A Cavity-Enhanced Ultraviolet Absorption Instrument for High-Precision, Fast Time-Response Ozone Measurements

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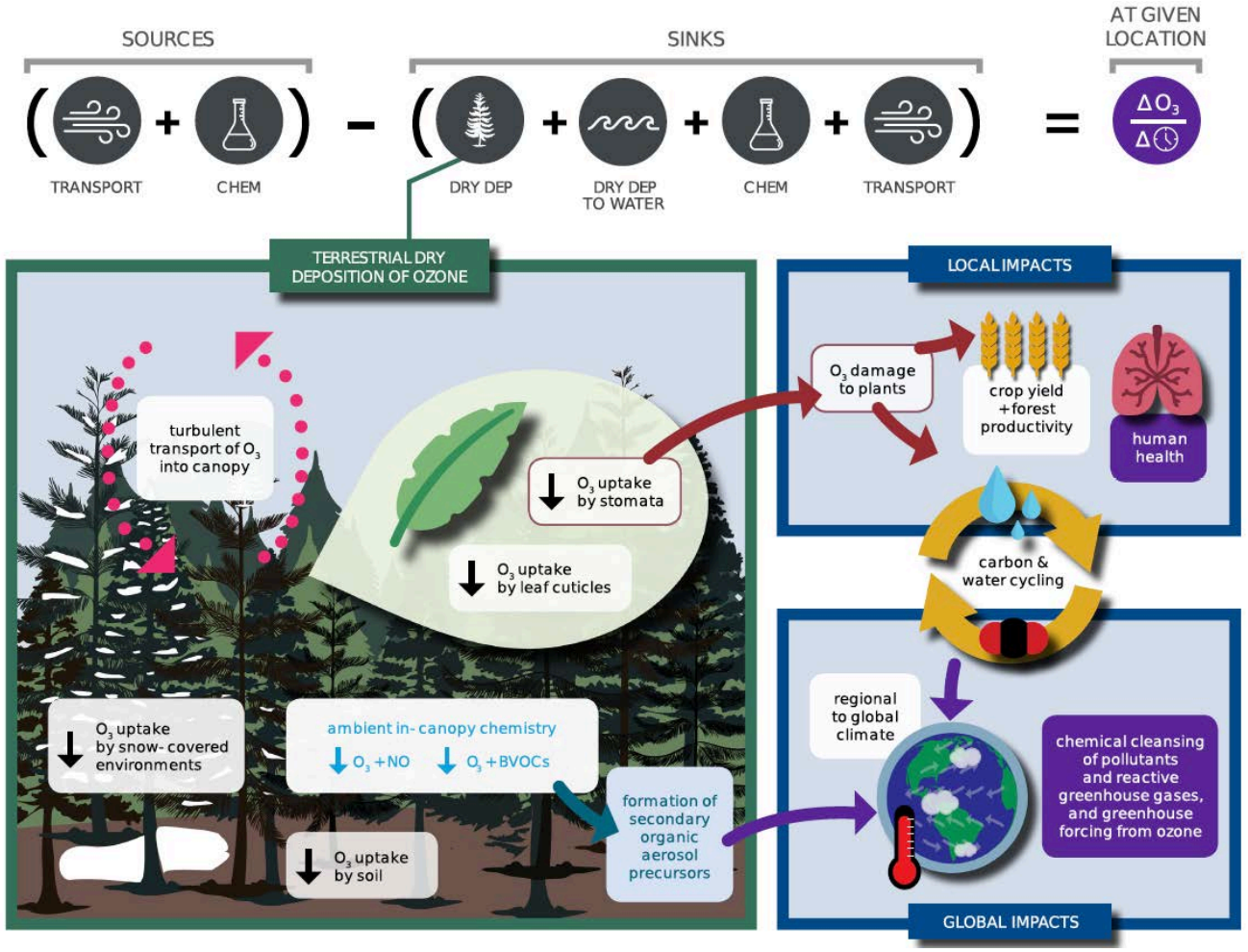
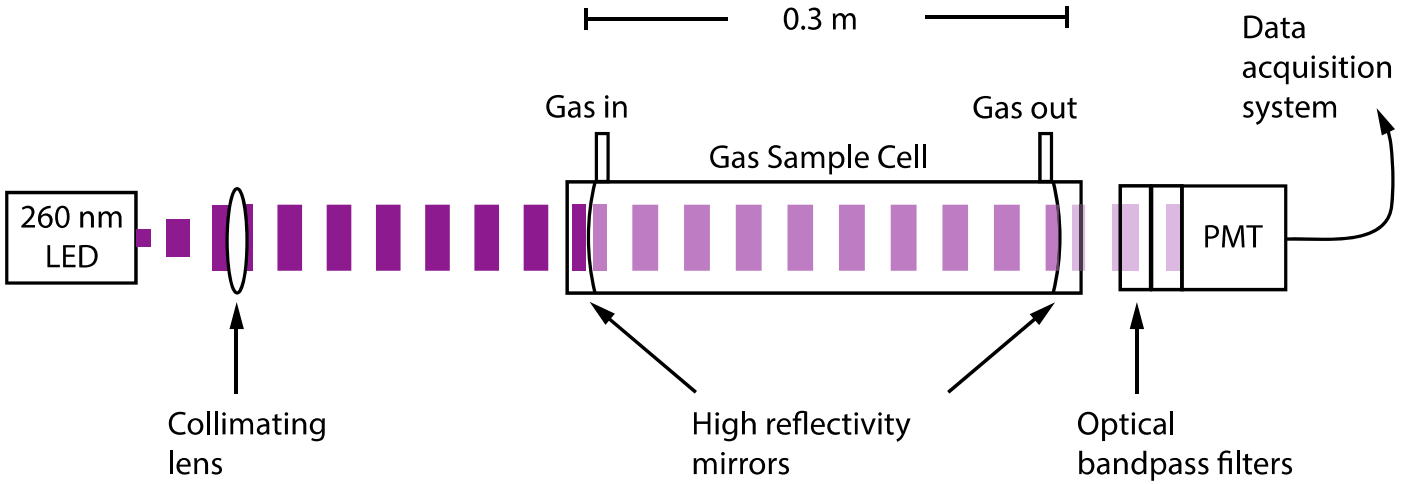
Motivation

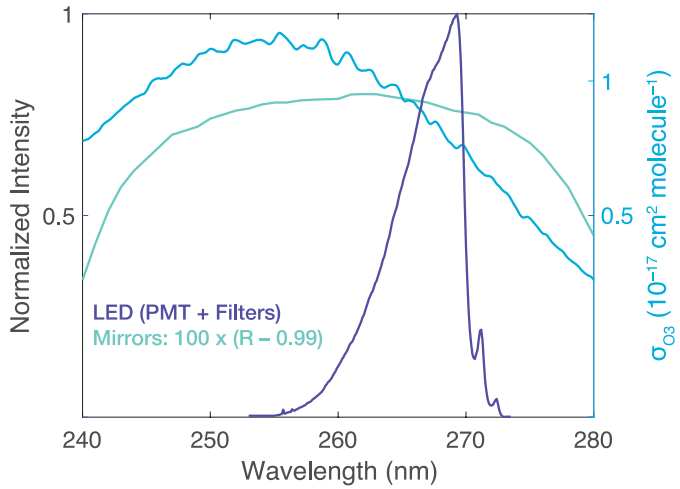
- Ozone dry deposition of ozone is an important loss mechanism
  - Models need accurate representations to predict transport
  - Deposition impacts plant health and crop yields
- Airborne eddy-covariance flux measurements require fast 1 – 10 Hz measurements of ozone with precision ~ 0.1 ppb/s.
- Chemiluminescence can achieve this sensitivity, but instrument is complicated and labor intensive



Approach

Develop compact, semi-autonomous UV absorption instrument with precision comparable to Chemiluminescence





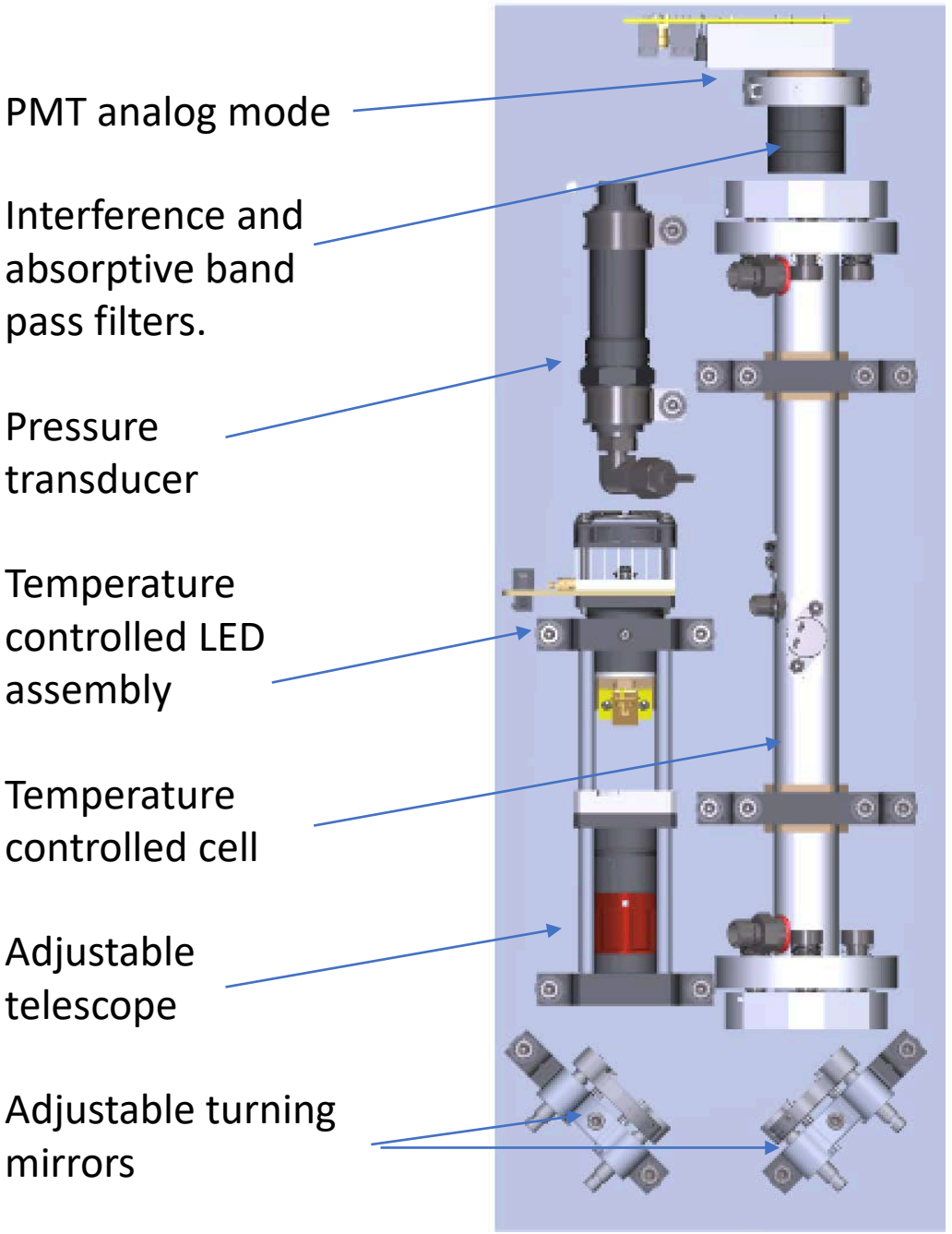
The technique is similar to common cavity-based designs. Effective pathlength ~ 100m.

Optical Design features

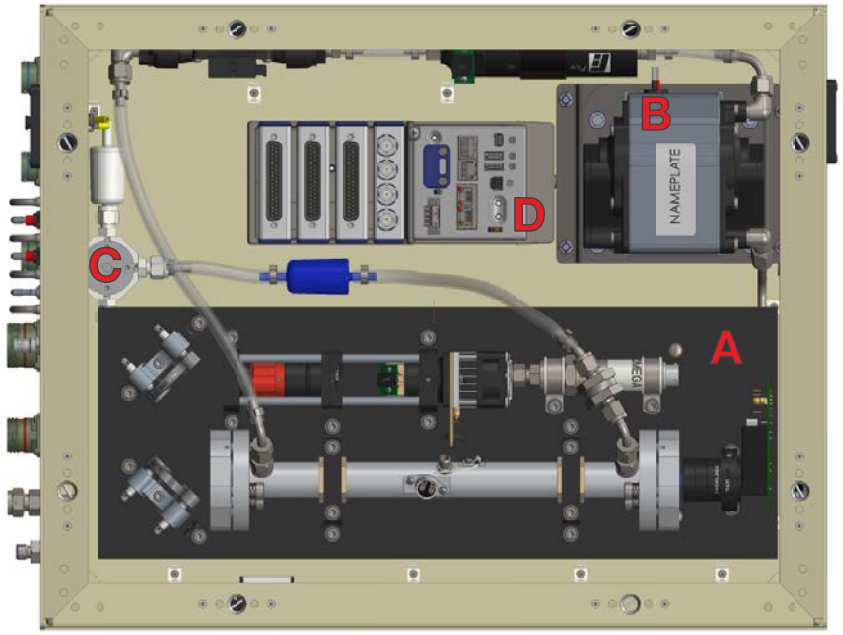
Mirror R ~ 99.7%
The optical cell is ~ 100 m effective optical path length.

Fixed mirrors in the cell.
No adjustment is needed.

Detection volume ~ 35 cm^3.
Flow rate ~ 300 cm^3/s.
Dispersed flow to minimize pulsing and dead volume.



Instrument Design: Rapid Ozone Experiment (ROZE)

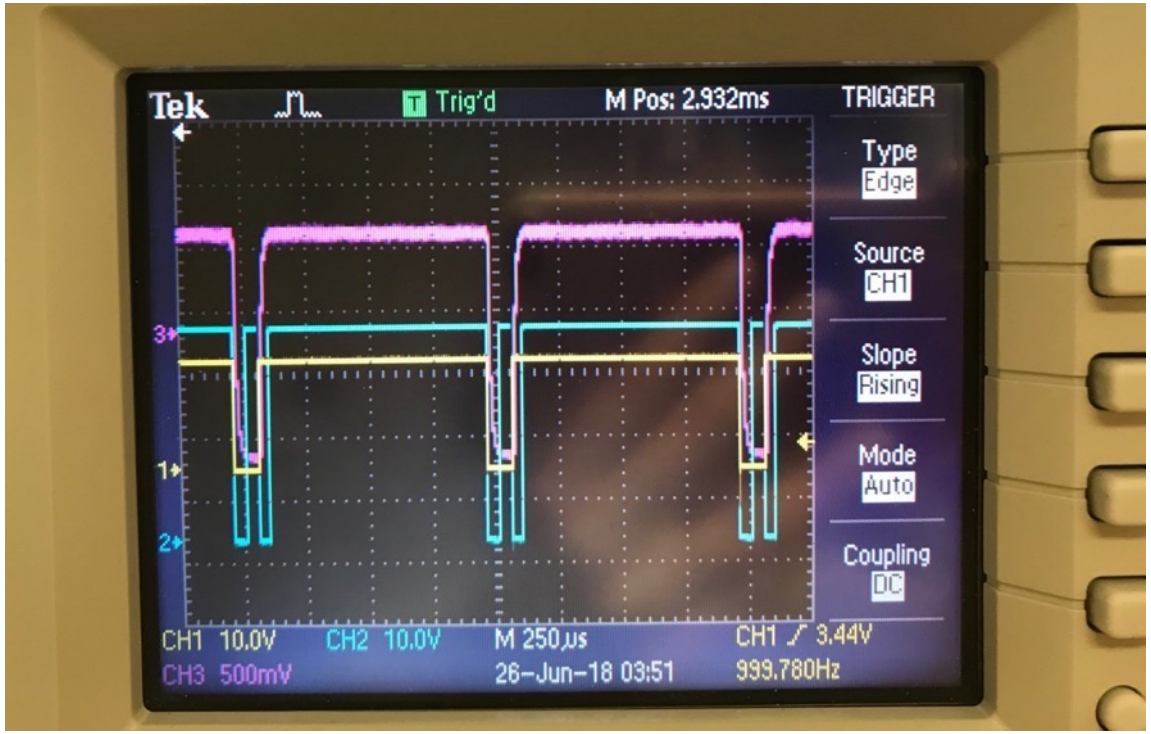


Specification	Value
Size	60 x 44 x 18 cm
Weight	19 kg
Power	< 200 W
Data rate	10 Hz
Precision (1σ-1s)	6.7 x 10^8 molec. cm^{-3}
Accuracy	6.2%
Time response	50 ms

ROZE is thermal vacuum tested up to 70 kft

Operated from –20 °C to > 40 °C

Data Acquisition



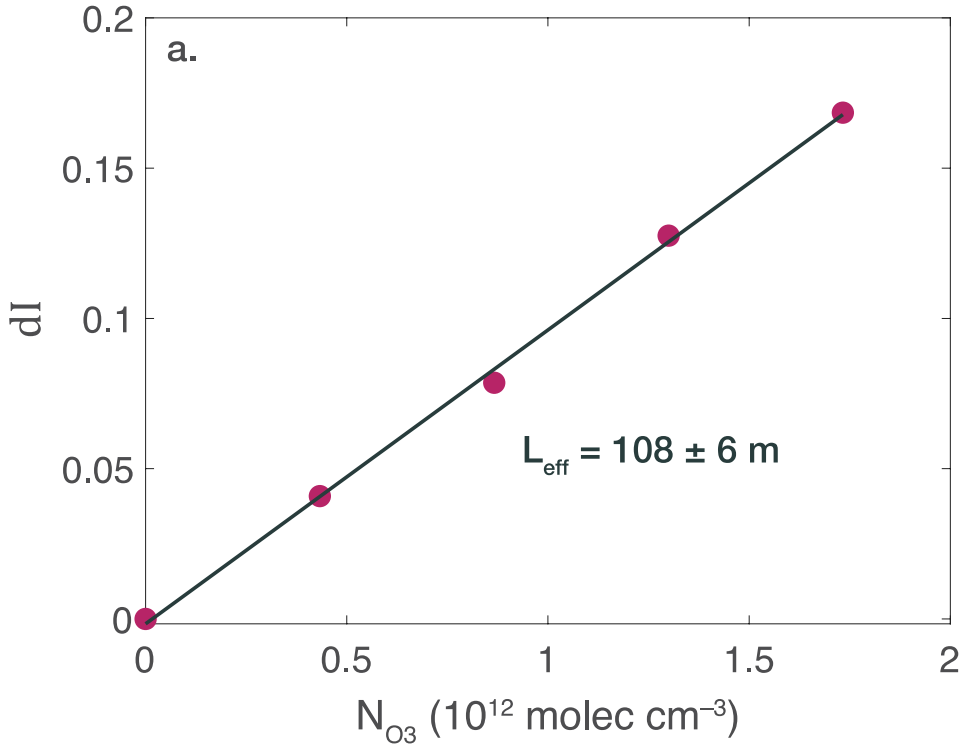
Yellow: LED Modulate signal (90% duty cycle, 1 kHz)

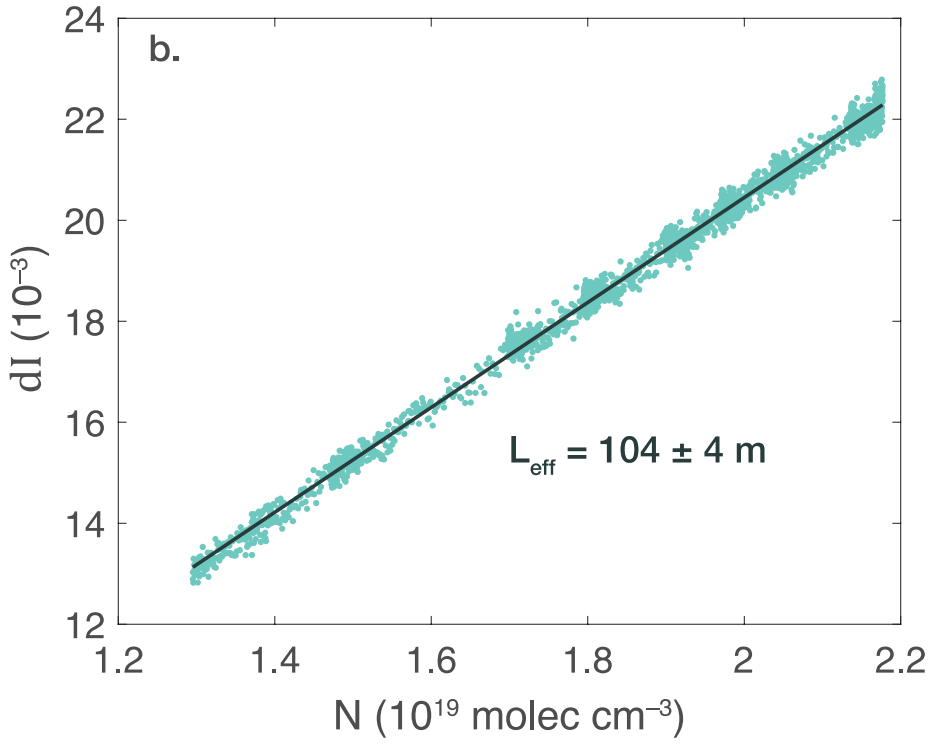
Pink: Amplified PMT signal

Blue: Averaging windows for LED ON and OFF

Signal = Mean(ON) – Mean(OFF)
1 kHz averaged to 10 Hz

Calibration

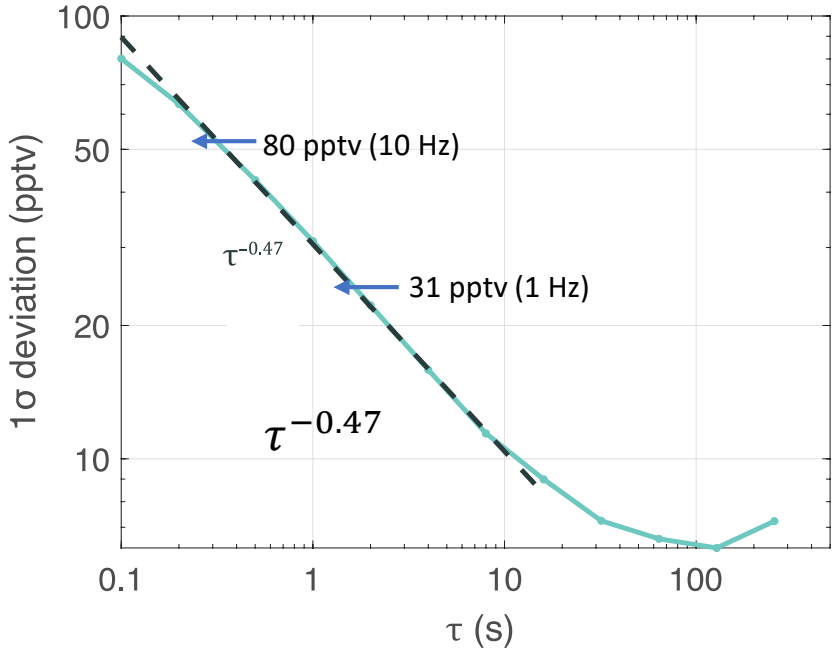


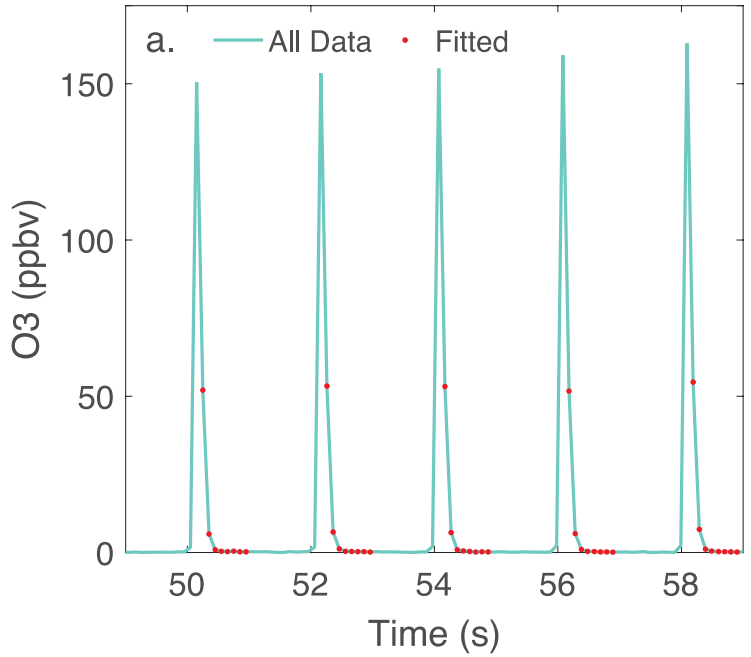


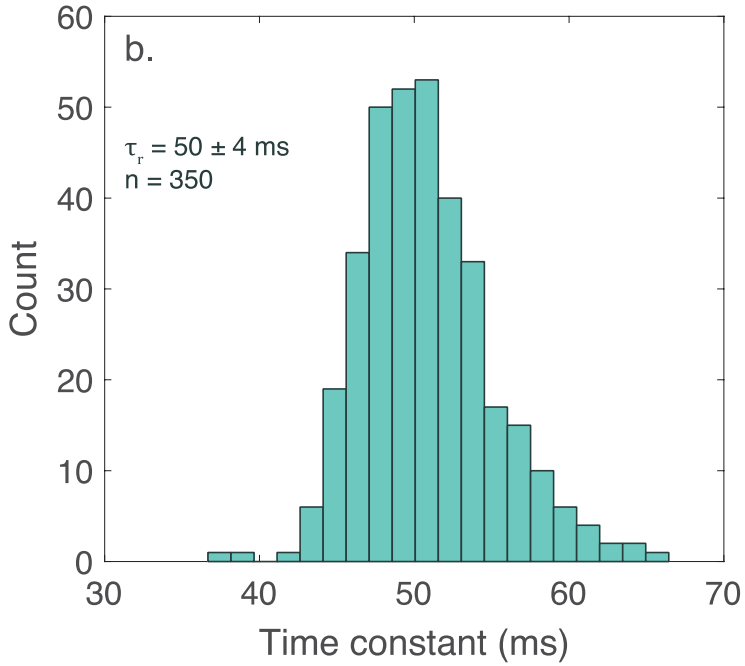
OZONE: calibration using commercial (2Btech) ozone source

Air: calibration using air (Rayleigh scattering extinction)

Precision and Time response





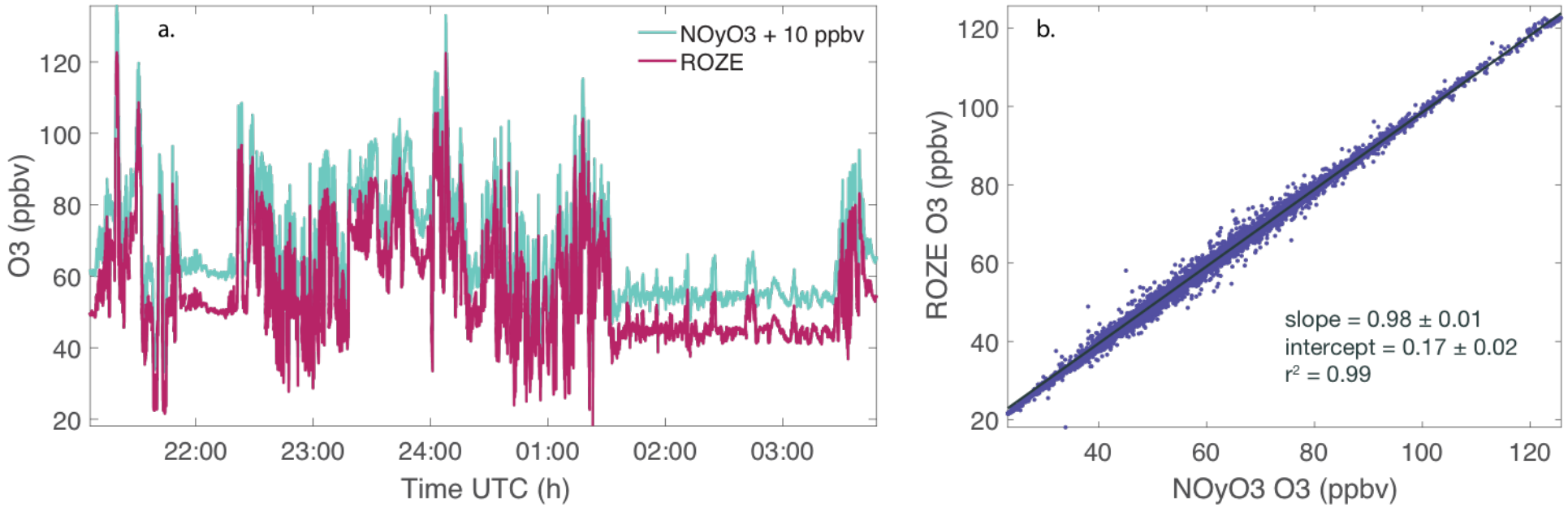


Allan deviation plot for 1.5 hr of sampling zero air at constant pressure (944 mbar).

ROZE time response: High ozone air was injected into the flow system via a pulsed valve (10 ms open time) with a sample flow of 18 SLM.

Field Demonstration

FIREX-AQ July 30, 2019

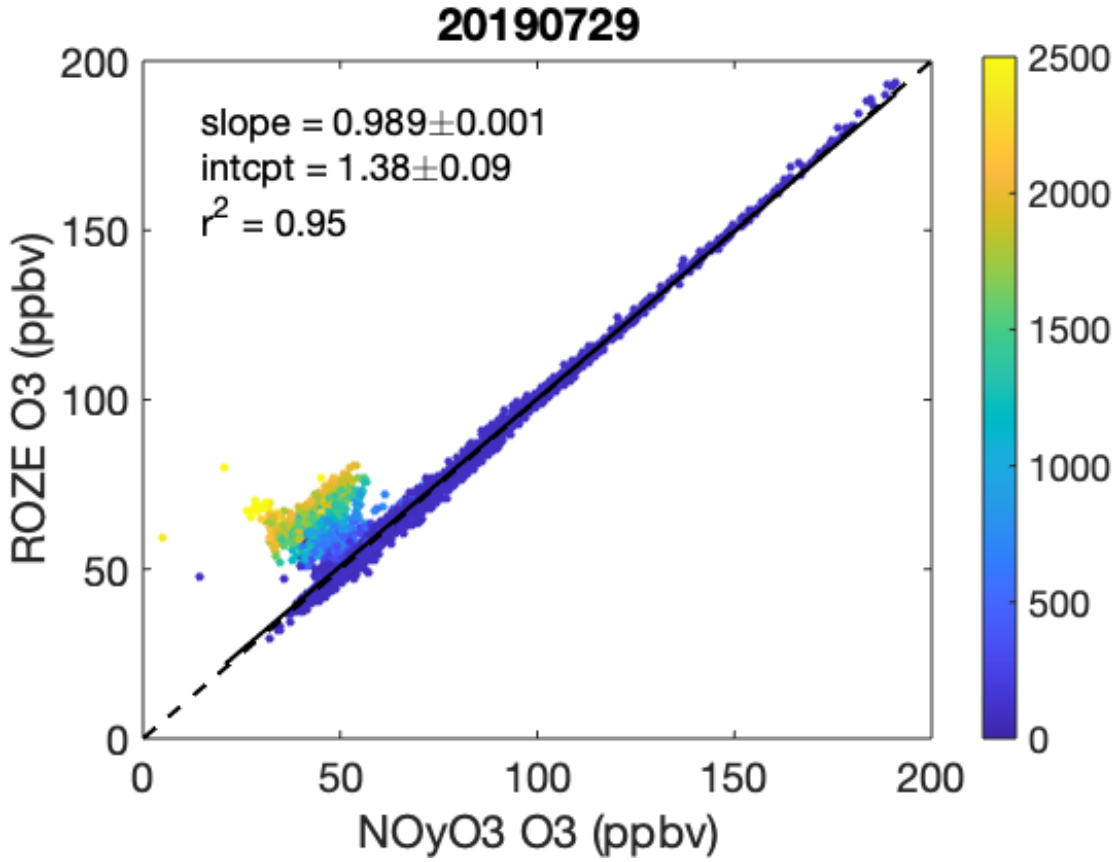


ROZE and NOyO3 measurements of O3 from the FIREX-AQ field campaign averaged to 1 second. For 14 other FIREX-AQ flights, slopes ranged from 0.96–1.04.

NOyO3 data courtesy of T. Ryerson

Field Demonstration: Interference

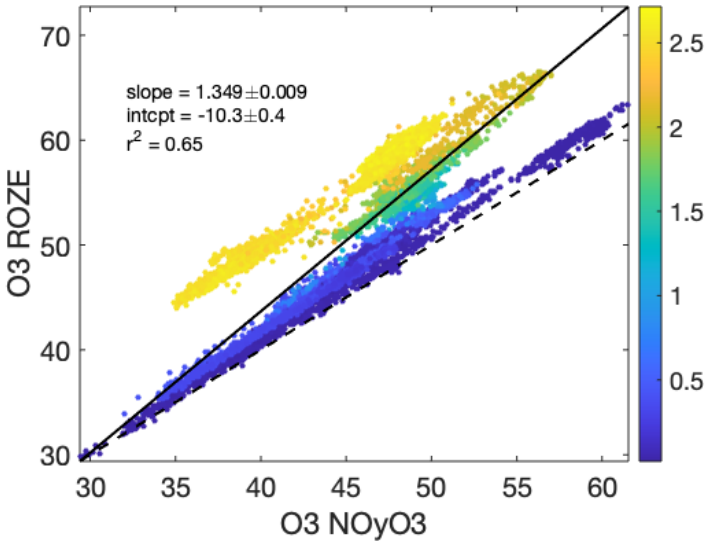
July 29 flight from Boise, ID to Northwestern forest wildfires

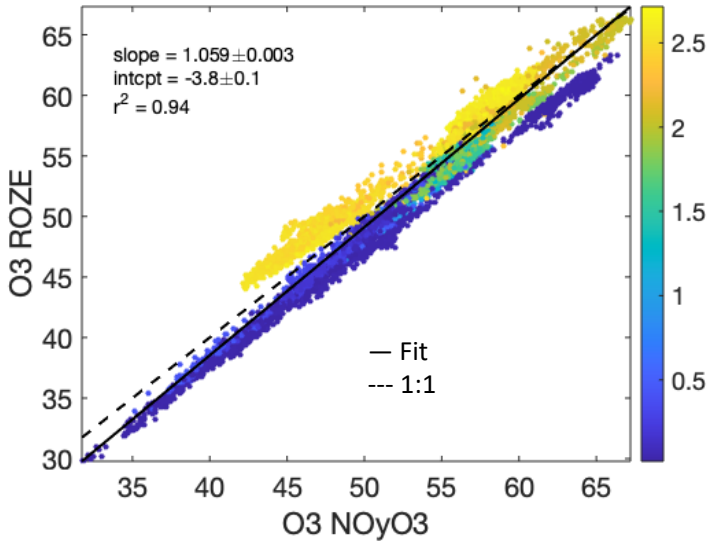


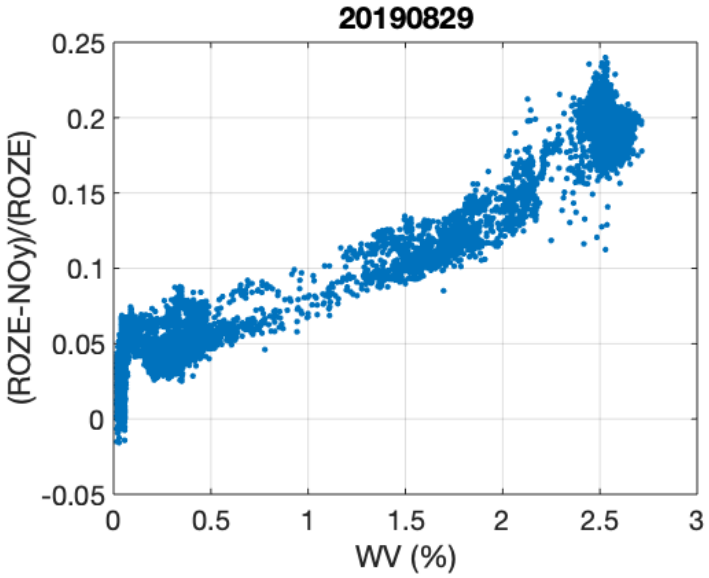
ROZE is subject to interference from UV-active species (e.g., aromatic hydrocarbons, SO_2). Figure colored by CO mixing ratio (ppbv) to indicate smoke.

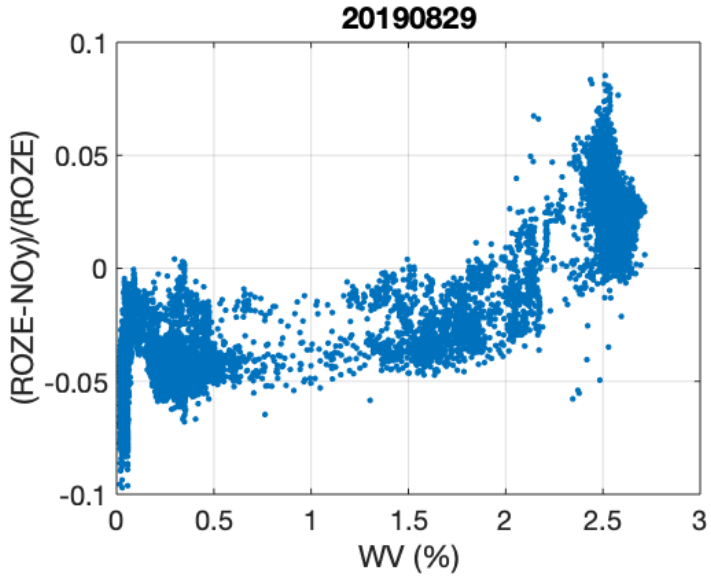
Field Demonstration: remaining biases

Aug 29 flight from Salina, KS flight over KS, NE, OK tallgrass prairie fires









Left: Prior to CL water-quenching correction (RA)

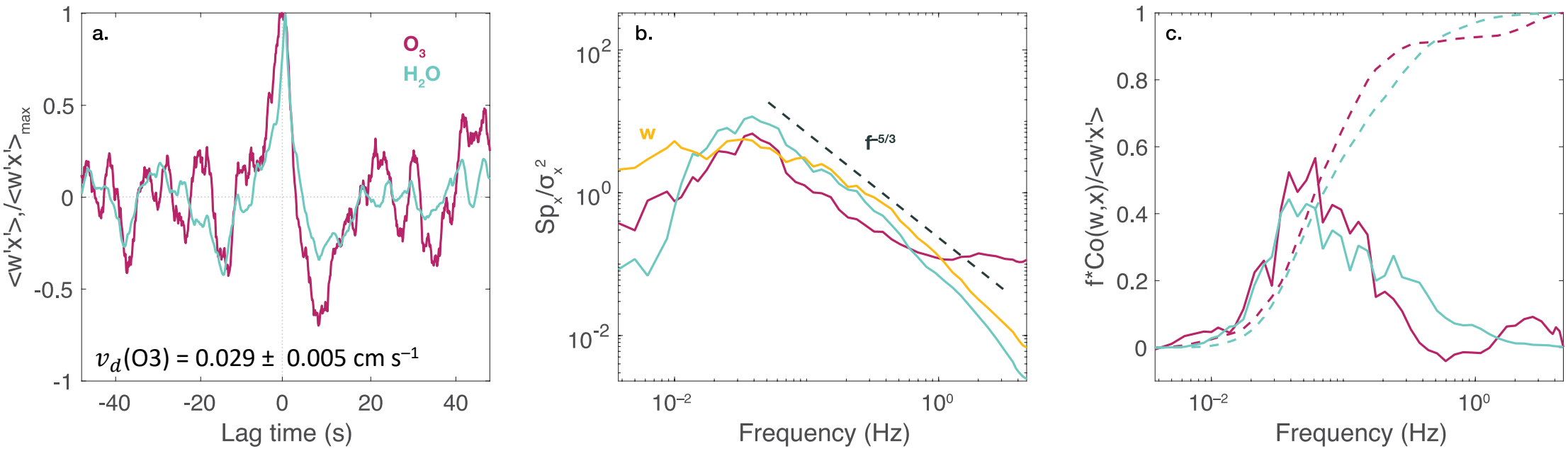
Right: post-correction (R0)

All plume data filtered out

DLH data courtesy of G. Diskin

Eddy covariance fluxes

SARP/FIREX-AQ July 17, 2019 Pacific Ocean, Altitude = 170 m



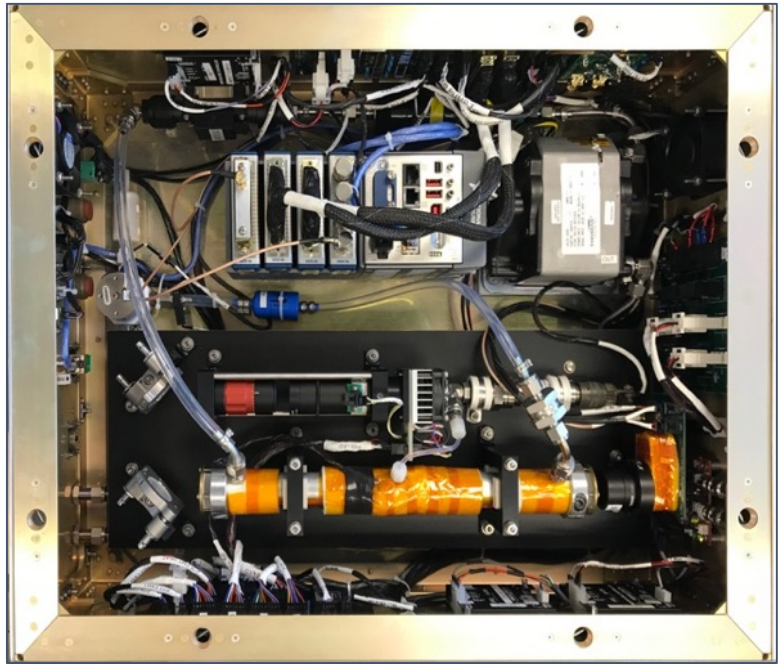
Example spectra from a 50 km flux leg: a) Vertical wind-scalar cross covariance functions; b) Power spectra, normalized to total variance; c) Co-spectral power of O3 and H2O with vertical wind (solid) and repective ogives (dashed).

MMS data courtesy of Paul Bui

ROZE Pictures

ROZE on DC-8 rack

Top view



Instrument front panel

Thanks!

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Preprints

Abstract | Discussion | Metrics

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Review status
This preprint is currently under review for the journal AMT.

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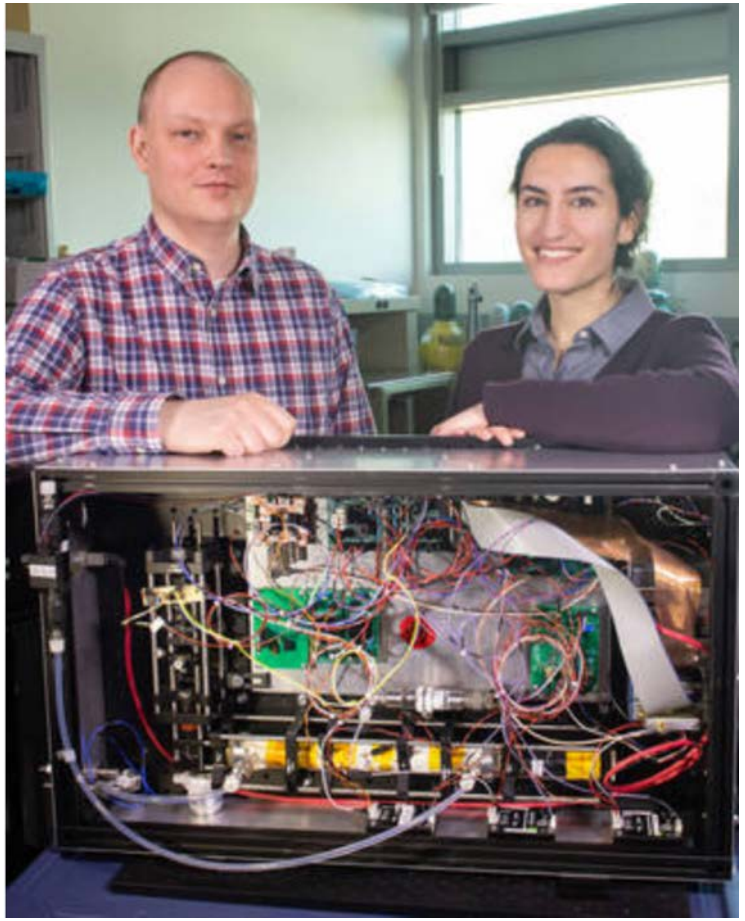

Reem Hannun and Andrew Swanson with the ROZE breadboard prototype