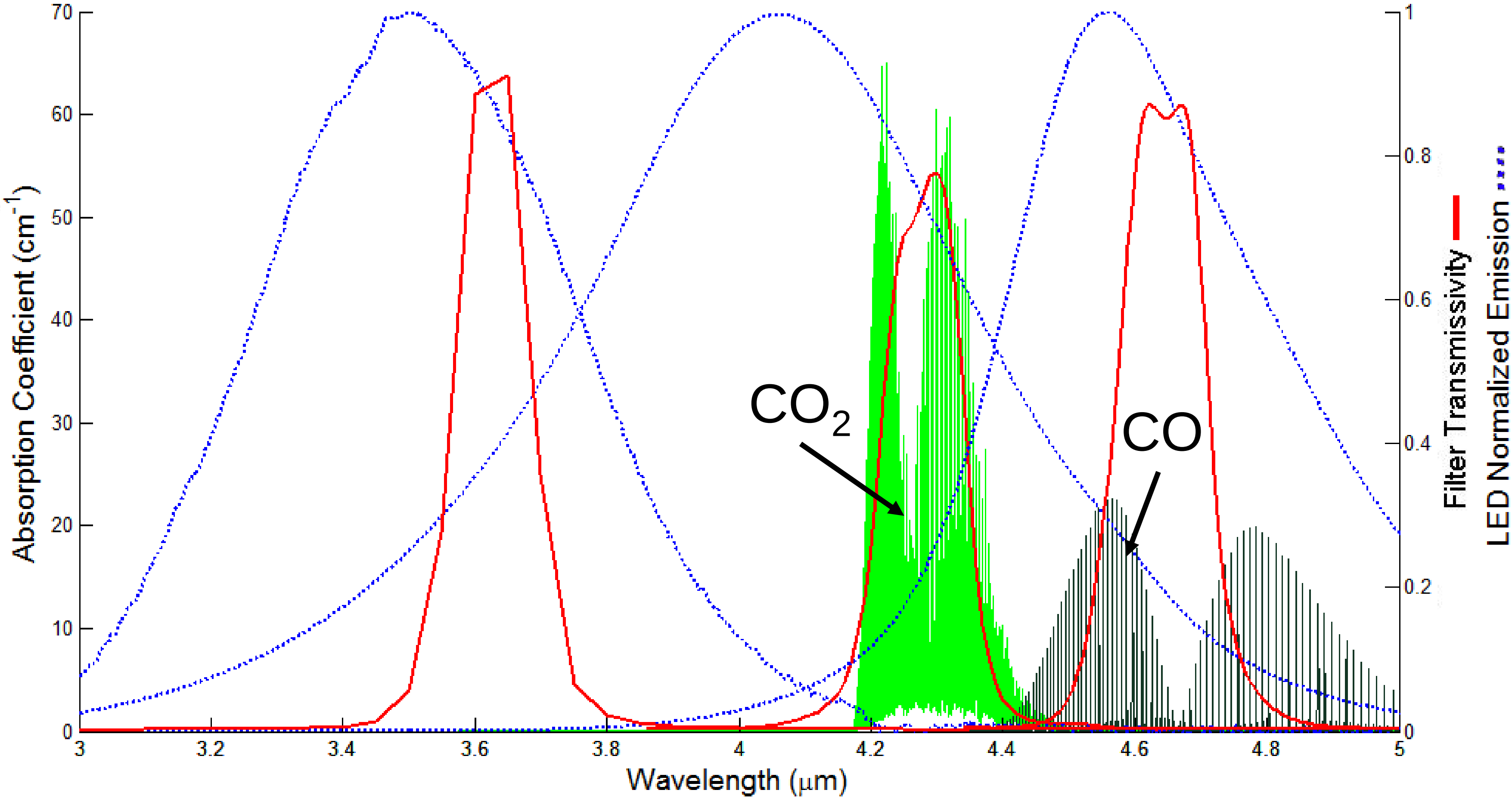
$$A_\lambda = \ln\left(\frac{I_\lambda}{I_{\lambda,0}}\right) = k_\lambda L X$$

A_λ = Spectral Absorbance (Typically 0-1)
I_λ = Transmitted Radiation at λ
$I_{\lambda,0}$ = Incident Radiation at λ
k_λ = Spectral Absorbance Coefficient (Intrinsic Property at λ)
L = Path Length of Gas Cell
X = Mole Fraction of Target Gas

Test Sample
(containing target gas)



Using LEDs in Absorption Spectroscopy



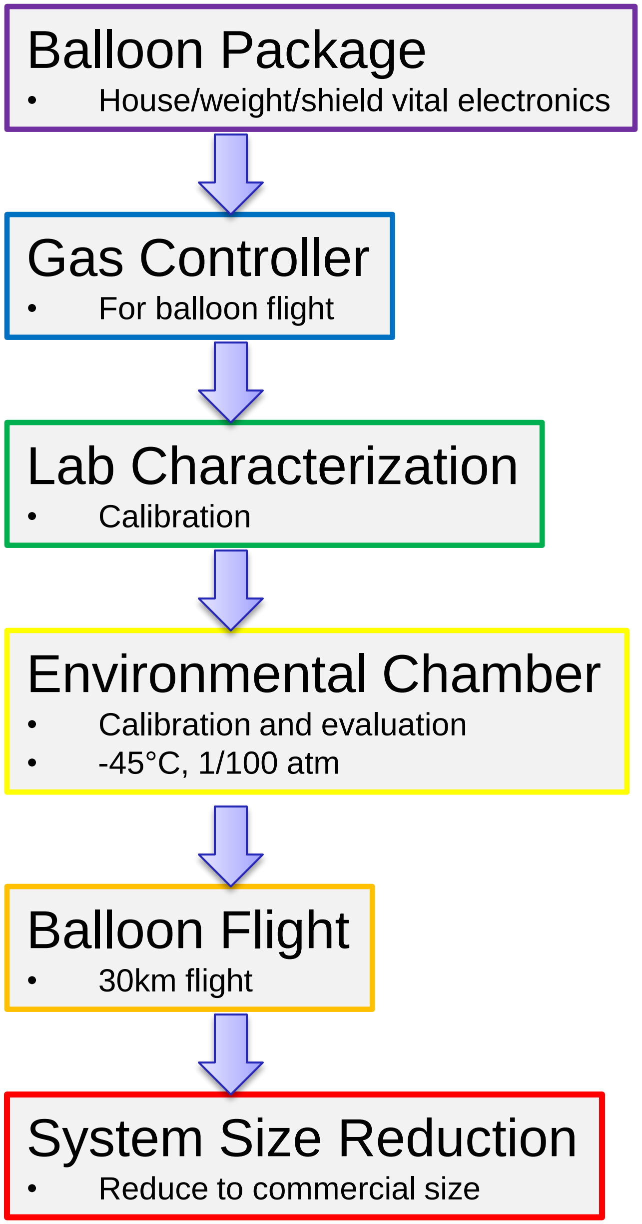
Schedule

Major Milestones

Achieved
- System integration of sensor components
- Sensor housing design for balloon test
- Convert system to run on cRIO DAQ
- Design and fabricate gas delivery system
- Integrate systems into final module
- Environmental Chamber Test Fall 2015
  - Preliminary run 10-12/2015
  - Full system diagnostic run 12/2015-4/2016
- Balloon Flight 9/1//2016

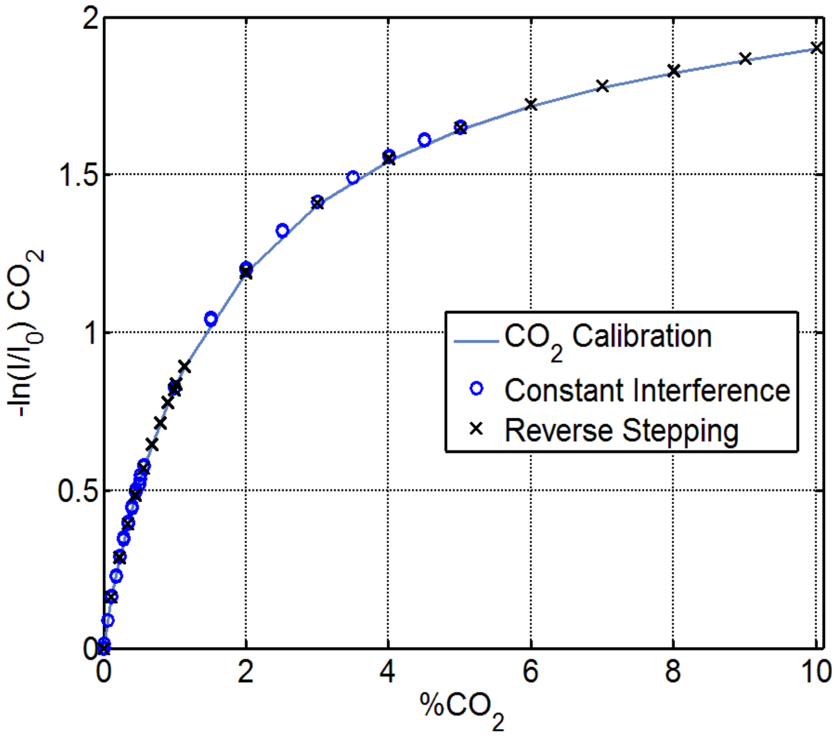
Ongoing
- Data analysis

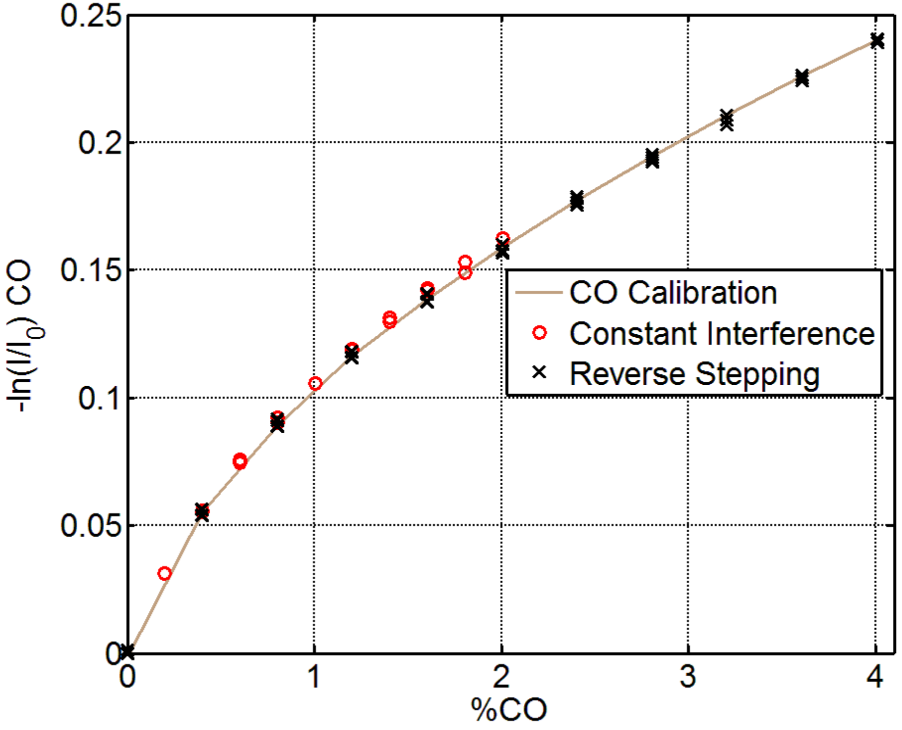
Planned
- System redesign to decrease size



Fundamental Cross-Interference Study

- Simultaneous measurements of CO and CO_2 showed no cross-interference.





Environmental Chamber Study

- UCF environmental chamber:
  - Courtesy of Dr. Robert Peale
- Verified system capabilities in low temperature/pressure environment
  - Pressure: 10mbar ($^{1}/_{100}$thatm)
  - Temperature: -20°C
- Validation of sensor functionality and Autonomous operation in a hazardous environment was achieved

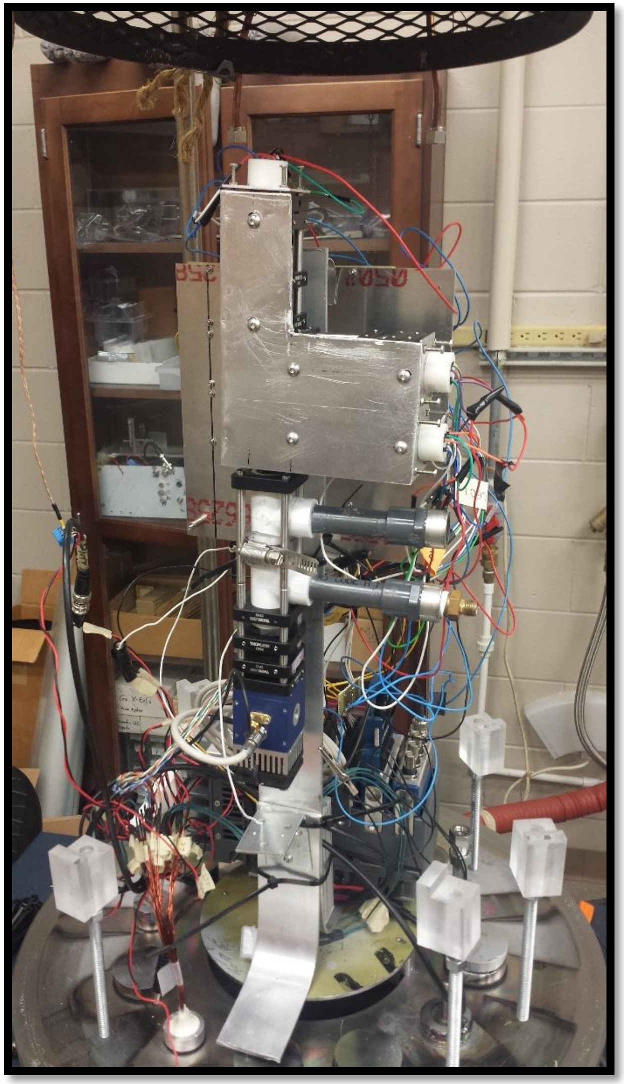
Environmental Chamber Study: Overview

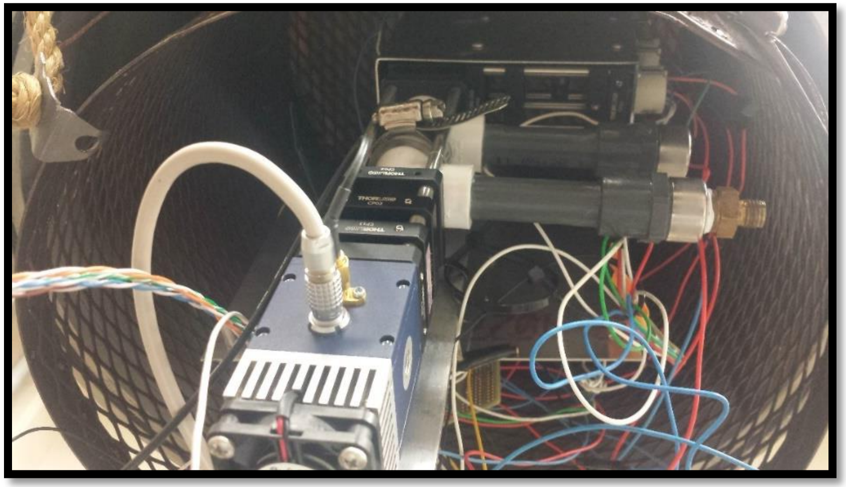
<u>Test Results:</u>

- Successful system operation over entire testing duration (Average run: ~4 hours)
- Steady LED output over range of temperatures(-20°C to 23°C) and pressure 10mbar to 1.01bar (1atm)

<u>Calculated PPM Measurement Limits:</u>

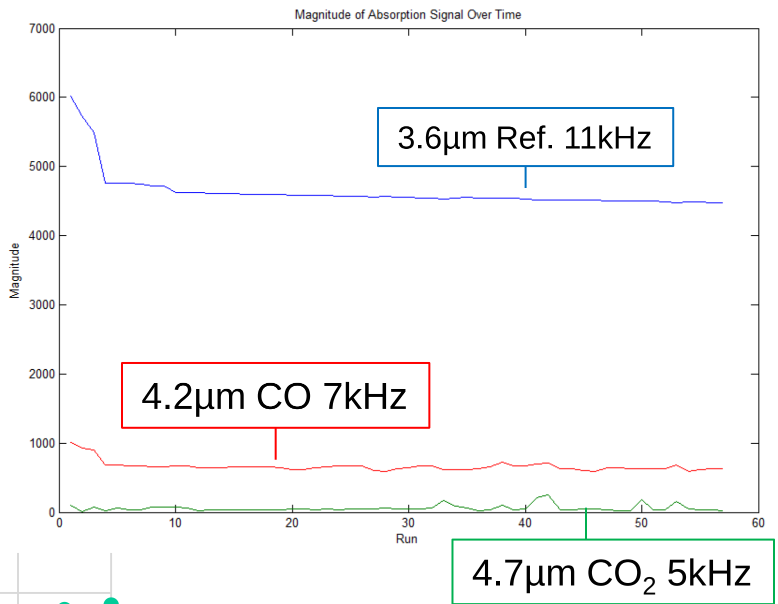
- CO 300ppm
- CO_2 8ppm

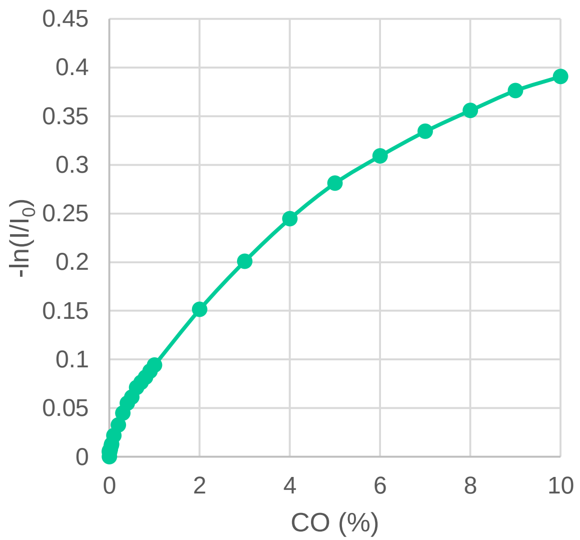


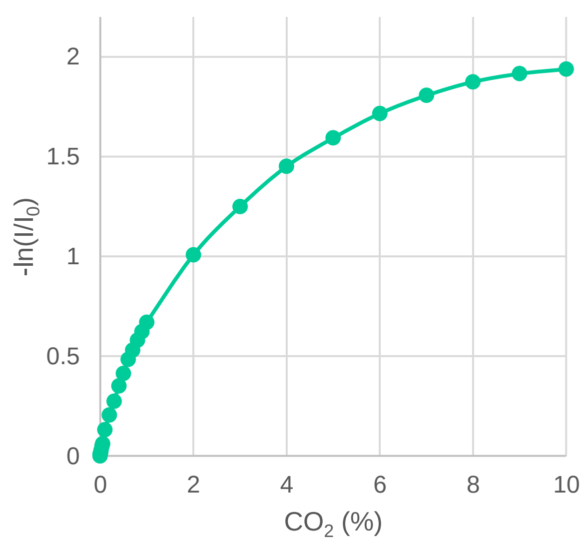


Environmental Chamber Study: Results

- Steady State LED output over time
  - Successful thermal management of system components
- Post analysis yields detection limits of:
  - 8ppm for CO_2
  - 300ppm for CO

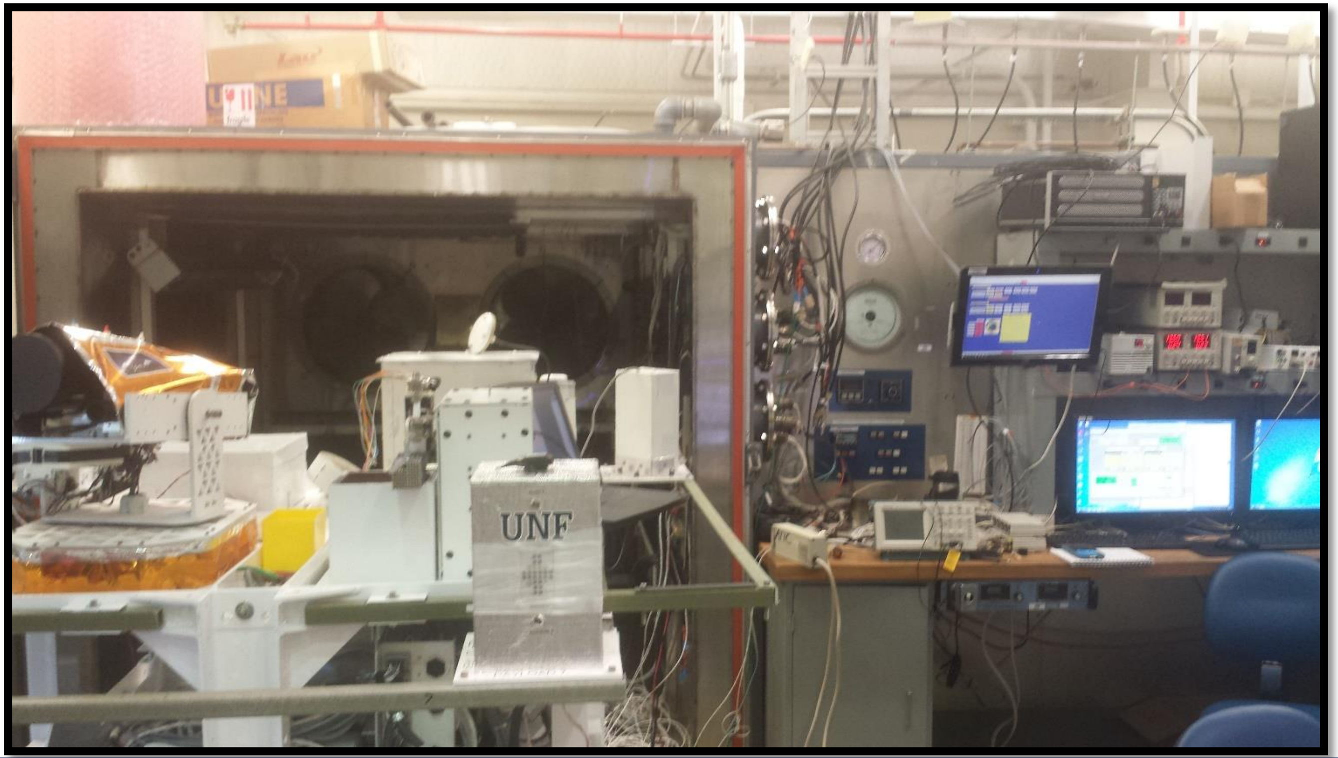






Environmental Chamber Study: NASA CSBF

- Second round of environmental chamber testing completed at NASA's Columbia Scientific Balloon Facility's Thermal Vacuum Chamber located in Palestine Texas.



Sensor Design:
HASP Flight Design

Test Duration:
08h:30m:00s

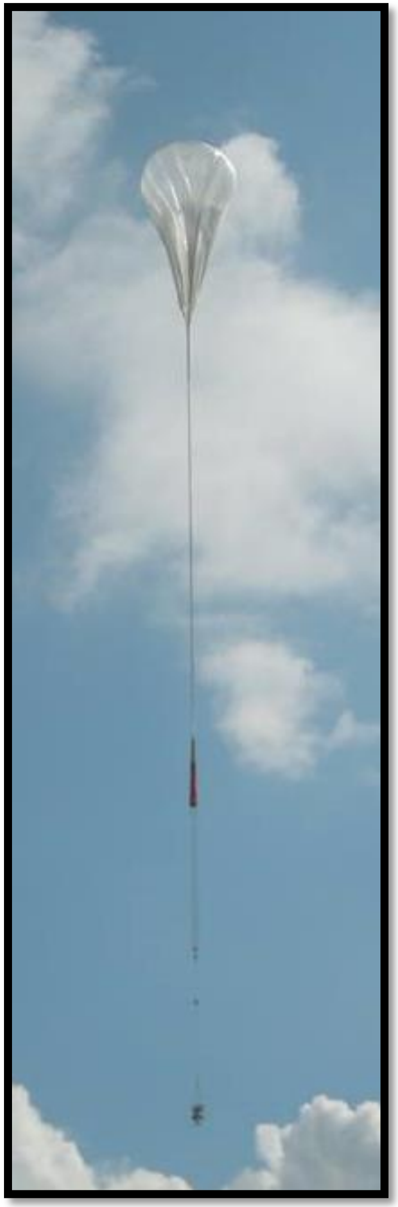
Temperature Range:
-60°C to 50°C Profile

Pressure Range:
8mbar to 1bar (1atm)

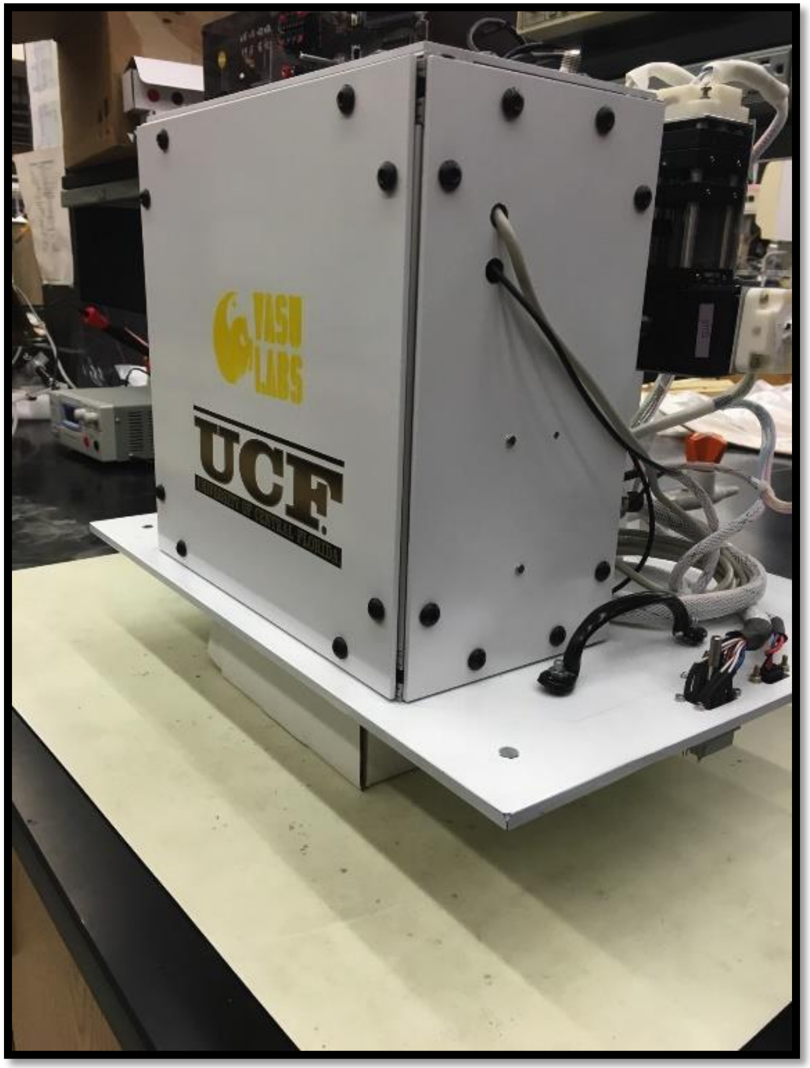
High-Altitude Balloon Flight

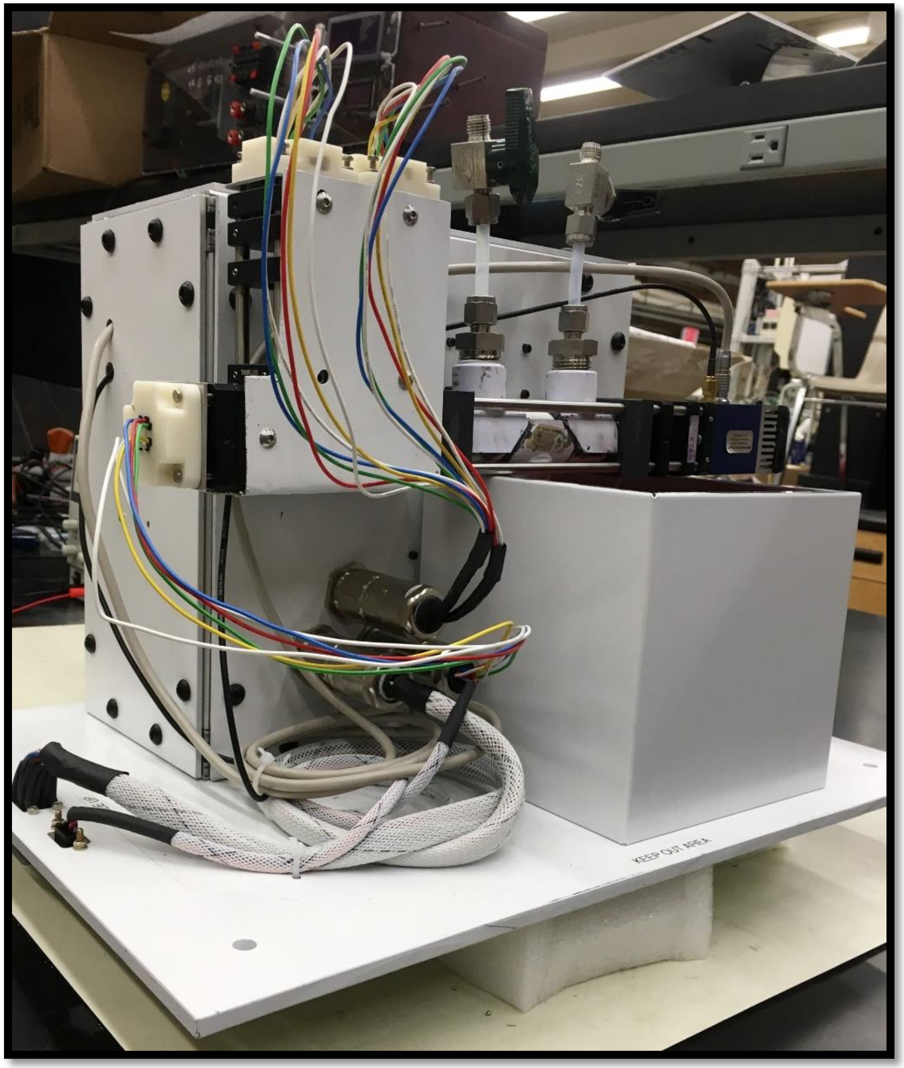
- The flight was provided by NASA Columbia Scientific Balloon Facility (Via LSU's HASP Program) from Fort Sumner, NM.

- Opportunity to test system in potential working conditions
  - Autonomous operation in a harsh/hazardous environment
  - Enables validation of Thermal/Vac. study results



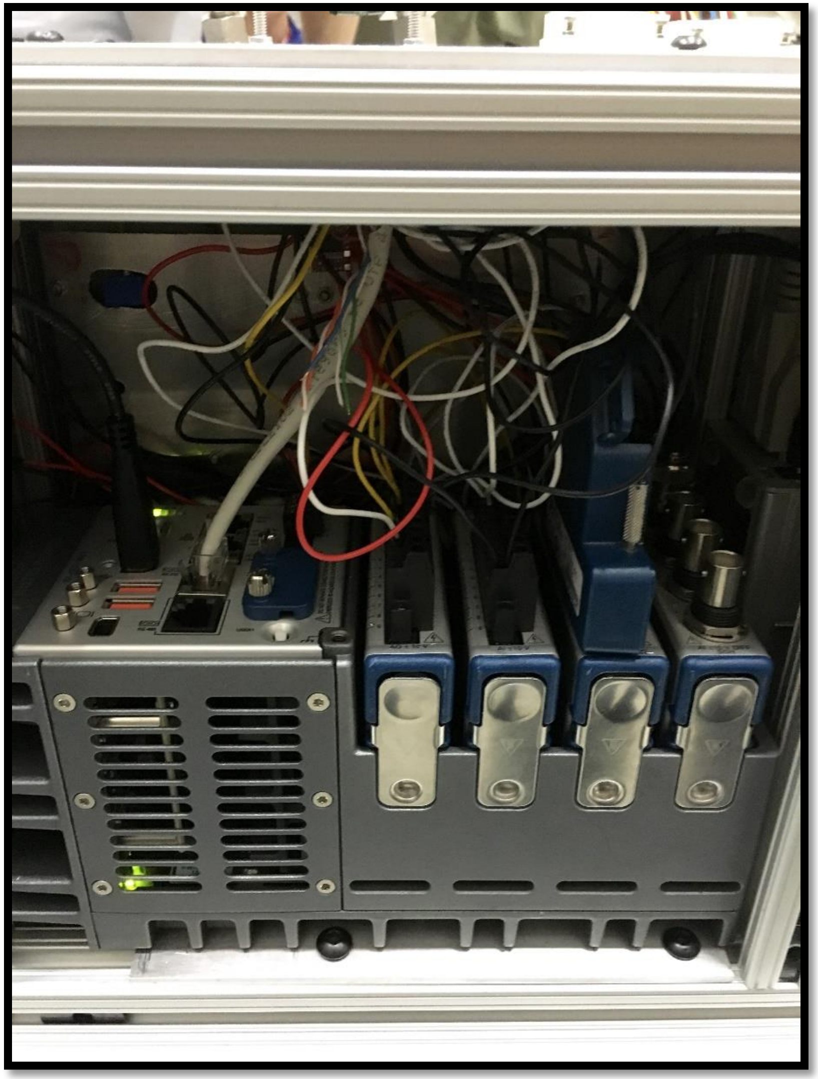
High-Altitude Balloon Flight System Design





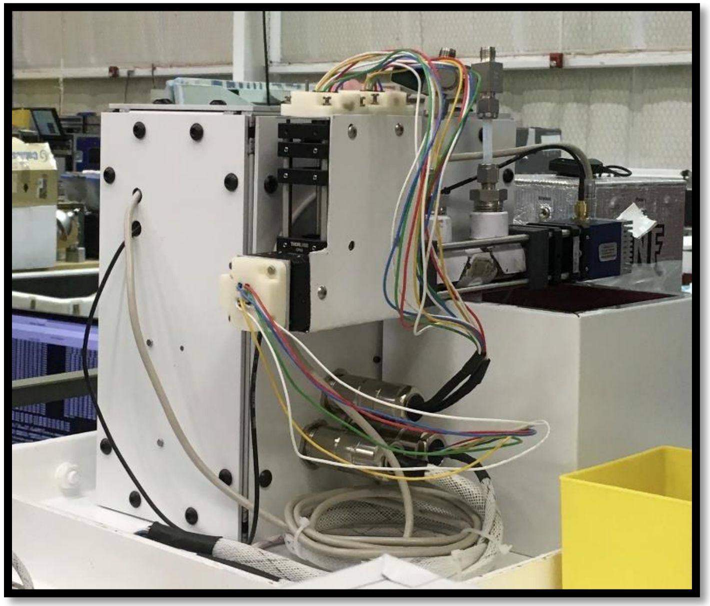
High-Altitude Balloon Flight System Design

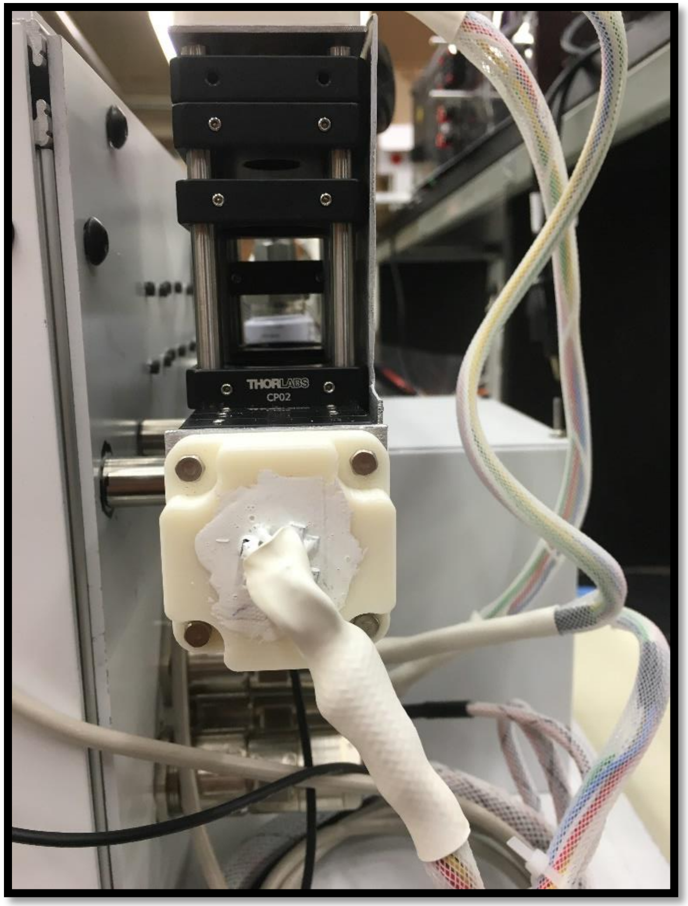
- Core system was redesigned to meet the unique constraints of a high-altitude balloon flight.
- Electronic logic boards were redesigned to improve signal integrity in a high noise environment.
- Isolated DC/DC Converters implemented to allow correct power allowances to subsystems:
    - cRIO DAQ: 24V
    - VIGO Detector: 12V
    - LEDs/Drivers: 6V



High-Altitude Balloon Flight System Design

- All electronics were placed inside a sturdy aluminum case for increased protection.
  - Optical rail was mounted to the case and an aluminum box was added to shield the Absorption Cell diaphragm.
- White powder coated external walls with Mirror-finished internals maximized radiation rejection.

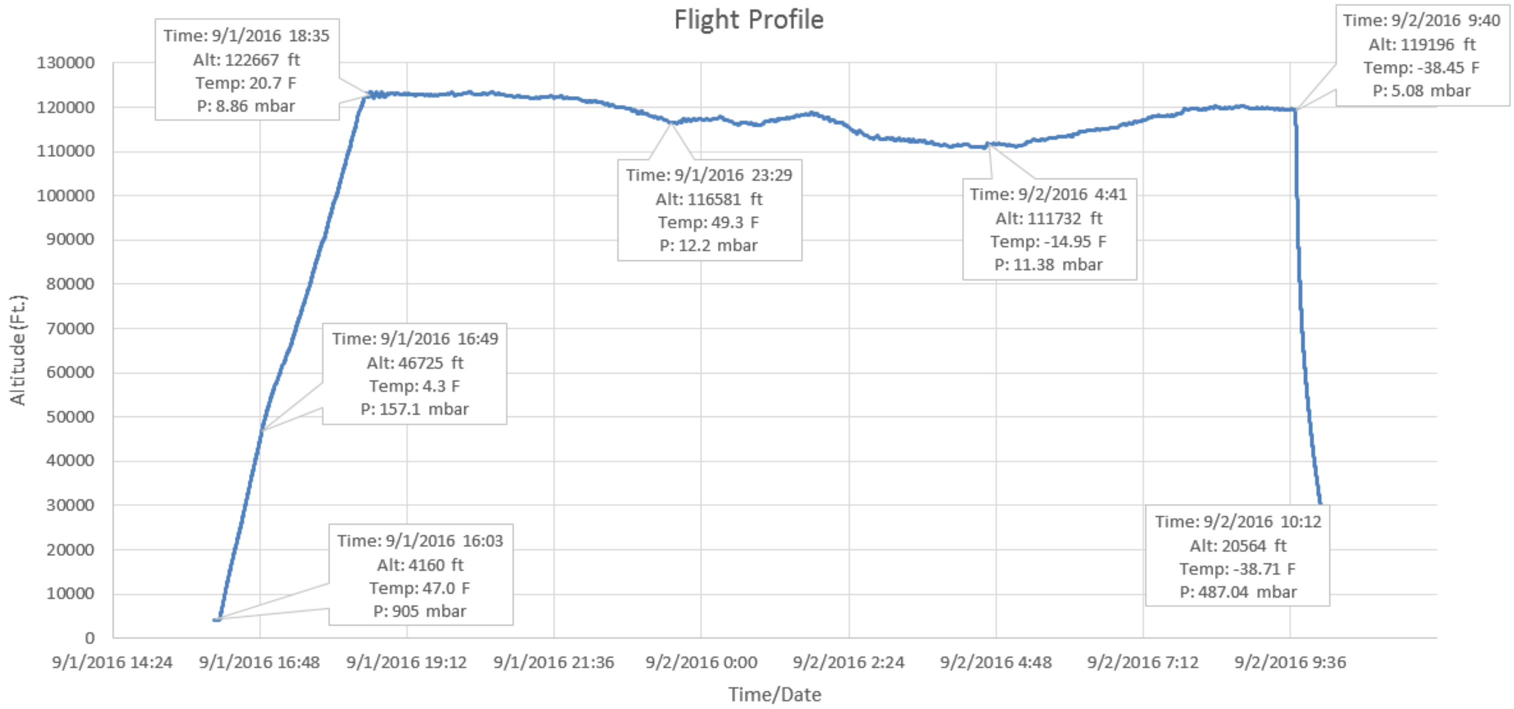




High-Altitude Balloon Flight: Results

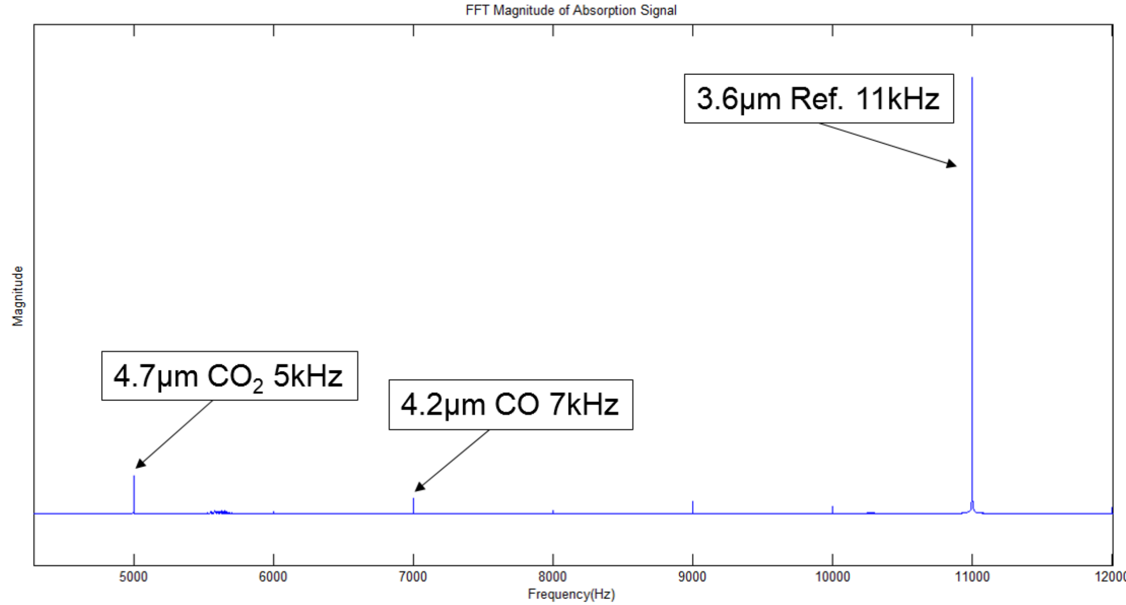
<u>Flight Conditions:</u>

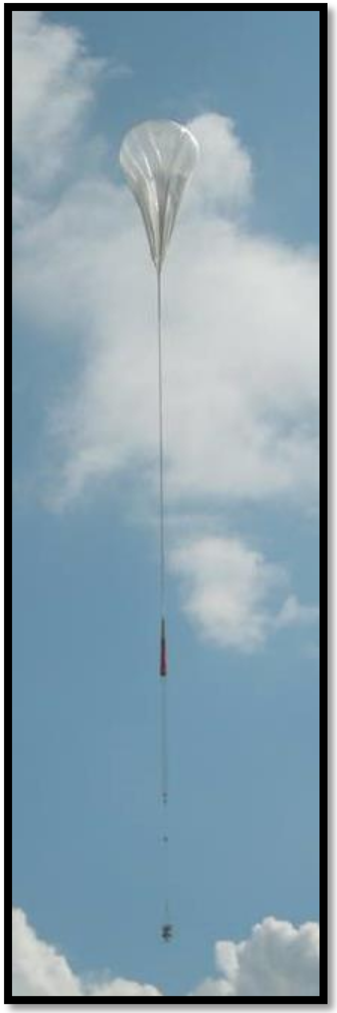
- **Max Altitude:**123,546 ft.
- **Temperature Range:** -54.47 °F to 53.76 °F
- **Pressure Range:** 0mbar to 910mbar
- **Float Duration:** 15h:08m:54s (Total: 18h:09m:30s)



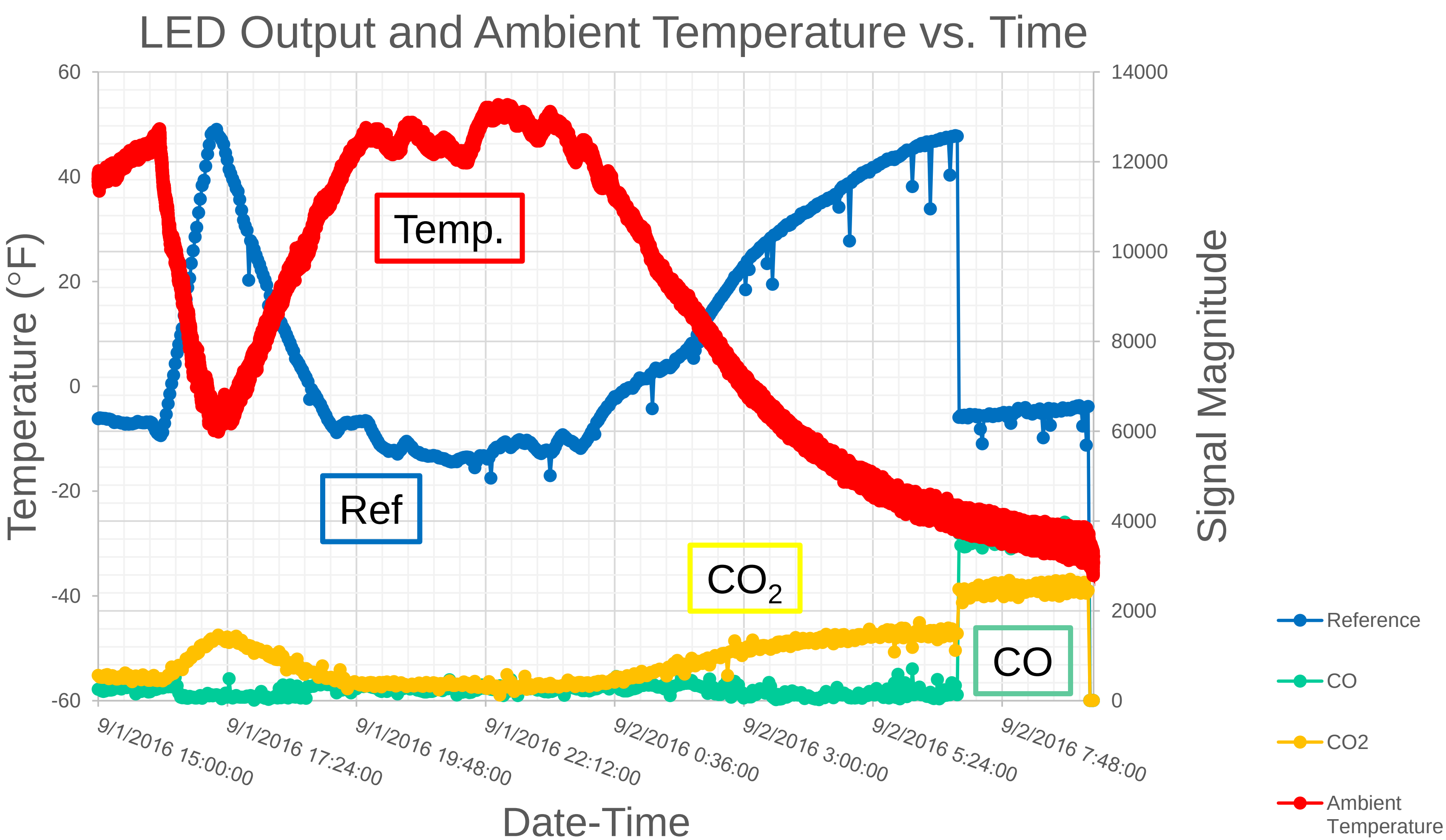
High-Altitude Balloon Flight: Prelim-Results

- The sensor successfully completed high altitude flight testing to simulate harsh working environments
- System was flown with a pre-mixture of N_2(89.51%), CO(4.97%) and CO_2(5.52%).
- Successful sensor operation/data collection was achieved throughout flight duration.





High-Altitude Balloon Flight: Prelim-Results



Applicability to the Industry

- CO & CO_2 measurements help protect health and safety of the crew
  - Provides real-time knowledge of gas levels
  - Information that can be used to determine probability of fire or gas spread
  - Both gases combined can measure total carbon output and, as a result, indicating fuel input

- Time-resolved measurements of CO could be used to detect fuming, which may lead to explosions

Future Work

- Miniaturization: Sensor design and housing design must be optimized for spacecraft environment. This would require a caged design that will house every component keeping the weight to the allowable values

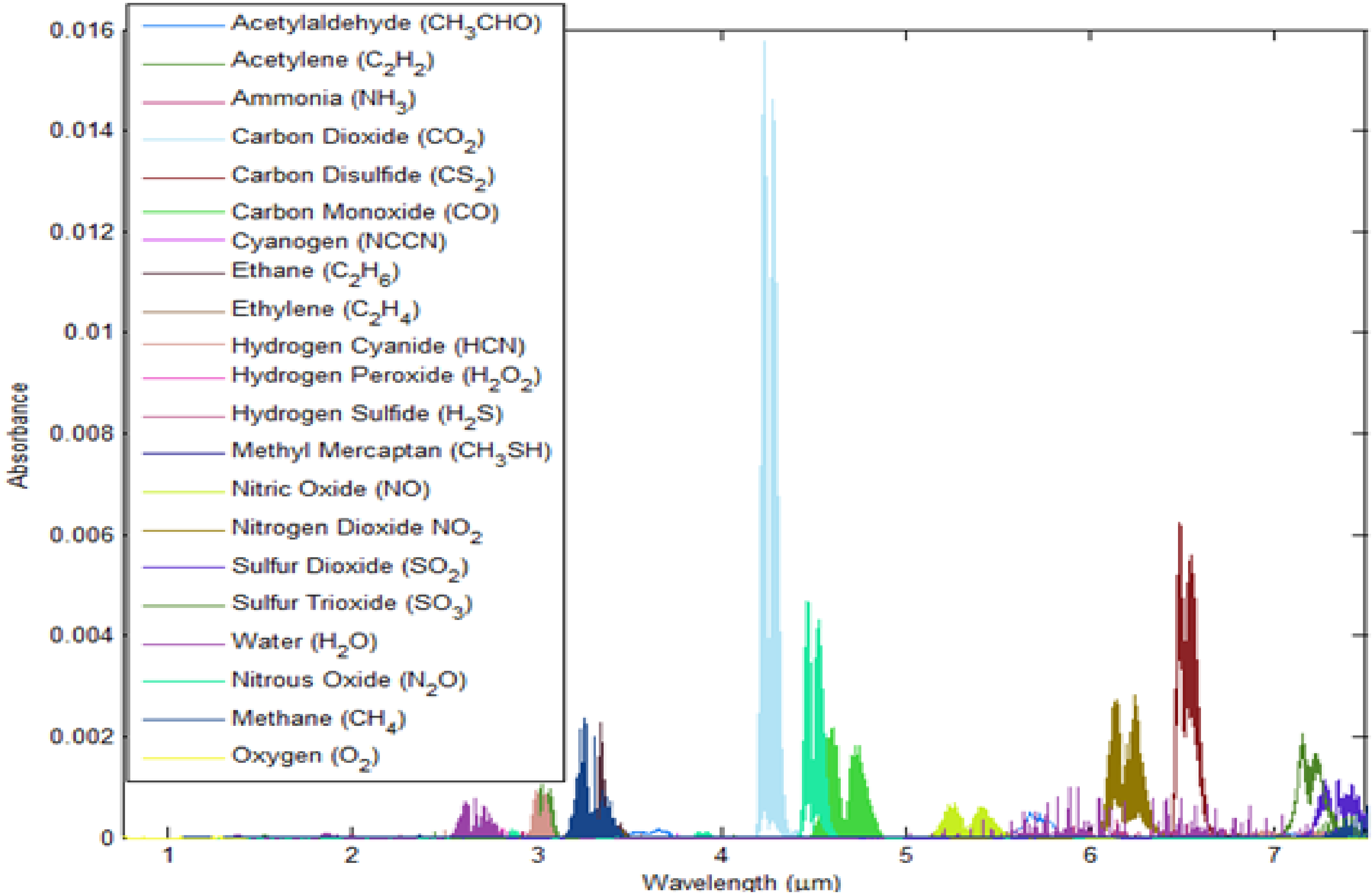
- Broader Species Detection: N_2O (oxidizer), HCN (cabin hazard), H_2O, etc.
  - Improve detection limits through:
  - Optimizing optical arrangements
  - Developing stable LED driver circuits
  - New filter selections
  - Adding additional LEDs

- Develop models for broad spectrum absorption which will allow on the fly path length adjustments and theoretical designing for other gas targets
  - Demonstrate technique for other wavelengths to target more species (e.g. N_2O)

Acknowledgements

- Research at UCF was supported by financial assistance from FAA-COE-CST, Space Florida, and Florida Space Institute.
- M.V., A.P., and J.U. would like to acknowledge travel support provided by the NASA FSGC Program.
- The authors thank Prof. Robert Peale and Kyle Thurmond for help with the environmental chamber tests, and Zach Loparo for suggestions regarding data processing.
- FAA AST: Nick Demidovich and Ken Davidian

Supplementary Slide: Mid-IR Absorption Spectra



Additional Possible Species in Sensor Absorption Range