Evaluation of a New Trace-Gas Analyzer Designed for Eddy Covariance Flux of Methane and Nitrous Oxide

Scott Cornelsen

Principal Engineer, Campbell Scientific, UT, USA



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Campbell SCIENTIFIC

Core Instruments for Eddy Covariance

Gas Sensor + 3D Anemometer

Imperfect measurements and the “observer effect”

Sensor limitations that matter…

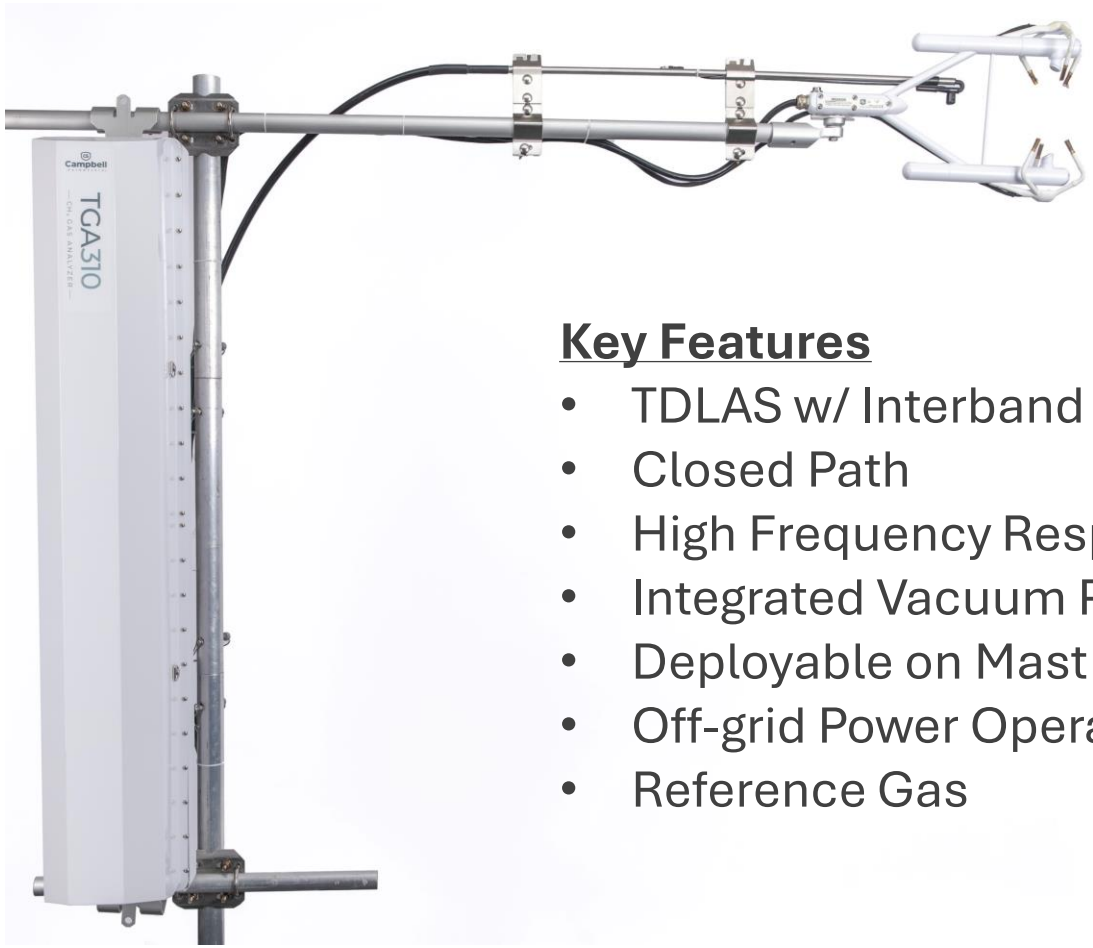
- Colocation
- Aerodynamics
- Synchronization
- Signal-to-Noise Ratio
- High Frequency Response
- Open vs. Closed Path have different trade-offs

Quality Metrics for EC Instrumentation

Parameter	Goal
Colocation	Gas measurement within 1 path length of 3D sonic
Aerodynamics	Horizonal symmetry, unobstructed prevailing wind
Synchronization	< 20 ms sample timing jitter
Low Noise	Single digit ppb for CH_4 and N_2O
Stability	(Drift < Noise) for flux interval 30 min typ.
Frequency Response	3-5 Hz to capture 95% of flux for typ. site
Spectroscopic corrections	Minimize by 1st principles design
Field Durable	IP65+ rating, Temperature rating -20 to 50° C
Low Power	Max 50-100W for a reasonable DC solar system
Low Maintenance	Monthly or seasonal site visits

TGA300 Series

— EDDY-COVARIANCE TRACE GAS ANALYZERS —



TGA310

— CH_4 GAS ANALYZER —

TGA320

— N_2O GAS ANALYZER —

Key Features

- TDLAS w/ Interband Cascade Laser
- Closed Path
- High Frequency Response
- Integrated Vacuum Pump
- Deployable on Mast
- Off-grid Power Operation
- Reference Gas

Key Specifications

Freq Response: > 3 Hz

Noise (10 Hz BW)

CH_4 : < 7 ppb rms

N_2O : < 1.5 ppb rms

Sync Jitter: ±10 ms

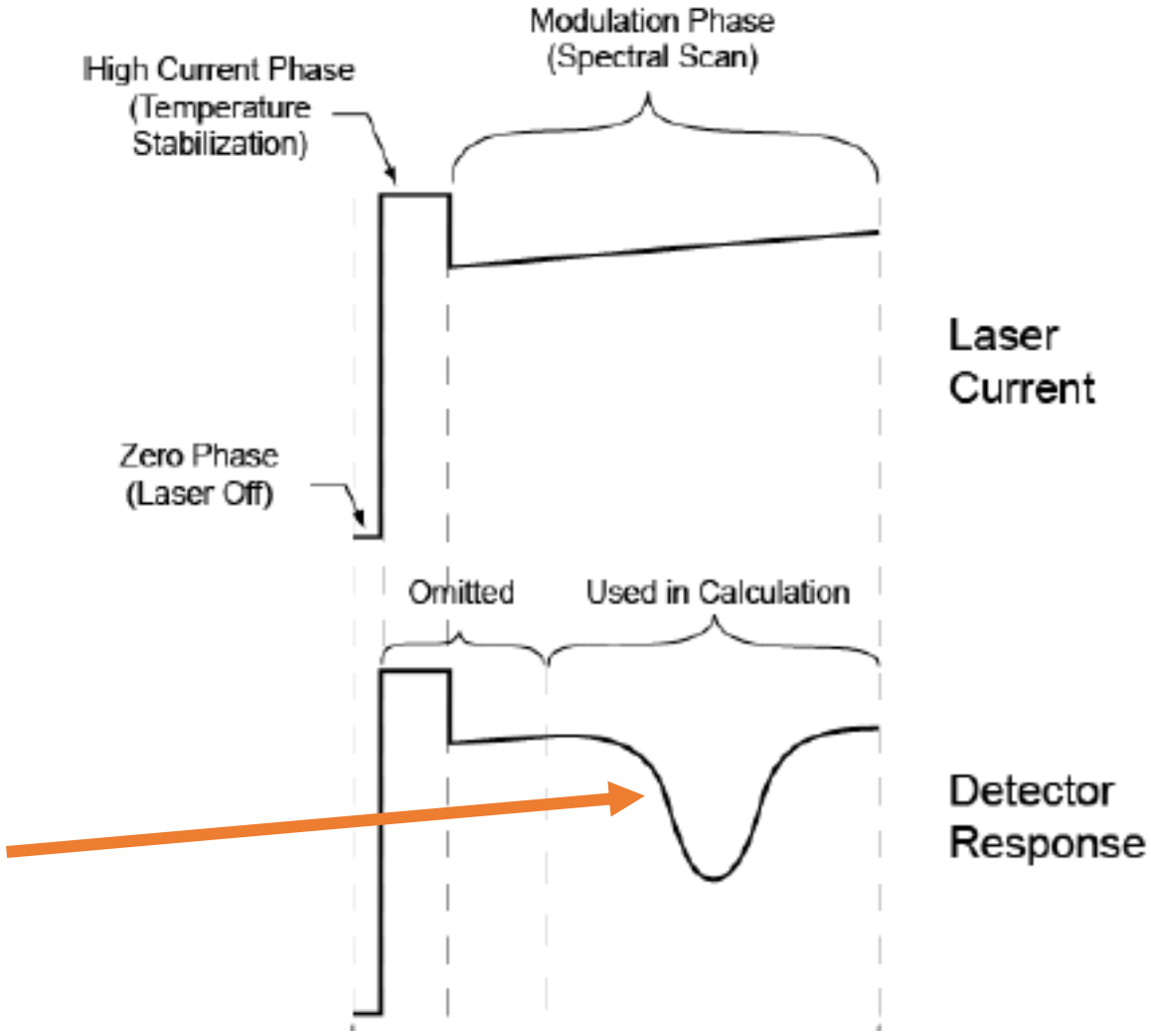
Power: < 50 W

Gas pressure: 30 kPa

Intake Length: 5 m

TDLAS Laser Scan

- **3 Phase Laser Sequence**
  - **Zero current phase:** measure the detector dark response
  - **High current phase:** replace heat lost during the zero phase
  - **Modulation phase**: laser current ramped over a small range (<1mA) causing a sweep of wavelengths (<1nm)
  - λ CH_4 : 4534 nm
  - λ N_2O : 3221 nm
- **Detector response**
  - Mimics the laser current plot except when passing through the absorption band
  - Amplitude of the “dip” is proportional to absorption
- **Scan sequence repeated every 1 ms**

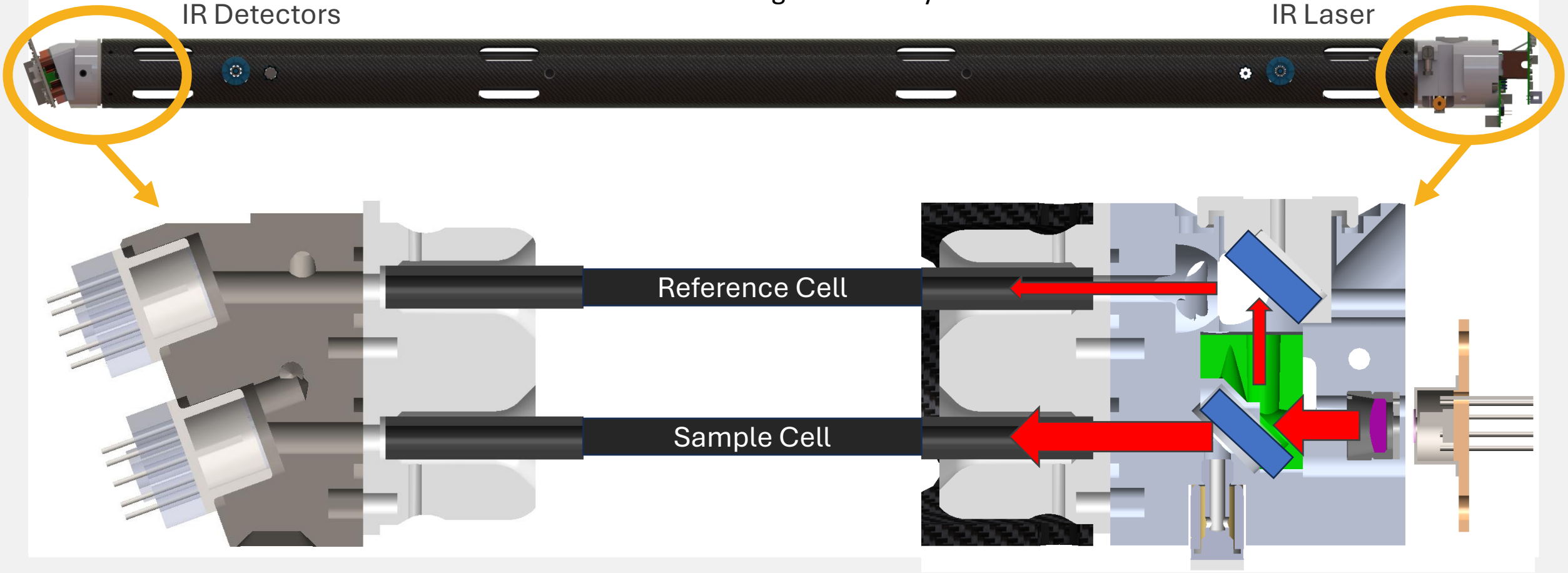


Optical Layout

Reference gas benefit
- Stable laser line lock
- Sets the gain accuracy

Dual TE-Cooled
IR Detectors

TE-Cooled
IR Laser



Concentration Calculation

- Reference and sample detector signals are corrected for nonlinearity and converted to absorbance.
- Temperature and pressure are maintained the same in the reference and sample cell to cancel these variables in the calculation.
- Linear regression of sample absorbance vs. reference absorbance gives the ratio of sample absorbance to reference absorbance.

$$C_s = (C_R)(D)$$

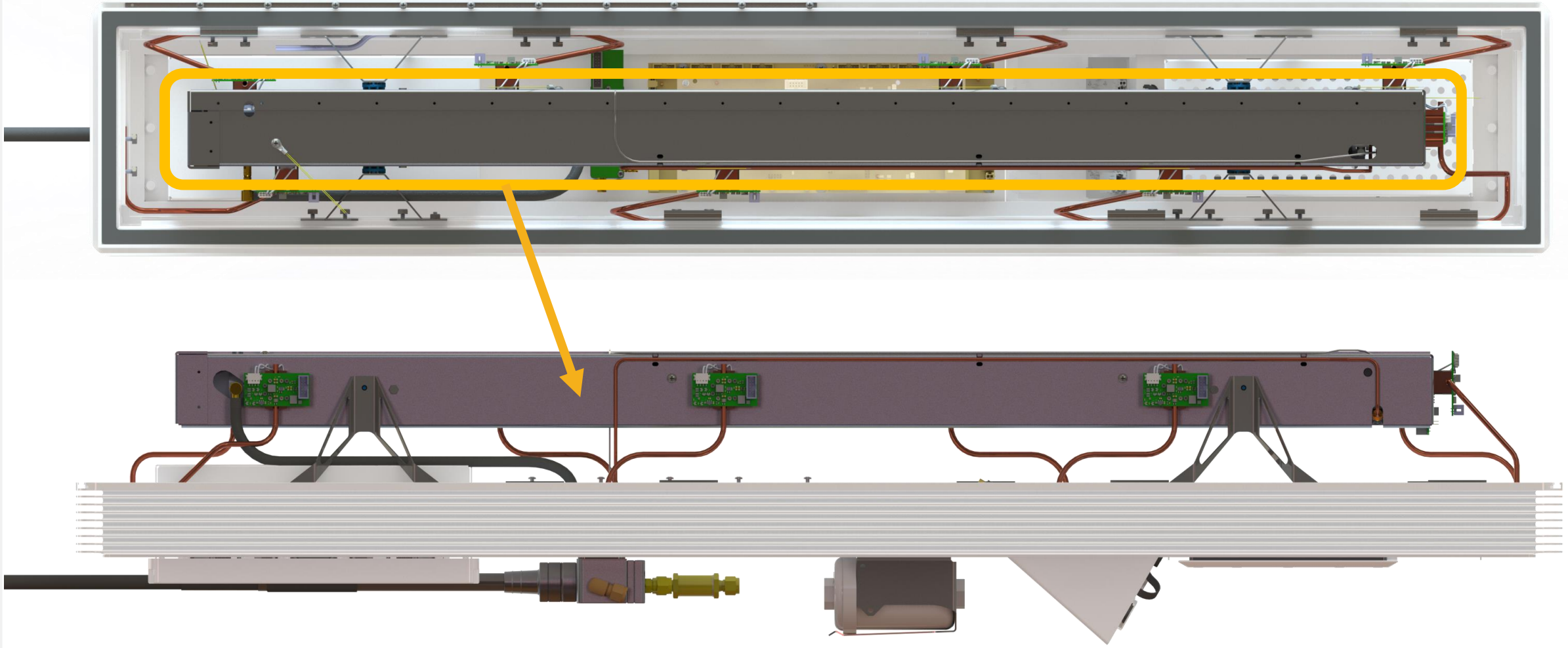
C_S = concentration of sample gas, ppm

C_R = concentration of reference gas, ppm

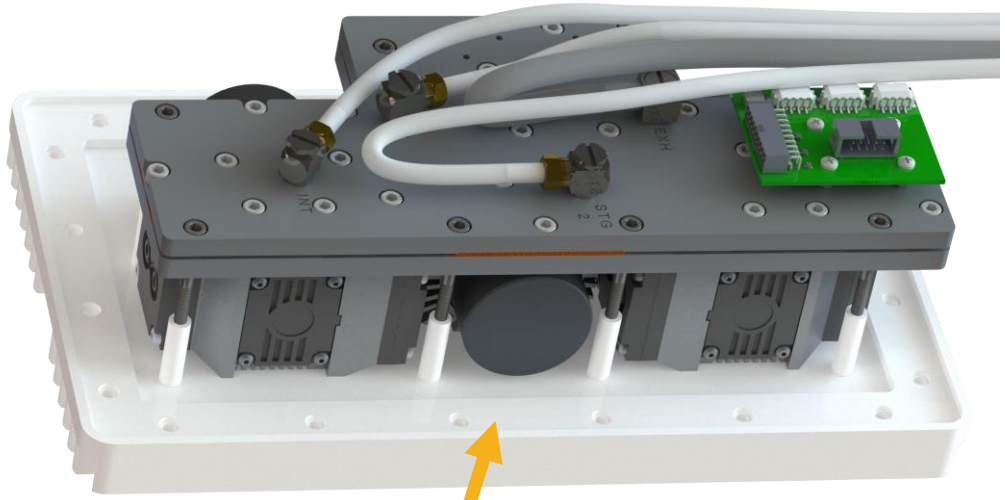
D = ratio of sample to reference absorbance

Optical Bench Thermal Control

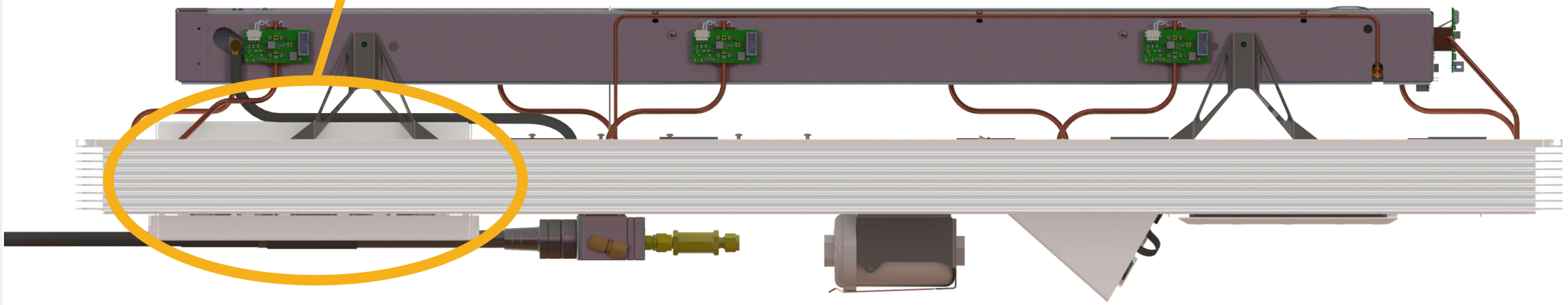
Ambient Operating Temp -20° to 50°C



Integrated Pumps



Sample Gas Flow: 1.8 SLPM
Reference Gas Flow: 10 ml/min
Vortex Bypass Flow: 6 SLPM
Sample Pressure: 30kPa
Pump Power: < 20 W



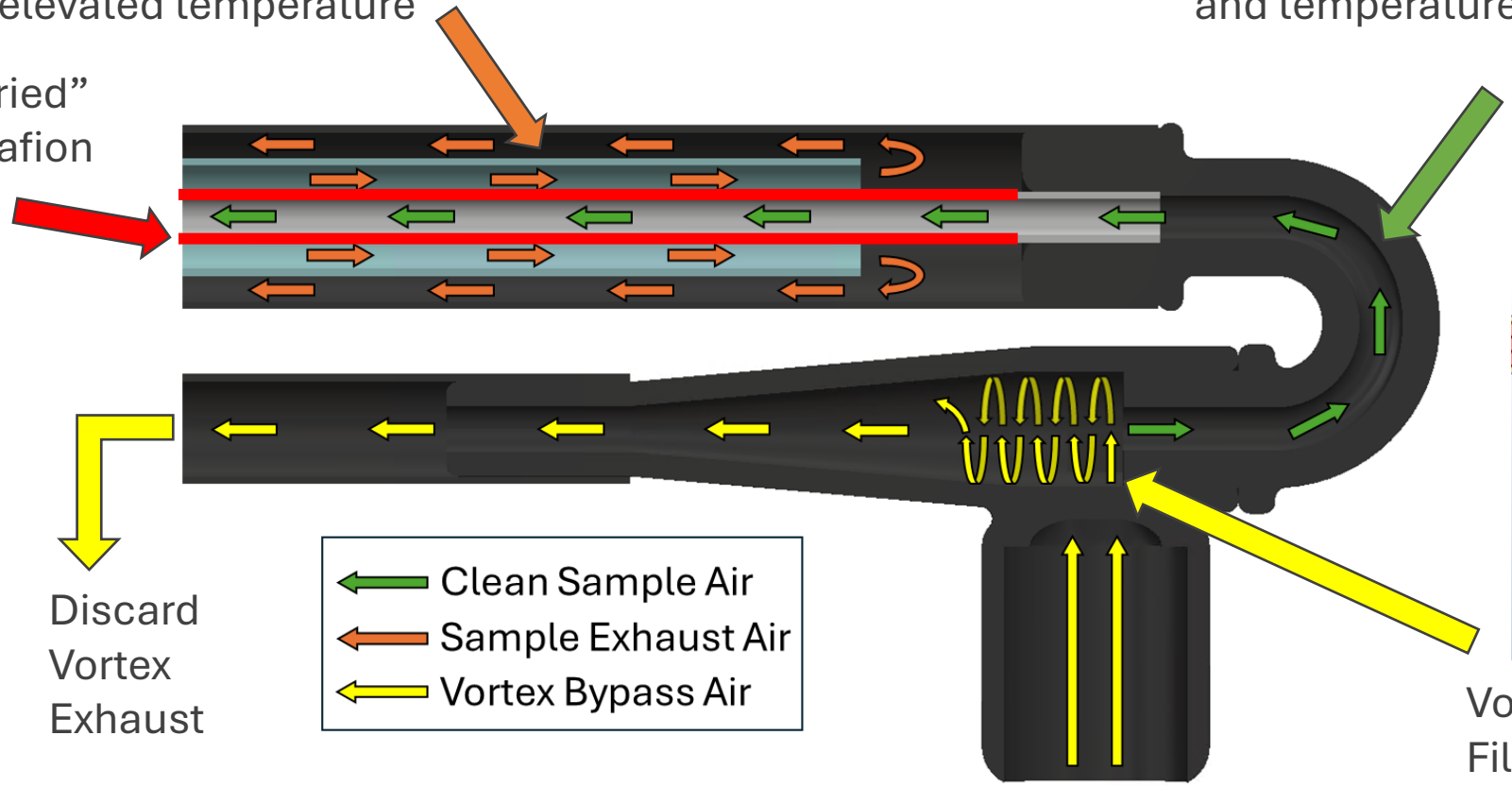
Advanced Sample Air Intake

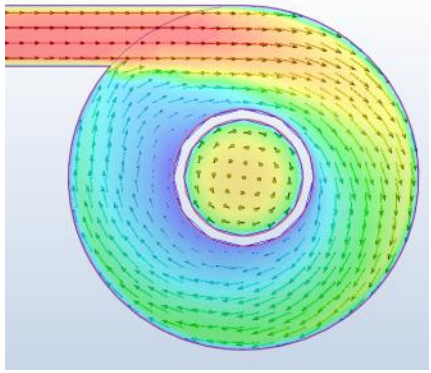
Counterflow air is provided by recirculating the post-measurement sample air at lower pressure and elevated temperature

Raw Sample Air at ambient pressure still contains high frequency water and temperature fluctuations

Sample Air is “dried” through a 4 m Nafion membrane tube

Note: Nafion is a specialized polymer that allows the transport of water molecules across the membrane when subjected to a partial pressure differential





Vortex Cleaner = Fewer Filter Replacements

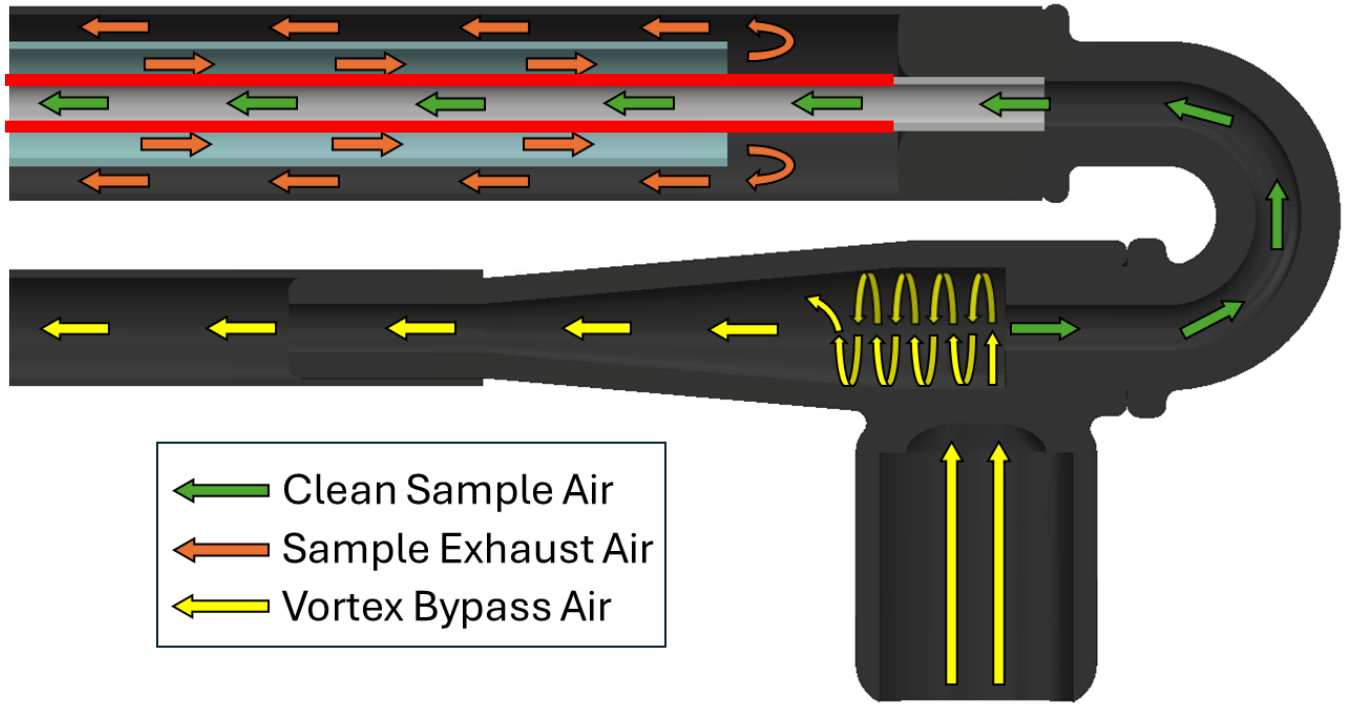
Reference: Burgon, R., Sargent, S., Zha, T. and Jia, X. (2015) Field-Performance Verification of Carbon Dioxide, Water, and Nitrous Oxide Closed-Path Eddy Covariance Systems with Vortex intakes. AGU Fall Meeting 2015 Poster B33C-0669

Advanced Sample Air Intake

Water and temperature variation reduced to a low-pass frequency bandwidth.

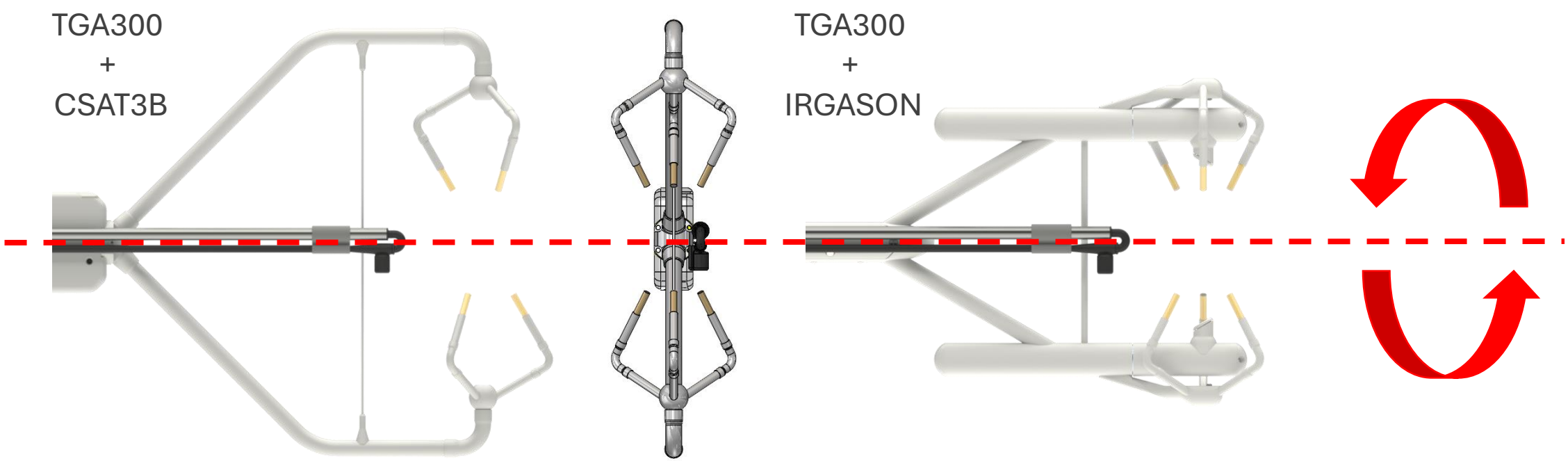
Eliminates the high-frequency effects on the scalars used in flux calculation.

Solution eliminates WPL corrections. Uncompromised mixing ratio as primary output.



Reference: Somers, J., Sargent S. (2015) A Novel Low-Power, High-Performance, Zero-Maintenance Closed-Path Trace Gas Eddy-Covariance System with No Water Vapor Dilution or Spectroscopic Corrections, AGU Fall Meeting Poster B33C-0668.

Aerodynamic Symmetry & Colocation



- Lack of symmetry above and below the horizontal plane of the measurement volume can cause biases in Uz.
- True colocation of the sonic and gas measurement volume is possible with an open-path design but must be compromised for a closed-path intake.

Reference: Hosseini, A., Baker, D., Cornelsen, S., Bogoev, I., Lawyer A., Singleton, A. (2024) Evaluating the Influence of an Integrated CO2/H2O Gas Analyzer on Flow Dynamics in the IRGASON Sonic Anemometer , AGU Fall Meeting Poster 1480.

16-Month Field Campaign



US-RGF Ameriflux Site
San Joaquin Valley, CA, USA
Aug 2023- Dec 2024
In Partnership with Lawrence Berkeley National Lab





Silage corn and winter wheat

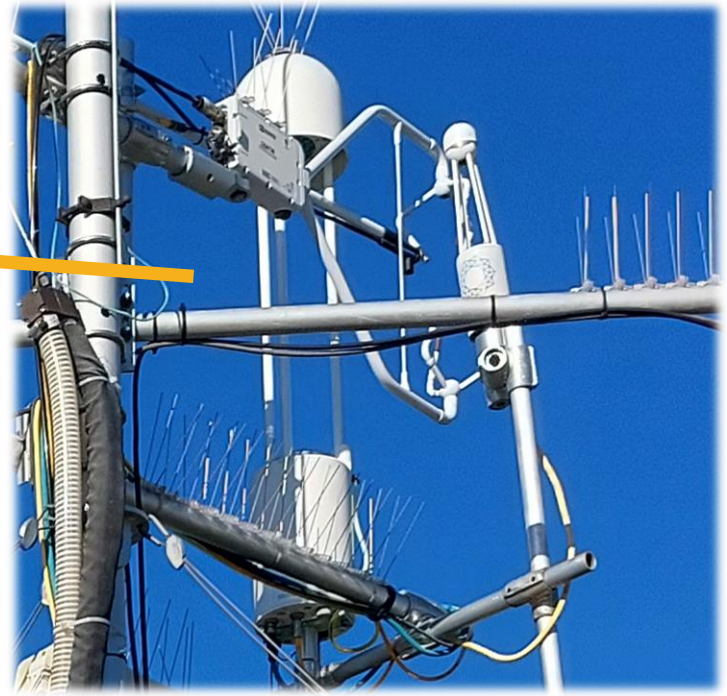
Side-by-Side Instrument Packages



Integrated System

Wind: IRGASON
CO_2: IRGASON
H_2O: IRGASON
CH_4: TGA310
N_2O: TGA320
Improved Aerodynamics





Legacy System

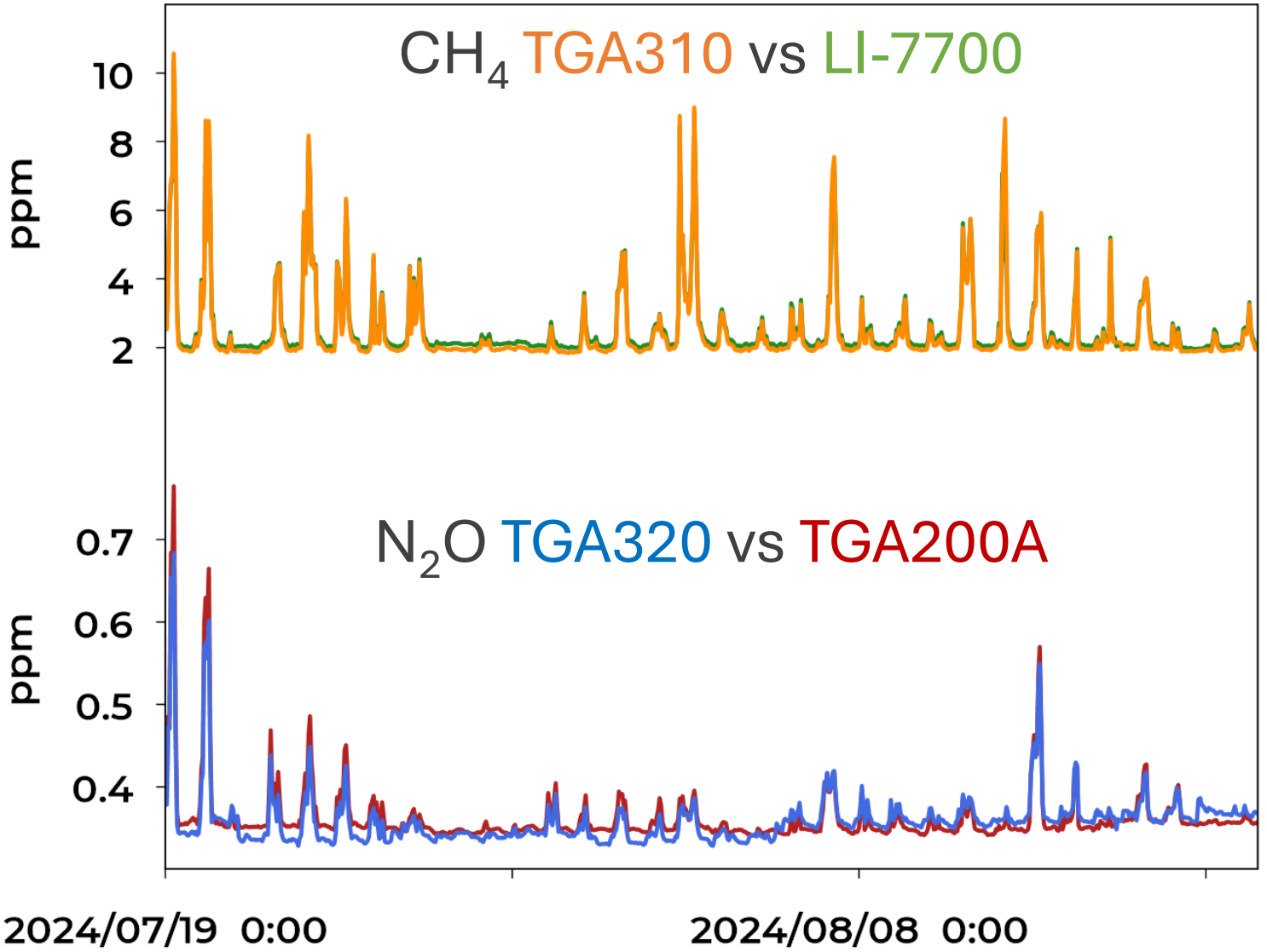
Wind: CSAT3B
CO_2: LI-7500
H_2O: LI-7500
CH_4: LI-7700
N_2O: TGA200A
Shadowing, Weak Colocation

Auxiliary Sensors

Young 81000RE, Picaro, SWS, soil sensors, etc

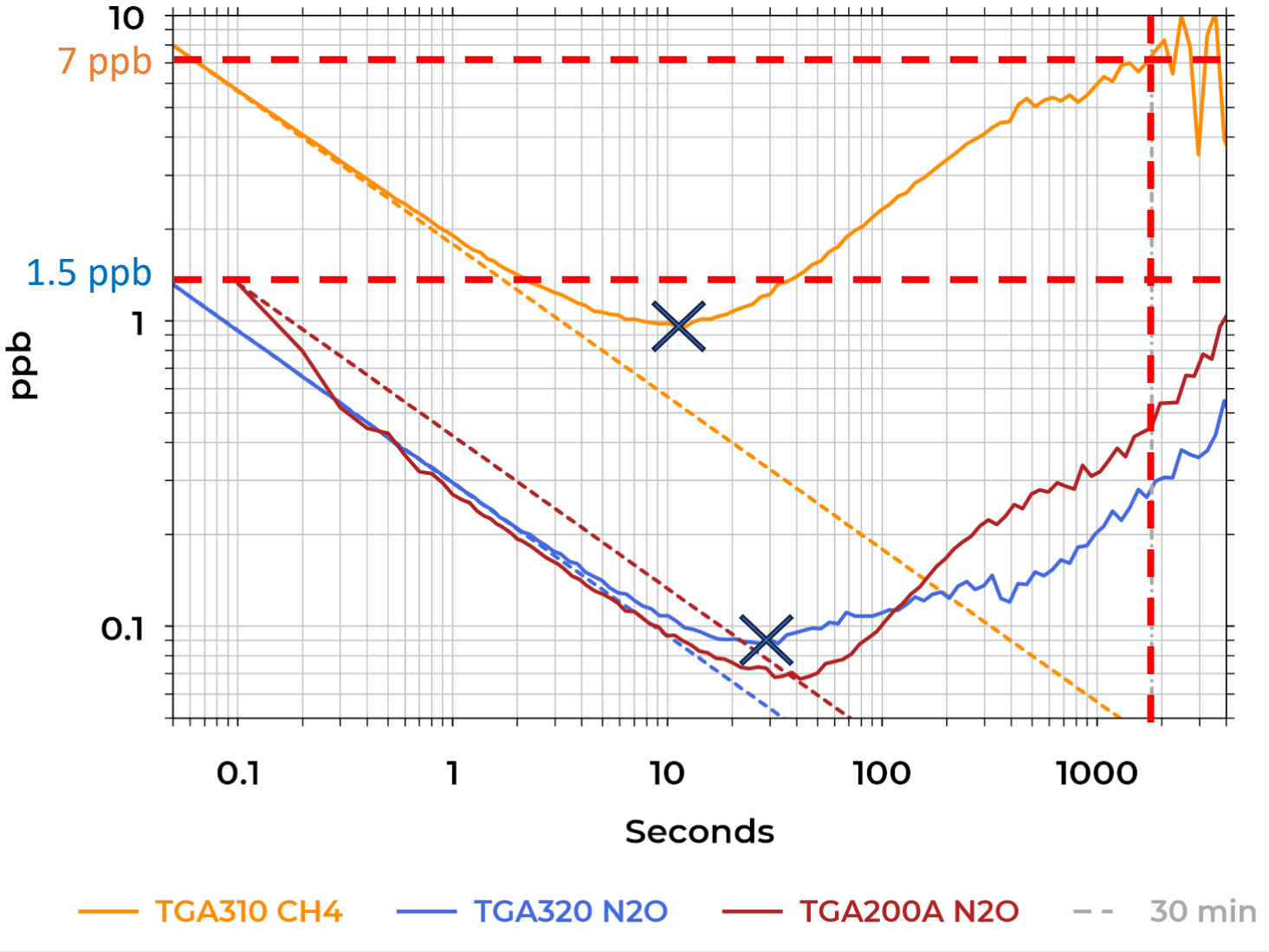
Long-scale Time Series

- Correlated responses
- 1-hr smoothing for visibility
- Consistent data availability
- Most instrument drift is contained in the offset which has minimal impact on EC
- Best practice is periodic zero and span – can be automated for closed path



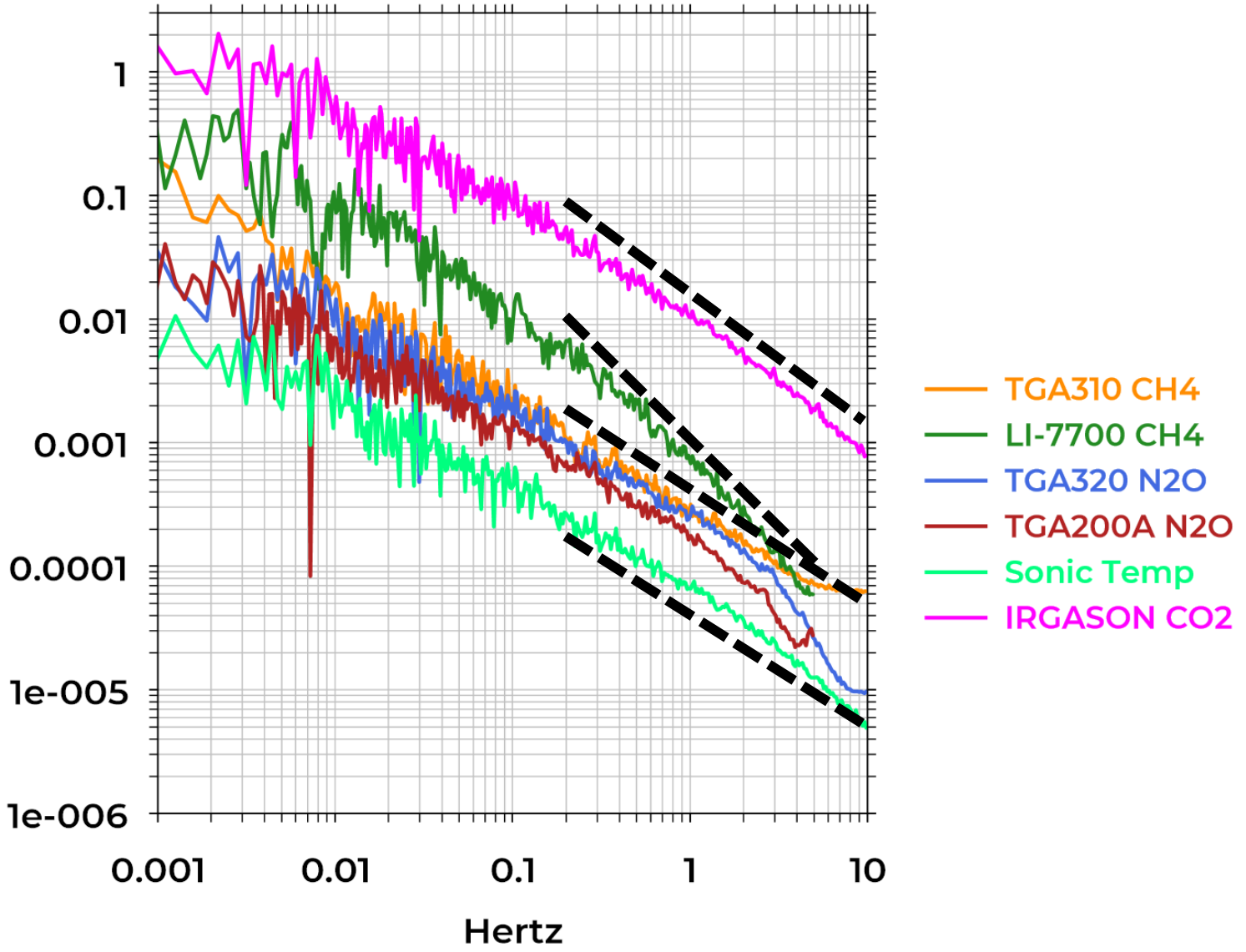
Noise Analysis using Allan Deviation

- Allan deviations computed on a 4-hour interval with no active gas flux
- Results match controlled laboratory experiments
- Minimal noise floor reached at 10-30 seconds
- Drift remains below the noise floor out to at least 30 minutes
- Indicates sufficient stability to not compromise the EC flux calculations



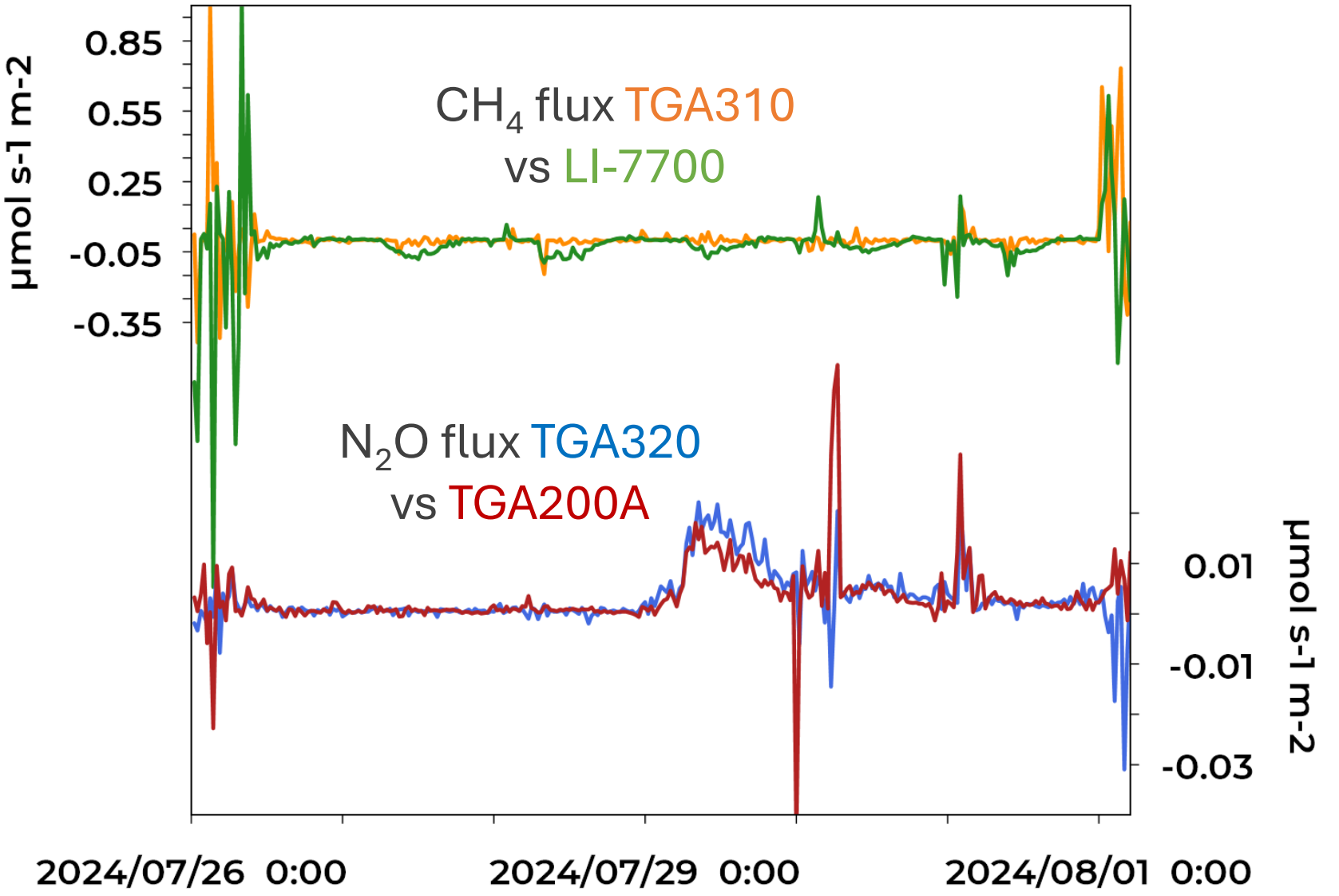
Frequency Response

- Normalized spectra of 4-hour sample with active gas fluxes
- Sonic temperature and IRGASON CO_2 shown as a reference for theoretical turbulent air spectrum with minimal attenuation to 10 Hz
- Open-path LI-7700: exhibits spectral attenuation faster than the reference requiring spectral correction
- Closed-path TGAs: follows the reference spectrum to 3+ Hz before attenuating



Flux Calculations

- One week of fluxes
- Demonstration of reasonable flux results
- Discrepancies attributed to site parameterization, collocation errors, and applied corrections
- Detailed analysis of flux data is ongoing for publication



Summary

- The new TGA300 instrument meets the quality metrics of noise, stability, frequency response
- Aerodynamic footprint was improved
- Field installation, maintenance schedule, and power draw of the TGA300 are competitive or surpass other available instrumentation at the site
- The intake dryer assembly of the TGA sufficiently removes fluctuations of air temperature and water vapor to yield mixing ratio without WPL corrections

References

- Somers, J., Sargent S. (2015) A Novel Low-Power, High-Performance, Zero-Maintenance Closed-Path Trace Gas Eddy-Covariance System with No Water Vapor Dilution or Spectroscopic Corrections, AGU Fall Meeting Poster B33C-0668.
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