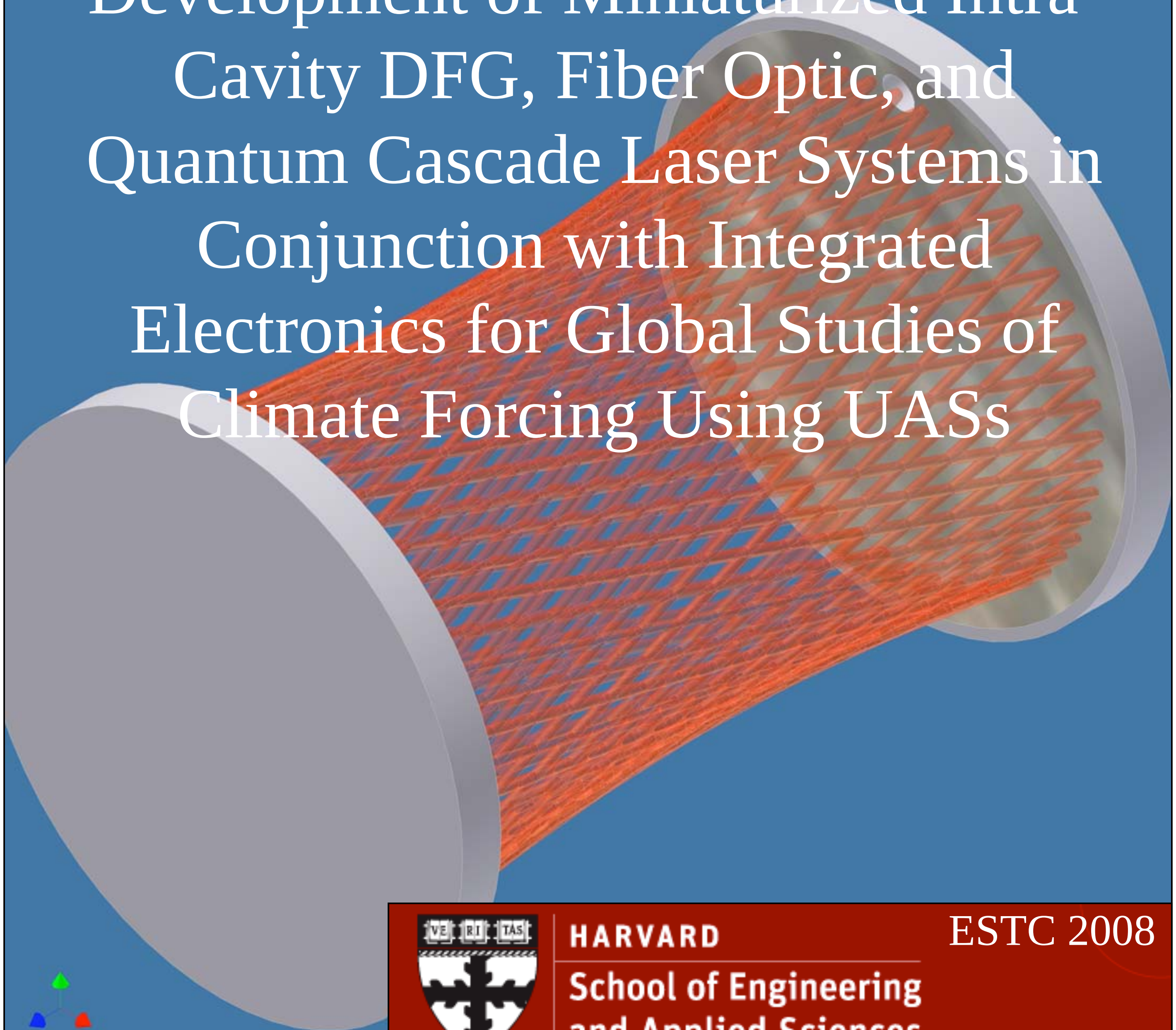
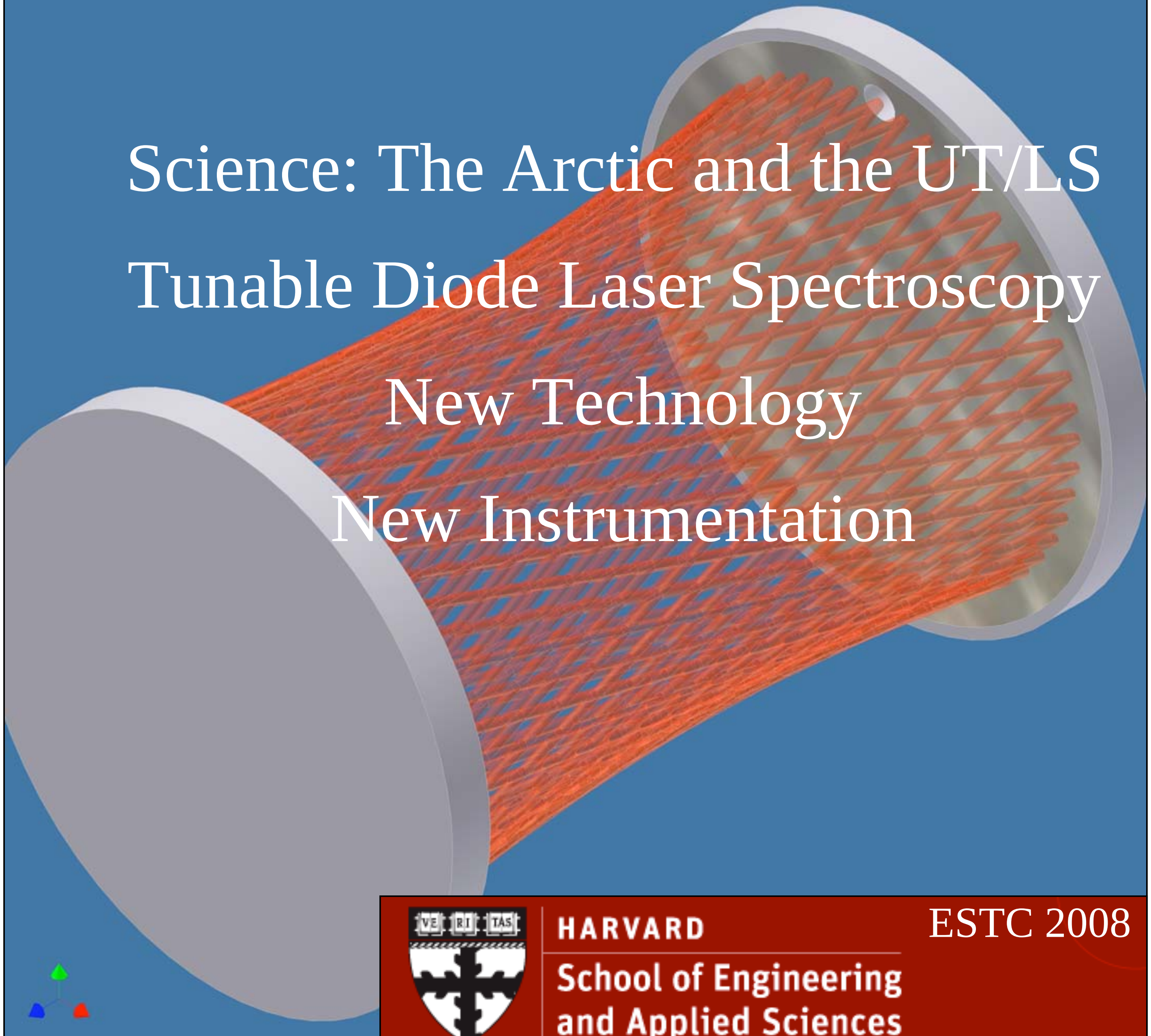
Development of Miniaturized Intra-Cavity DFG, Fiber Optic, and Quantum Cascade Laser Systems in Conjunction with Integrated Electronics for Global Studies of Climate Forcing Using UASs



HARVARD
School of Engineering and Applied Sciences

ESTC 2008



Science: The Arctic and the UT/LS

Tunable Diode Laser Spectroscopy

New Technology

New Instrumentation

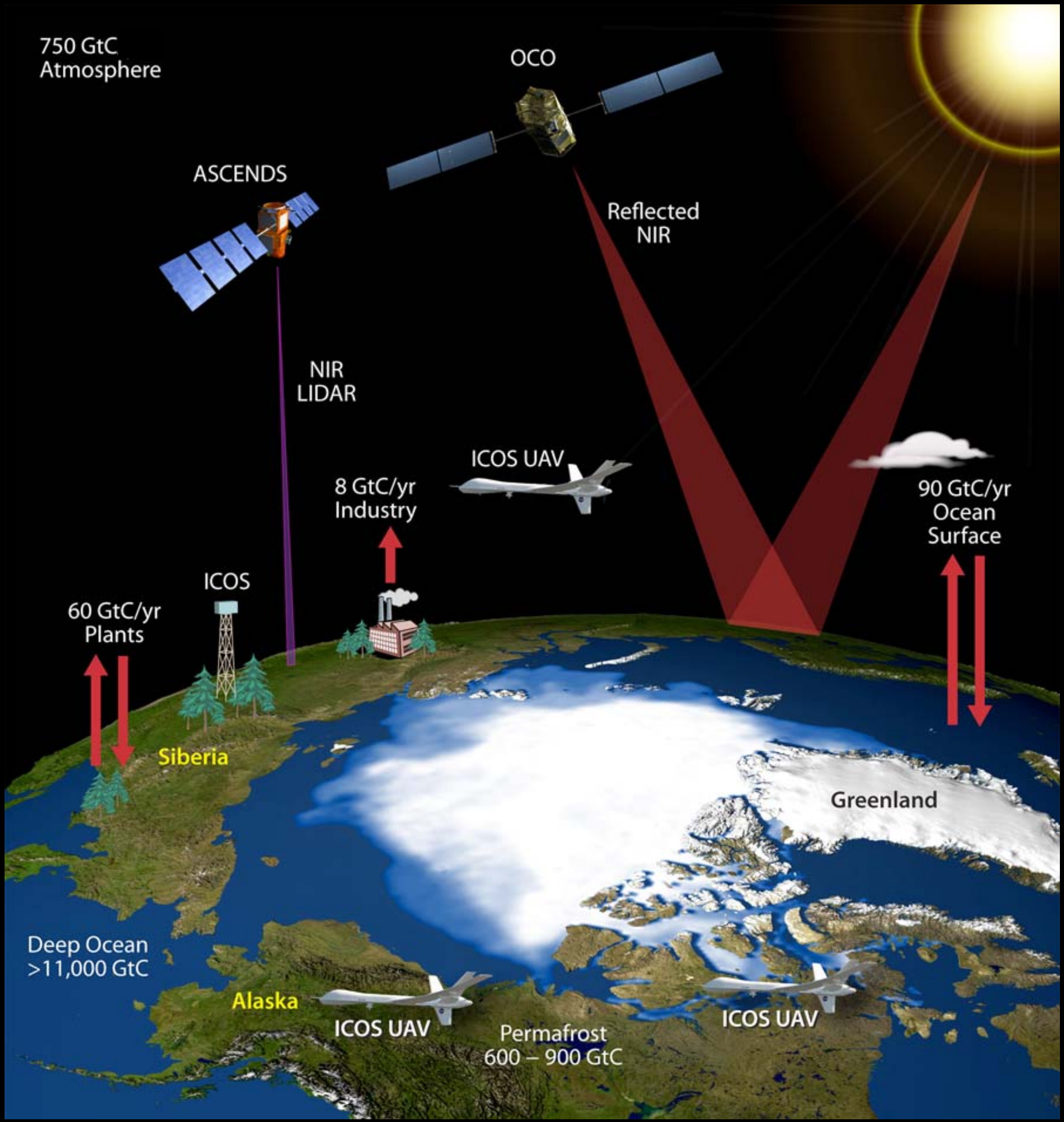
HARVARD
School of Engineering and Applied Sciences

ESTC 2008

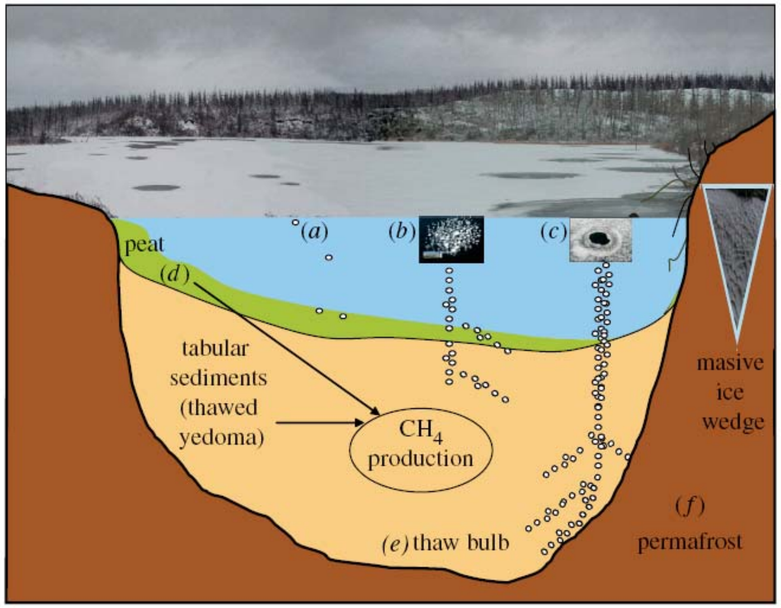
The Advanced Microwave Scanning Radiometer (AMSR-E) is a high-resolution passive microwave Instrument on NASA's Aqua satellite. AMSR-E provides a remarkably clear view of sea ice dynamics in greater detail than has ever been seen before. Researchers use this information to study polar bear habitats, plan expeditions to the ice, and to study the interactions between the ocean and sea ice from season to season. This data visualization shows Arctic sea ice from Jan. 1, 2007 to Sept. 16, 2007.

At the end of each summer, the sea ice cover reaches its minimum extent and the ice that remains is called the perennial ice cover, which consists mainly of thick multi-year ice floes. The area of the perennial ice has been steadily decreasing since the satellite record began in 1979, at a rate of about 10% per decade. But the 2007 minimum, reached around Sept. 14, is far below the previous record made in 2005 and is about 38% lower than the climatological average. This data visualization shows the annual sea ice minimum from 1979 through 2007.

High Latitude CO_2 / CH_4 Release



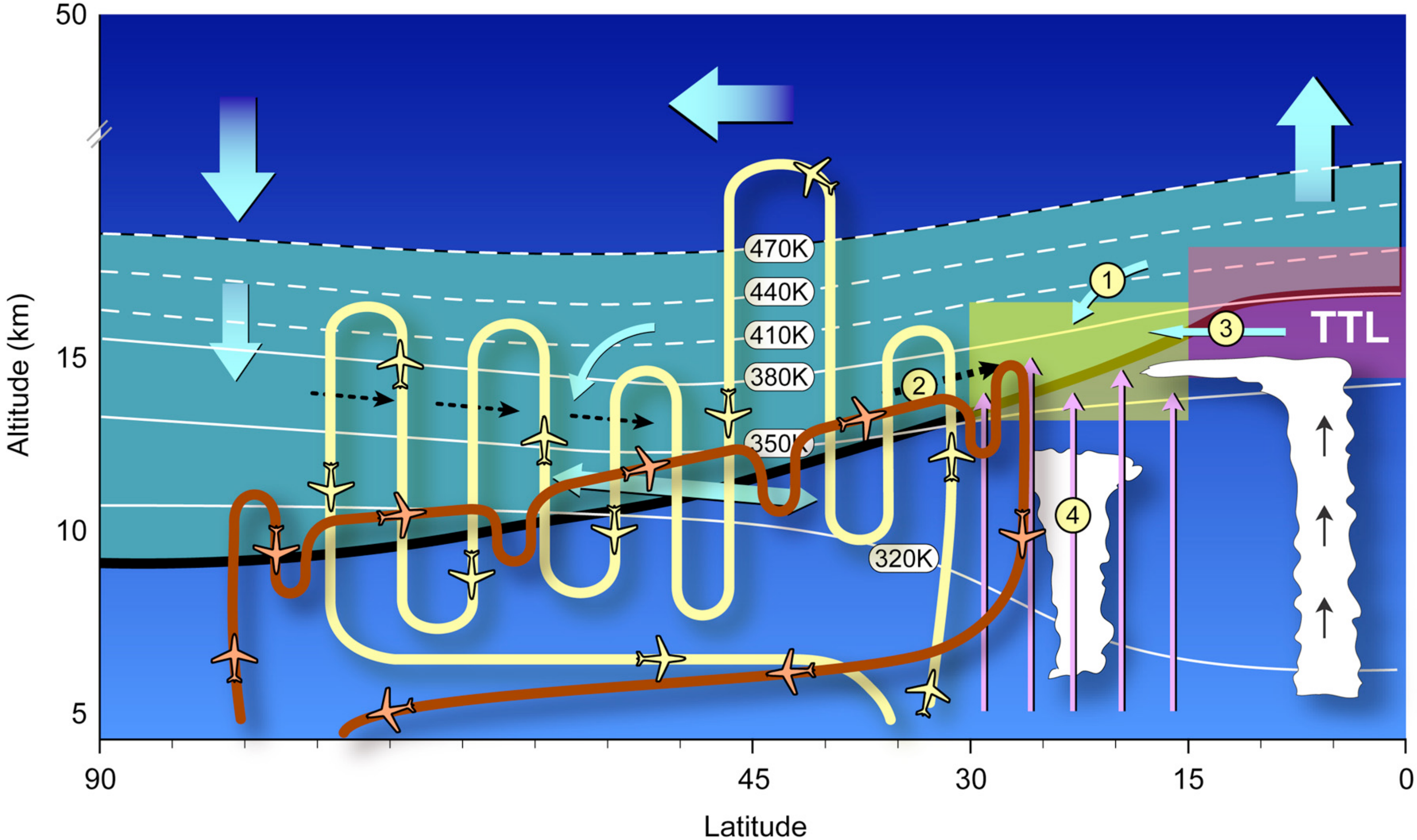
High Latitude CO_2 / CH_4 Release



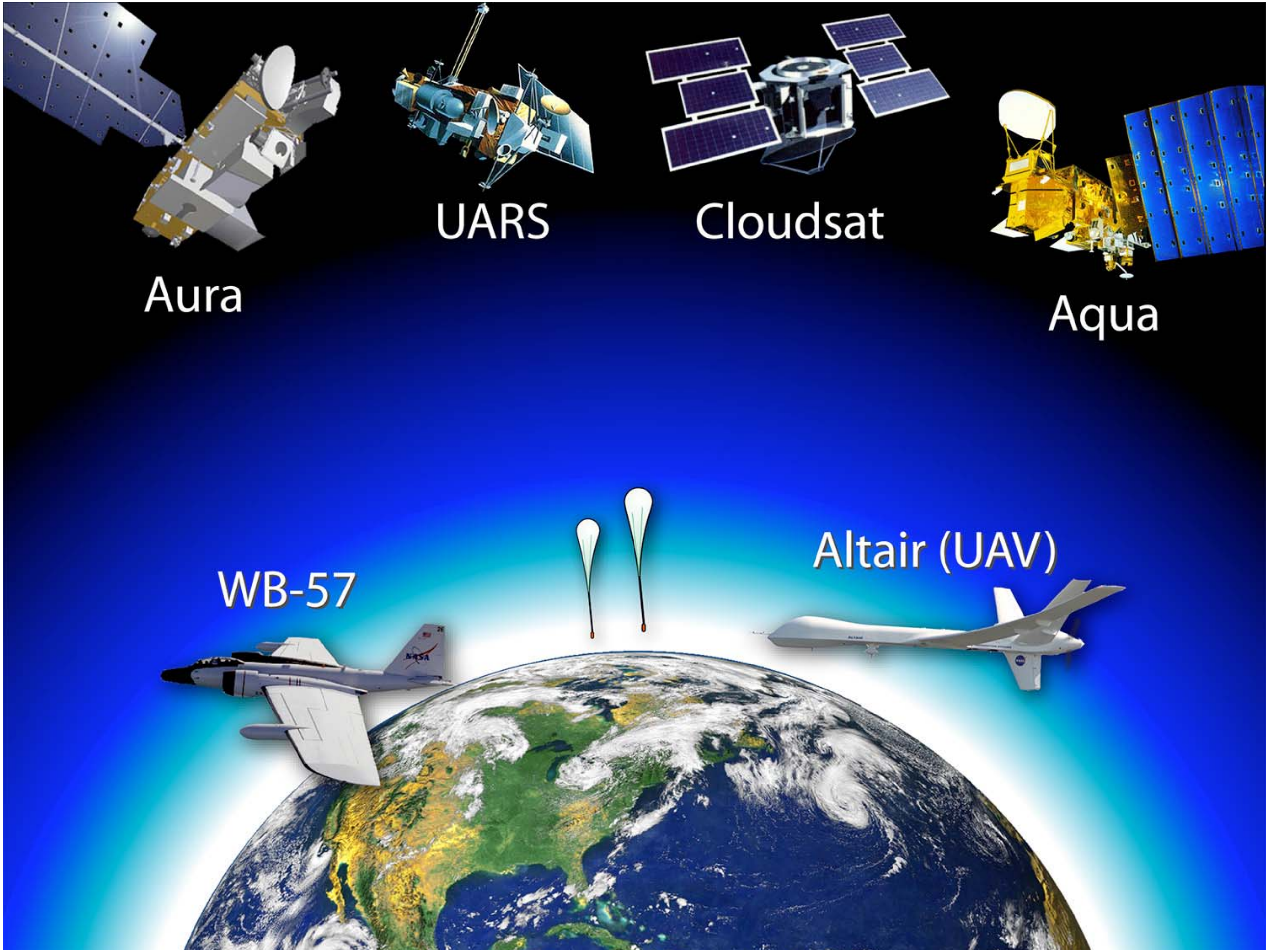
CH_4 Bubbles Trapped in Lake Ice in October

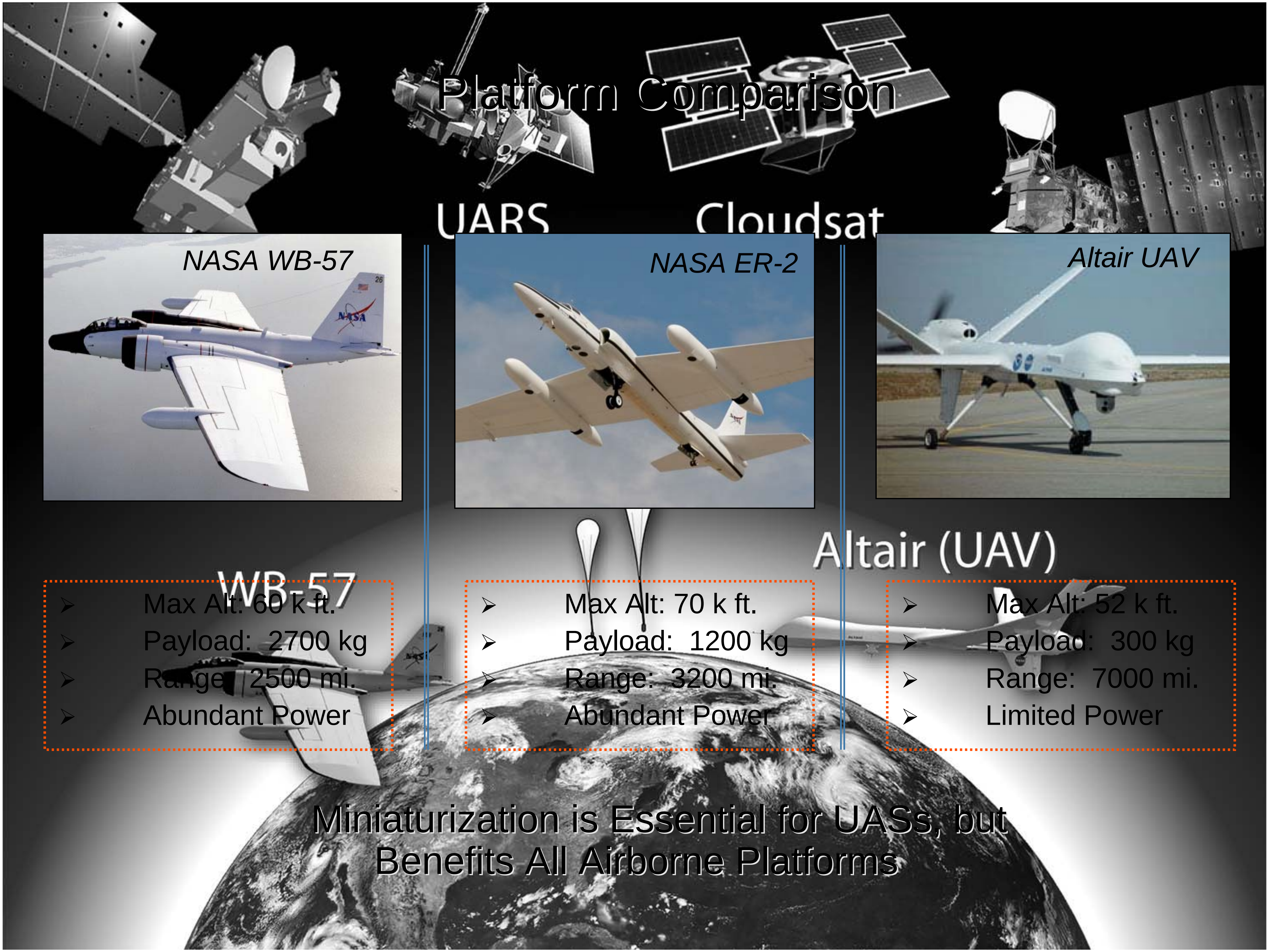
Prof. K. Walter Igniting CH_4 in Alaskan Lake

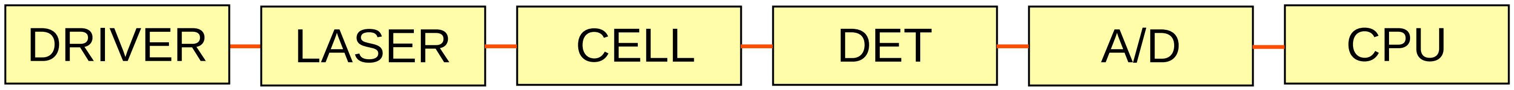
Upper Troposphere/Lower Stratosphere (UT/LS) Transport

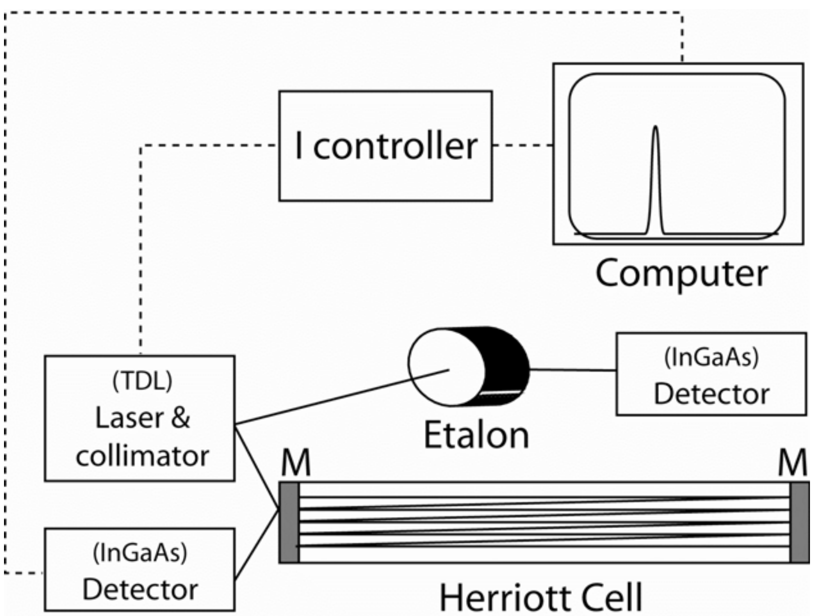


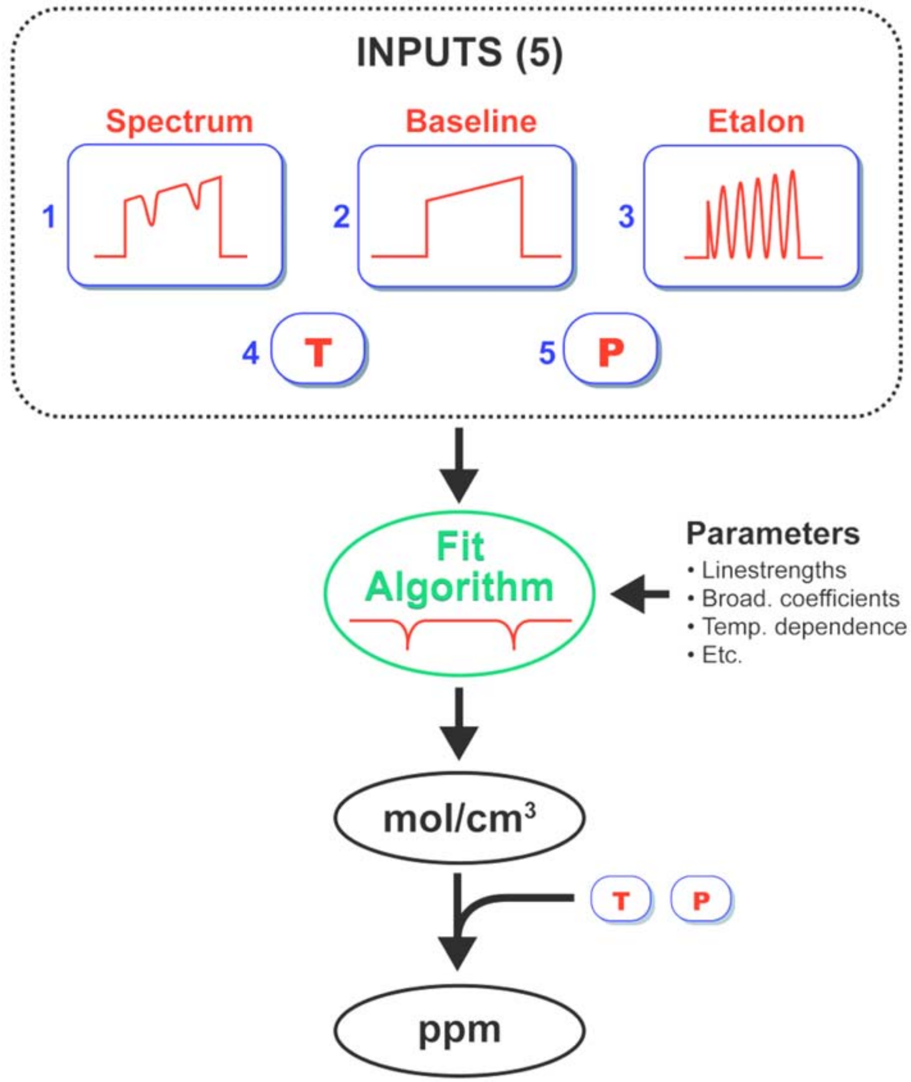
Tracer data (O_3, CO_2, CO, HDO/H_2O, NO_y, N_2O, CH_4, halogen source molecules) are used to quantify the extent of horizontal mixing and entrained ambient air and to pin the pattern of the age of the air


Aura
UARS
Cloudsat
Aqua
WB-57
Altair (UAV)


Platform Comparison
UARS
Cloudsat
NASA WB-57
NASA ER-2
Altair UAV
Altair (UAV)
WB-57
Max Alt: 60 k ft.
Payload: 2700 kg
Range: 2500 mi.
Abundant Power
Max Alt: 70 k ft.
Payload: 1200 kg
Range: 3200 mi.
Abundant Power
Max Alt: 52 k ft.
Payload: 300 kg
Range: 7000 mi.
Limited Power
Miniaturization is Essential for UASs, but
Benefits All Airborne Platforms

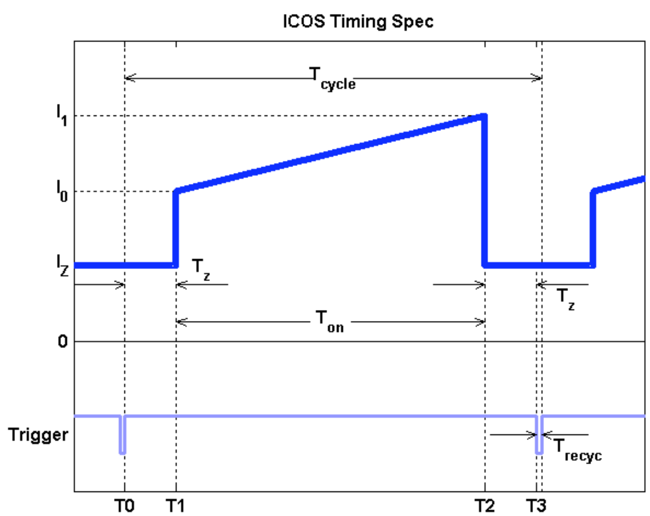

DRIVER
LASER
CELL
DET
A/D
CPU

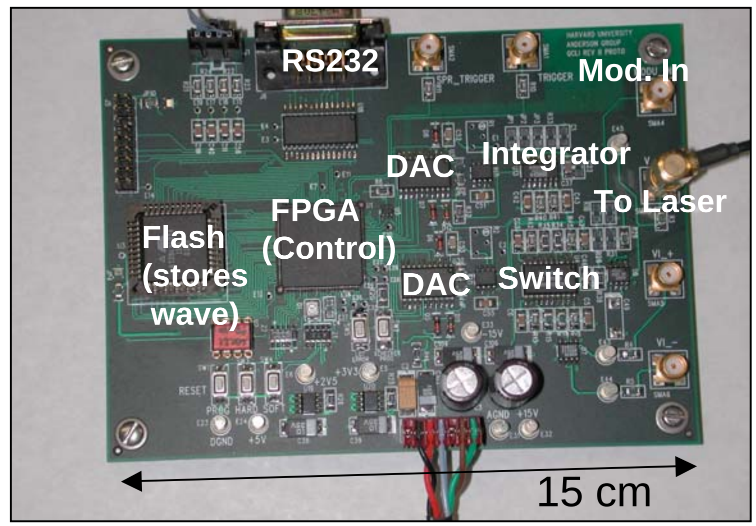

I controller
Computer
(TDL)
Laser &
collimator
Etalon
(InGaAs)
Detector
M
M
(InGaAs)
Detector
Herriott Cell


INPUTS (5)
Spectrum
Baseline
Etalon
1
2
3
4
T
5
P
Fit
Algorithm
Parameters
• Linestrengths
• Broad. coefficients
• Temp. dependence
• Etc.
mol/cm3
T
P
ppm

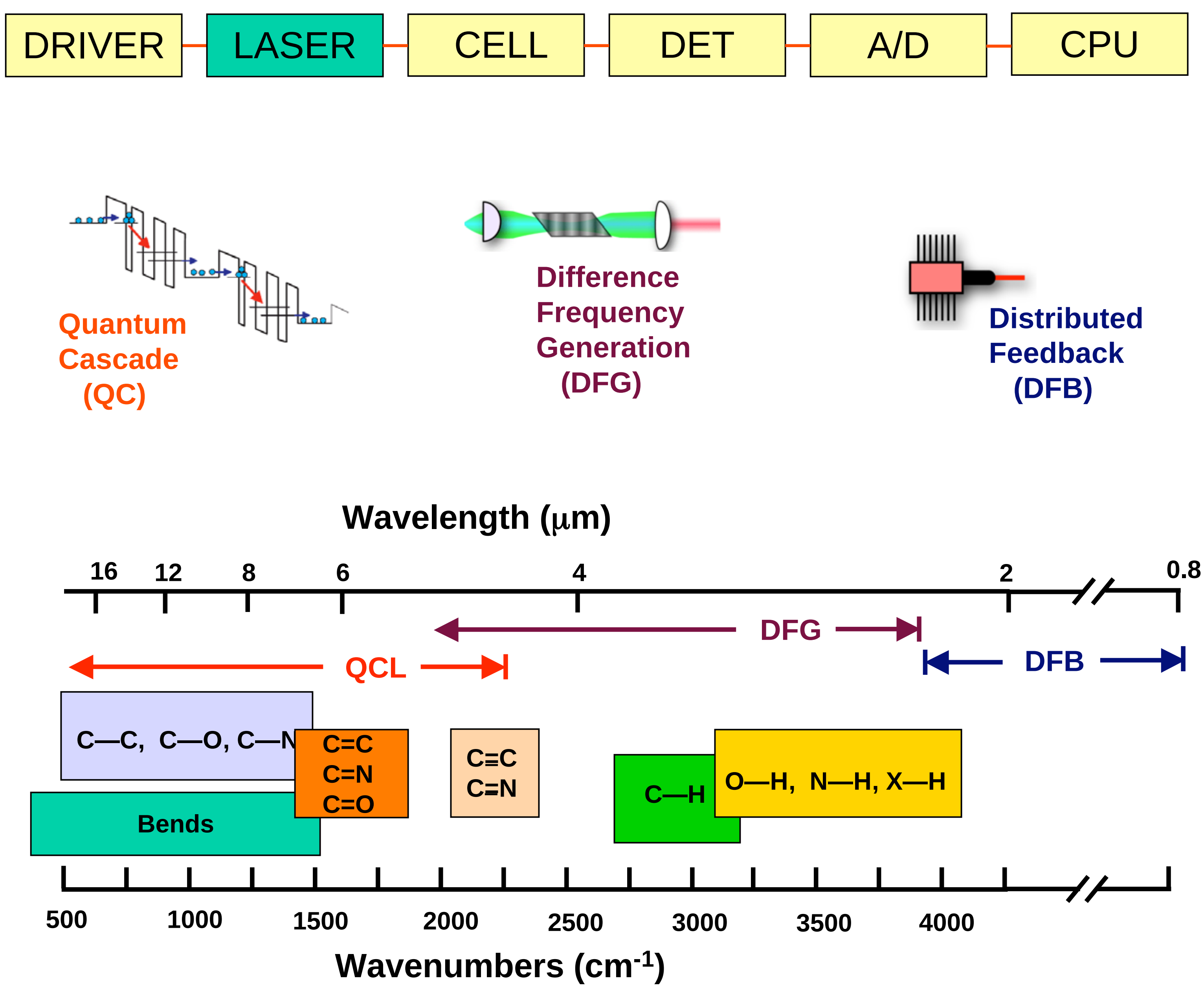
DRIVER — LASER — CELL — DET — A/D — CPU

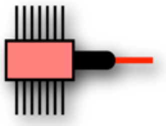
The QCLI is responsible for producing arbitrary waveforms for ICOS, CRDS, and traditional TDLAS





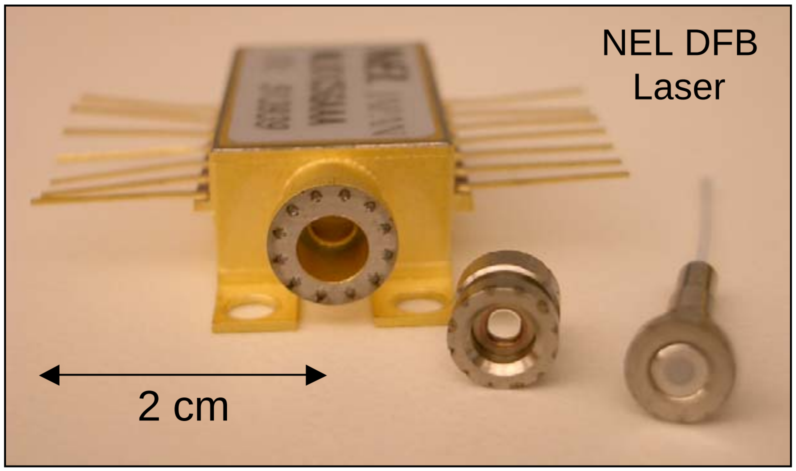
- True Analog Waveforms
- Current Noise < 50 μA (RMS)
- Laser Temperature Interlock
- Flight Tested in Stratosphere

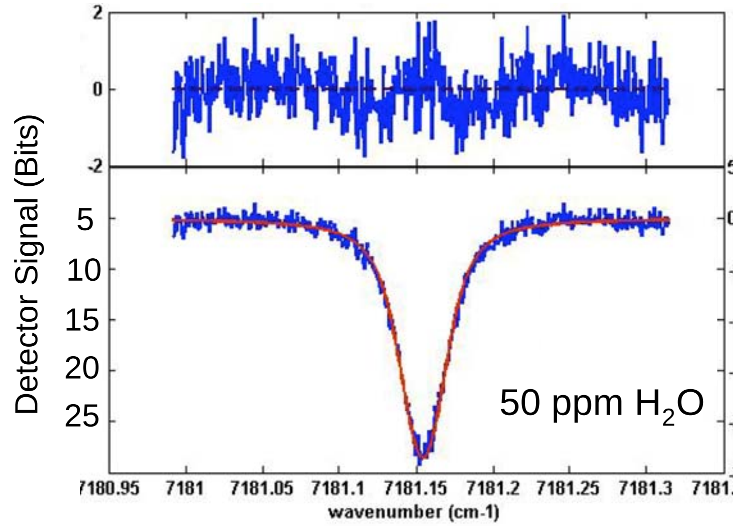

DRIVER
LASER
CELL
DET
A/D
CPU
Quantum Cascade (QC)
Difference Frequency Generation (DFG)
Distributed Feedback (DFB)
Wavelength (μm)
16
12
8
6
4
2
0.8
DFG
QCL
DFB
C—C, C—O, C—N
C=C
C=N
C=O
C≡C
C≡N
C—H
O—H, N—H, X—H
Bends
500
1000
1500
2000
2500
3000
3500
4000
Wavenumbers (cm-1)



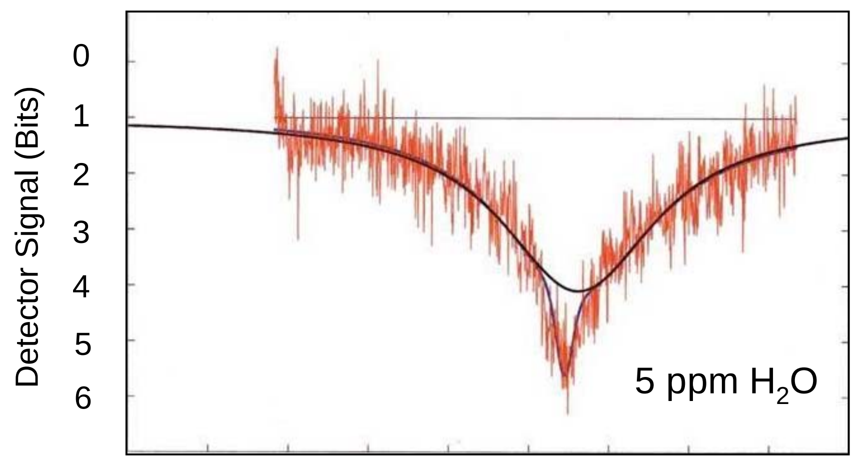
Distributed Feedback (DFB)

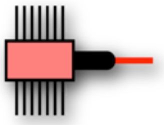
LASER — CELL — DET — A/D — CPU





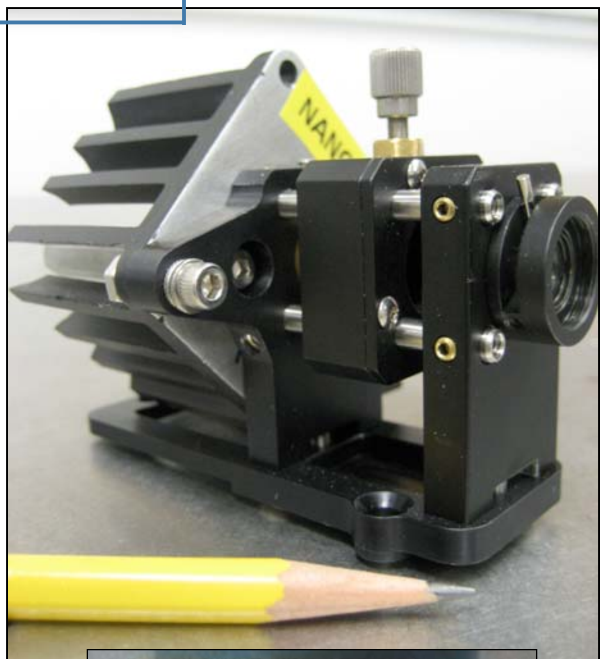
- COTS Laser (NEL)
- 1.39 μm, 10 mW
- Fiber Coupled
- Single Frequency

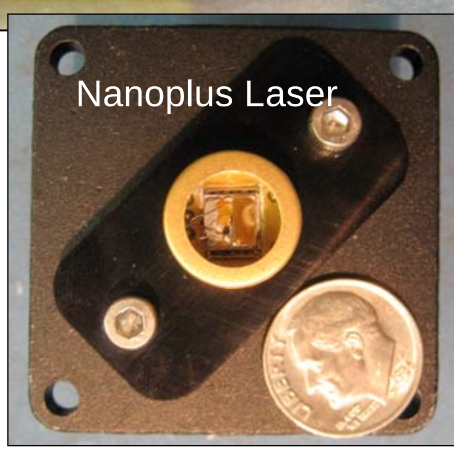


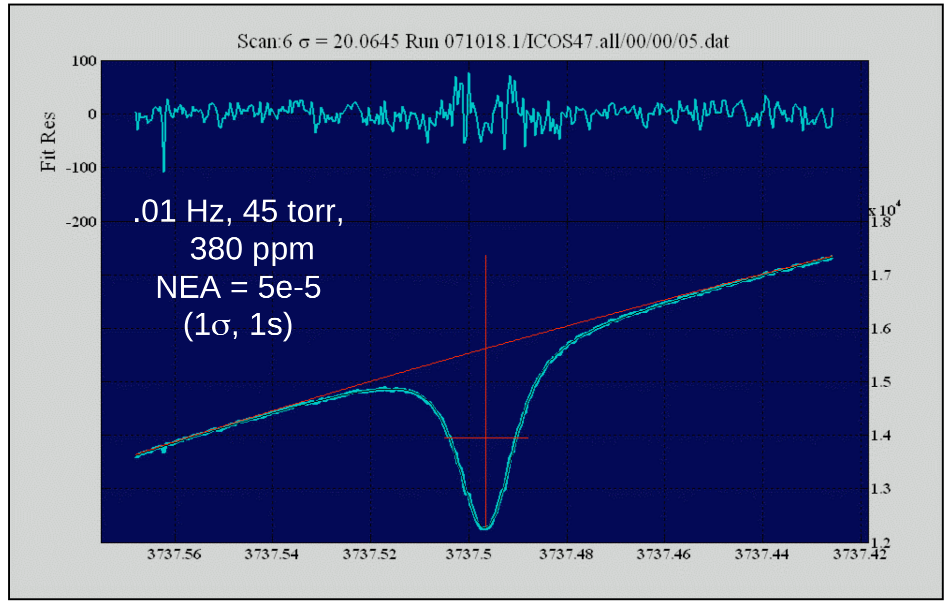


Distributed Feedback (DFB)

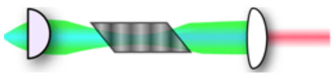
LASER — CELL — DET — A/D — CPU



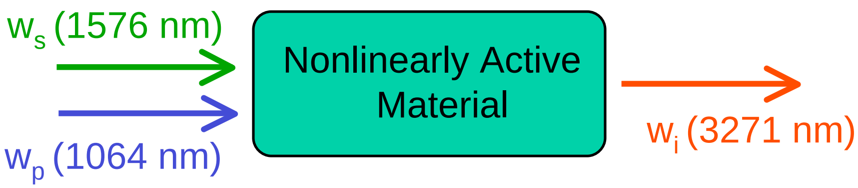


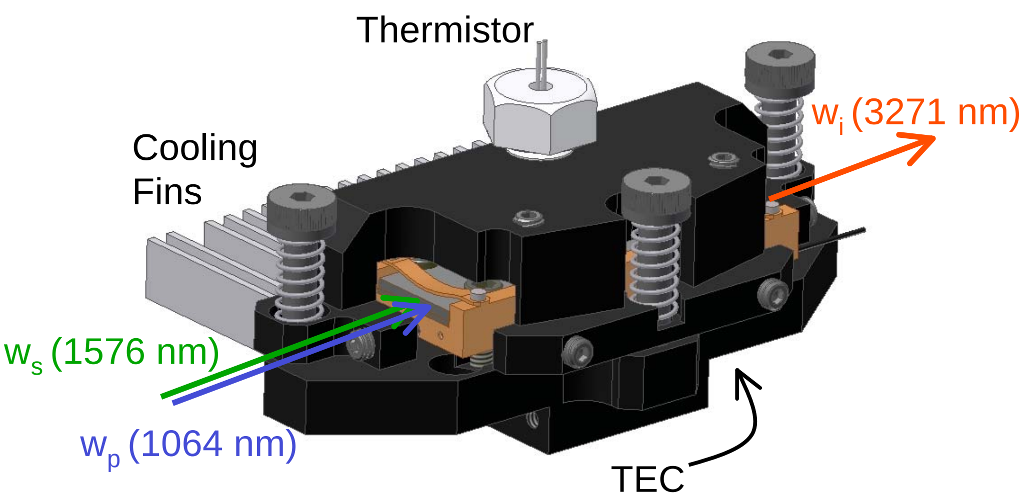


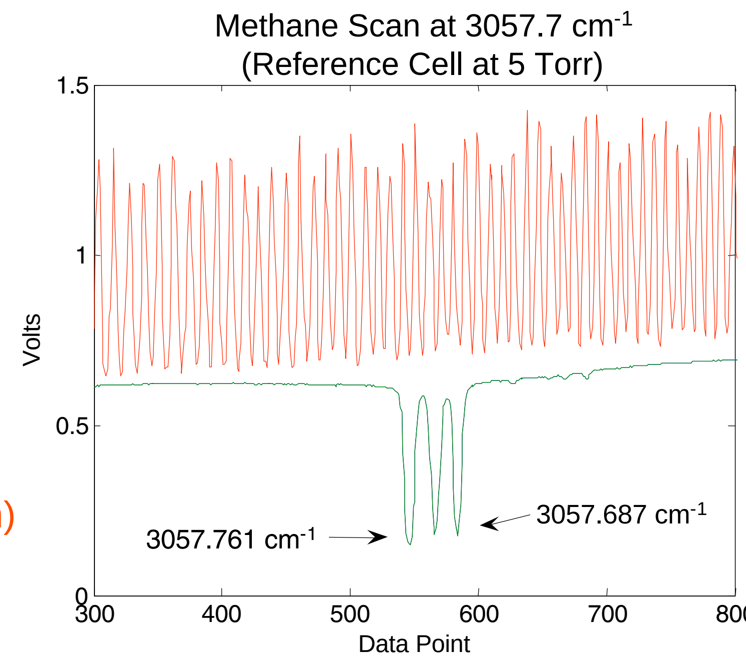
- COTS (Nanoplus GmbH)
- 2.682 μm, 2 - 20 mW
- Built-In TEC (2 Stage)
- AR Asphere, *f* = 5 mm



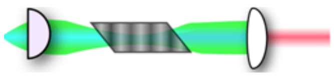
Difference Frequency Generation (DFG)







- P = 600 μW
- Narrow Linewidth (~1 MHz)
- Suitable for For Field Deployment



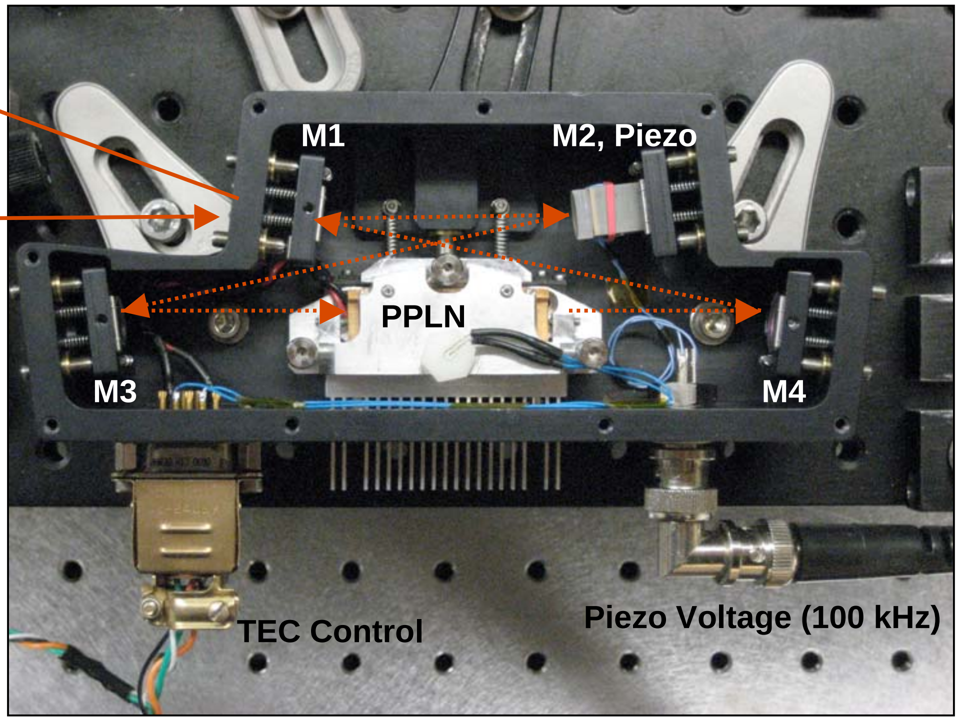
Difference Frequency Generation (DFG)

LASER — CELL — DET — A/D — CPU

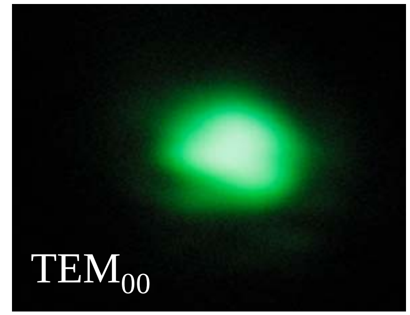
Cavity Enhanced DFG

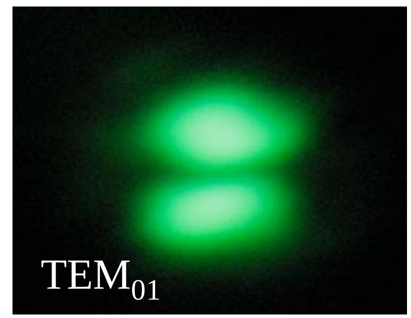
Cavity Output

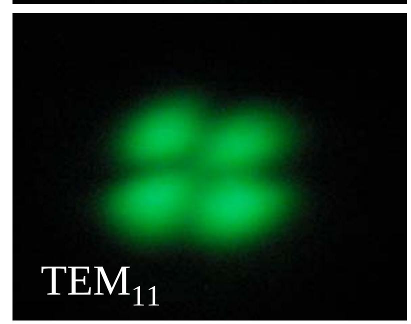
800 mW 1064,
800 mW 1550

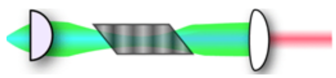


M1: 5%T @ 1064, HT @ 1550
M2,M3: HR @ 1064, 1550
M4: HR @ 1064, HT @ 1550









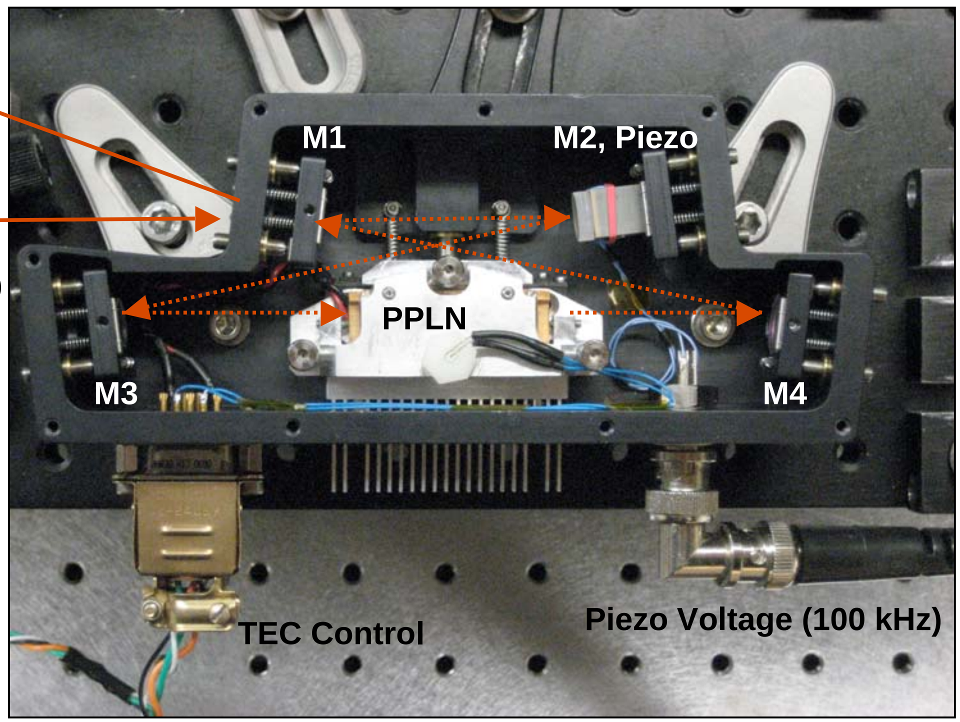
Difference Frequency Generation (DFG)

LASER — CELL — DET — A/D — CPU

Cavity Enhanced DFG

Cavity Output

20 mW 1064, 800 mW 1550



M1: 5%T @ 1064, HT @ 1550
M2,M3: HR @ 1064, 1550
M4: HR @ 1064, HT @ 1550

$$Enhancement\ when\ L = \frac{n\lambda}{2}$$

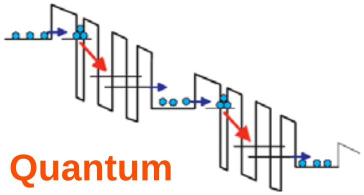
Calculate Enhancement

$$\frac{I_{caivty}}{I_{input}} = \frac{T_1}{(1-\sqrt{R_1 R_2 \ldots R_n L_1 L_2 \ldots L_m})^2} \approx 20$$

$$20\ x\ 600\ \mu W = 12\, mW$$

$$And\ Measure\ 6\, mW$$

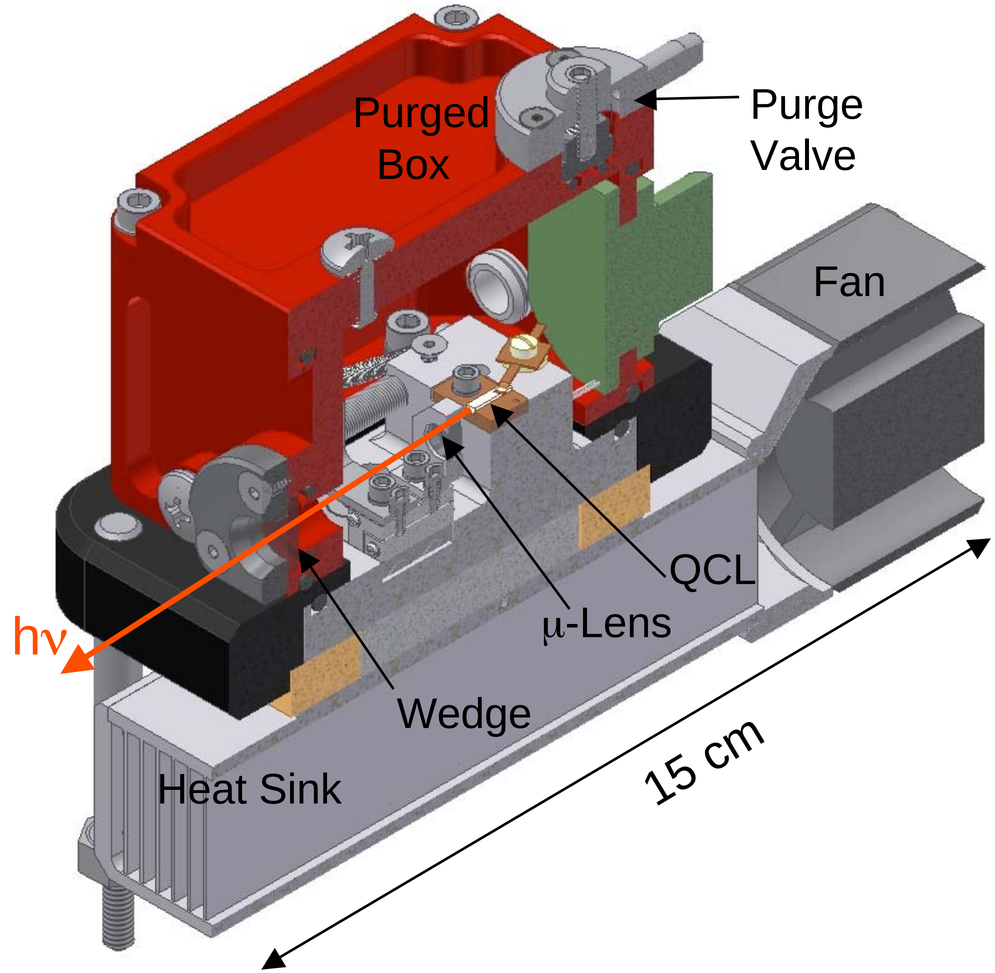
$$\therefore Cavity\ Enhancement = 10\, x$$

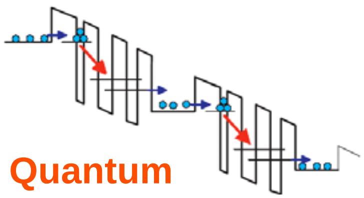


Quantum Cascade (QC)

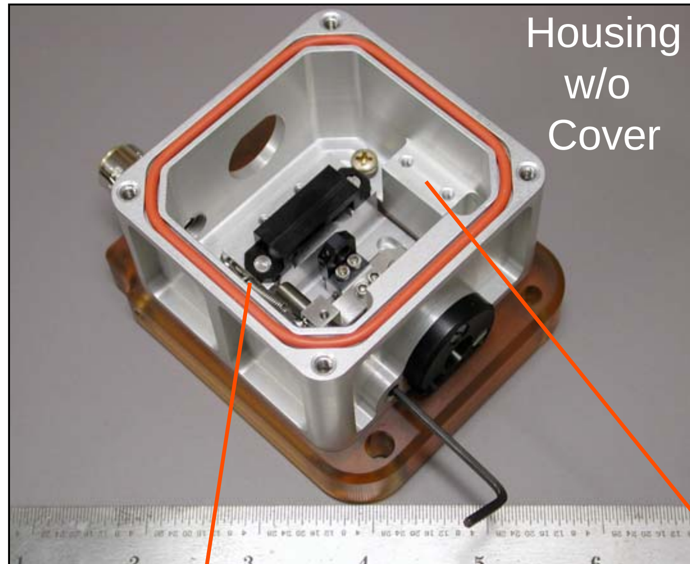
LASER — CELL — DET — A/D — CPU

- Translatable AR Asphere
- 2 Stage TE Cooler (min. Temp. = -20°C, *cw*) with Air-Cooled Heat Sink
- Wedged, AR Exit Window

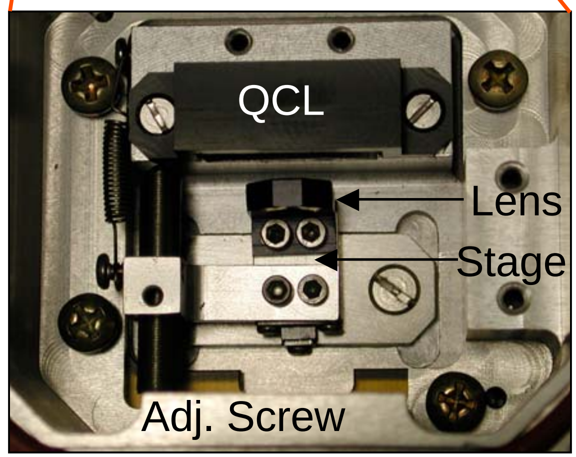




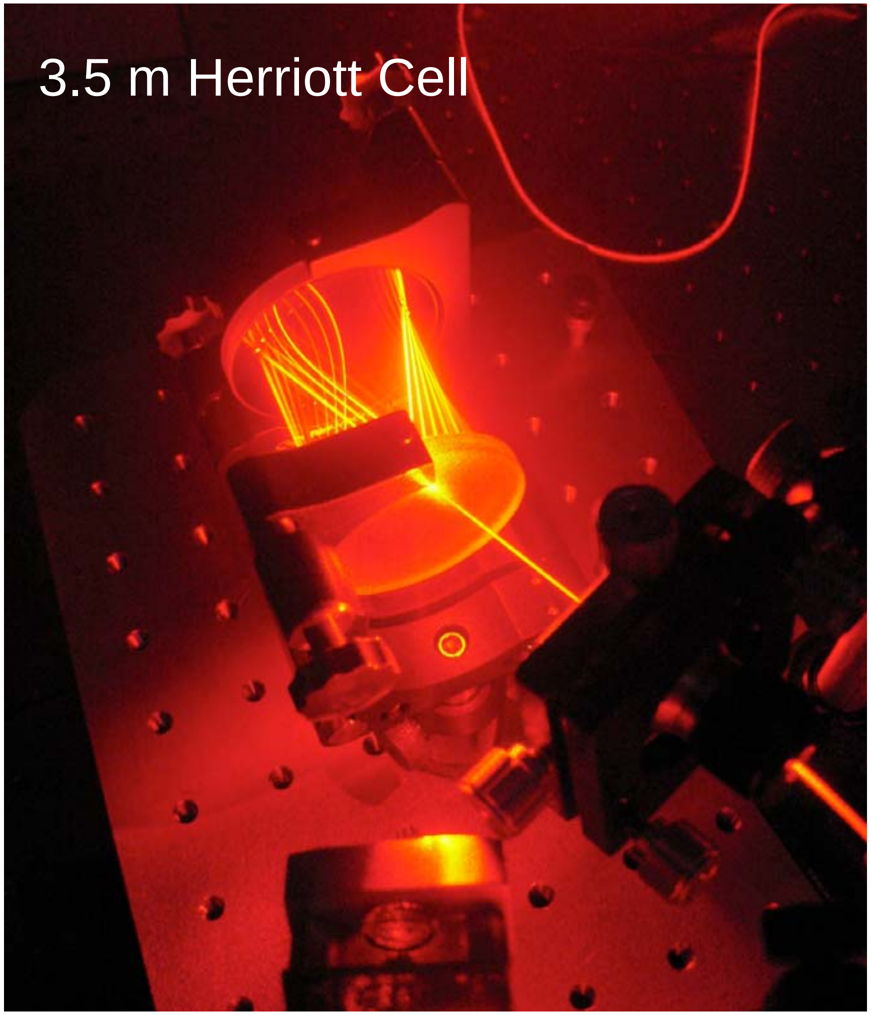
Comparison of Cryo QCL (2005) with 2 Stage TE Cooled QCL (2008)



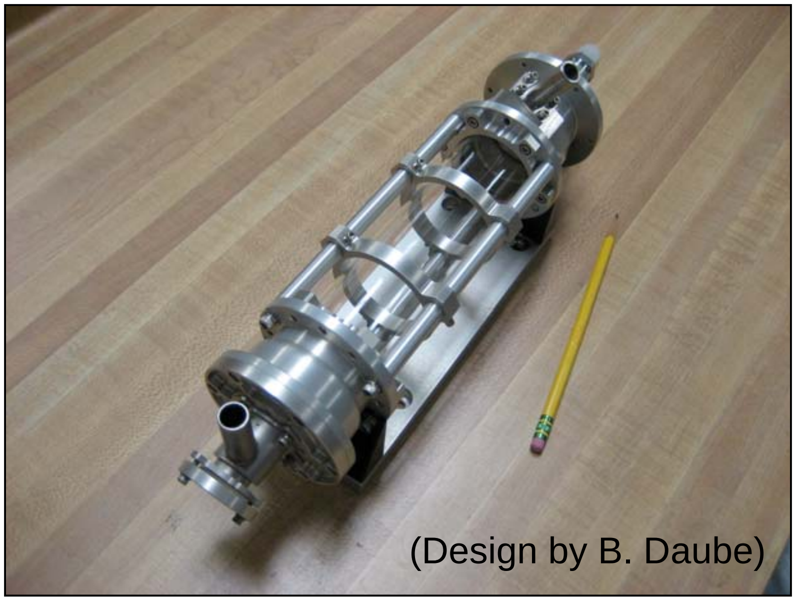
- First *cw* Air Cooled QCL for Field
- In Testing Phase



DRIVER — LASER — CELL — DET — A/D — CPU



DRIVER — LASER — CELL — DET — A/D — CPU



(Design by B. Daube)

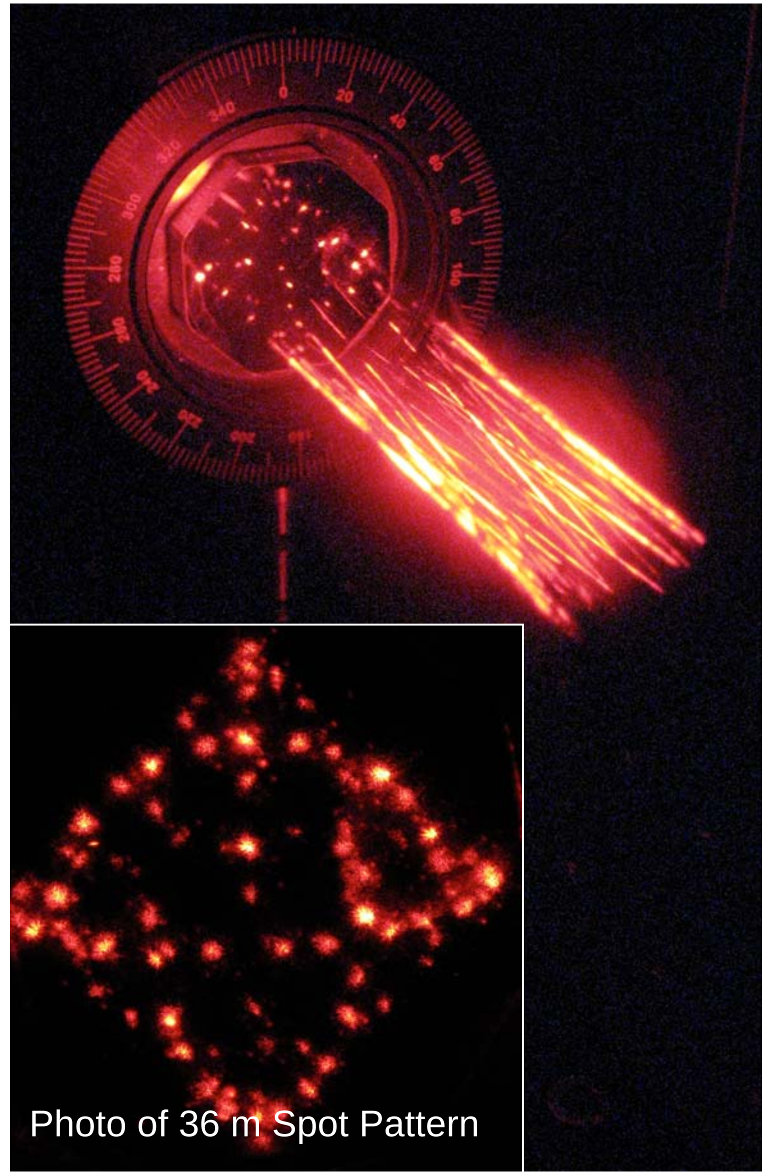
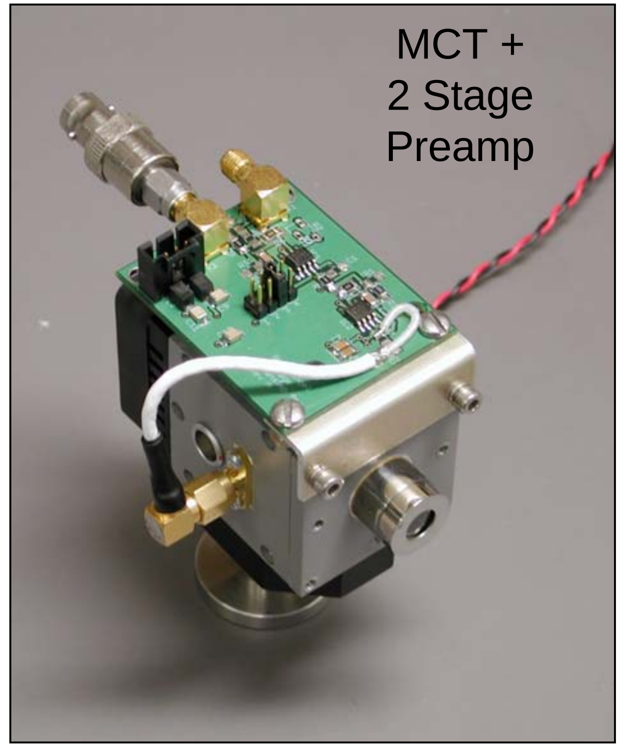


Photo of 36 m Spot Pattern

- Pathlength: 36 m (measured)
- Weight: 0.5 kg
- Offset Input/Output Ports
- All Aluminum (Almost)

DRIVER — LASER — CELL — DET — A/D — CPU

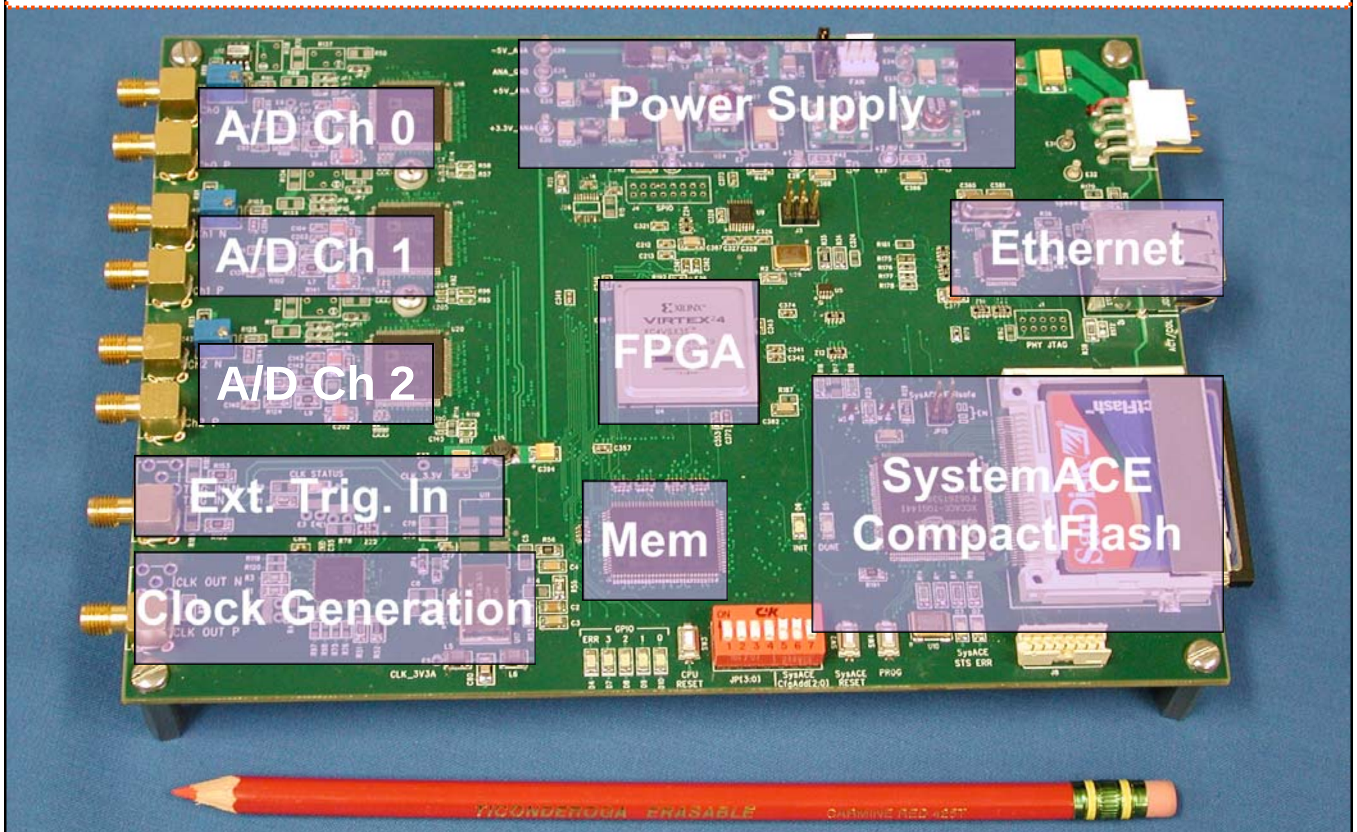
Comparison of Cryo MCT (2005) with 3 Stage TE Cooled MCT (2008)



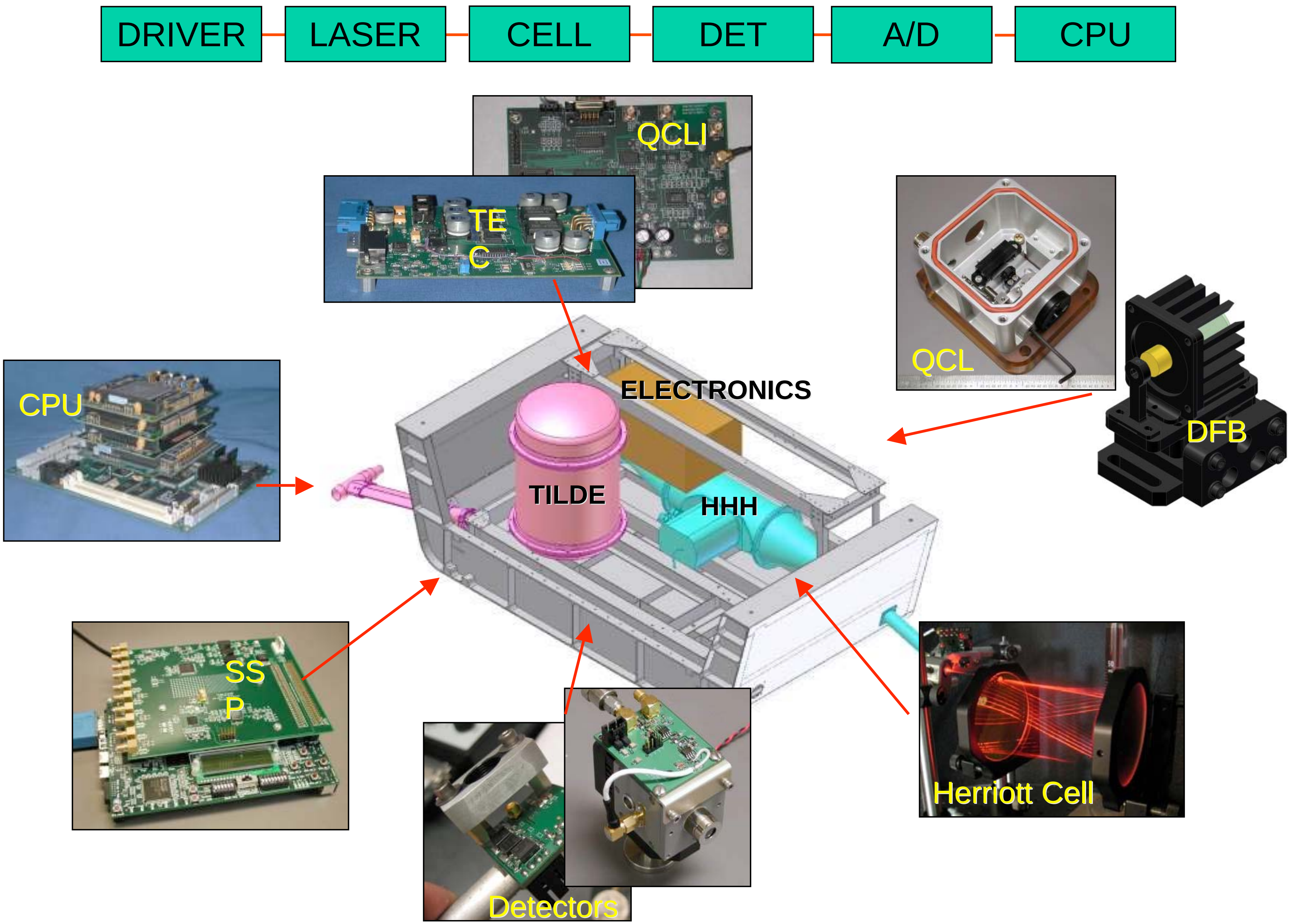
- 3 Stage TEC
- D*: 1 x 10^{10} (8 μm)
- Area: .25 x .25 mm

DRIVER – LASER – CELL – DET – A/D – CPU

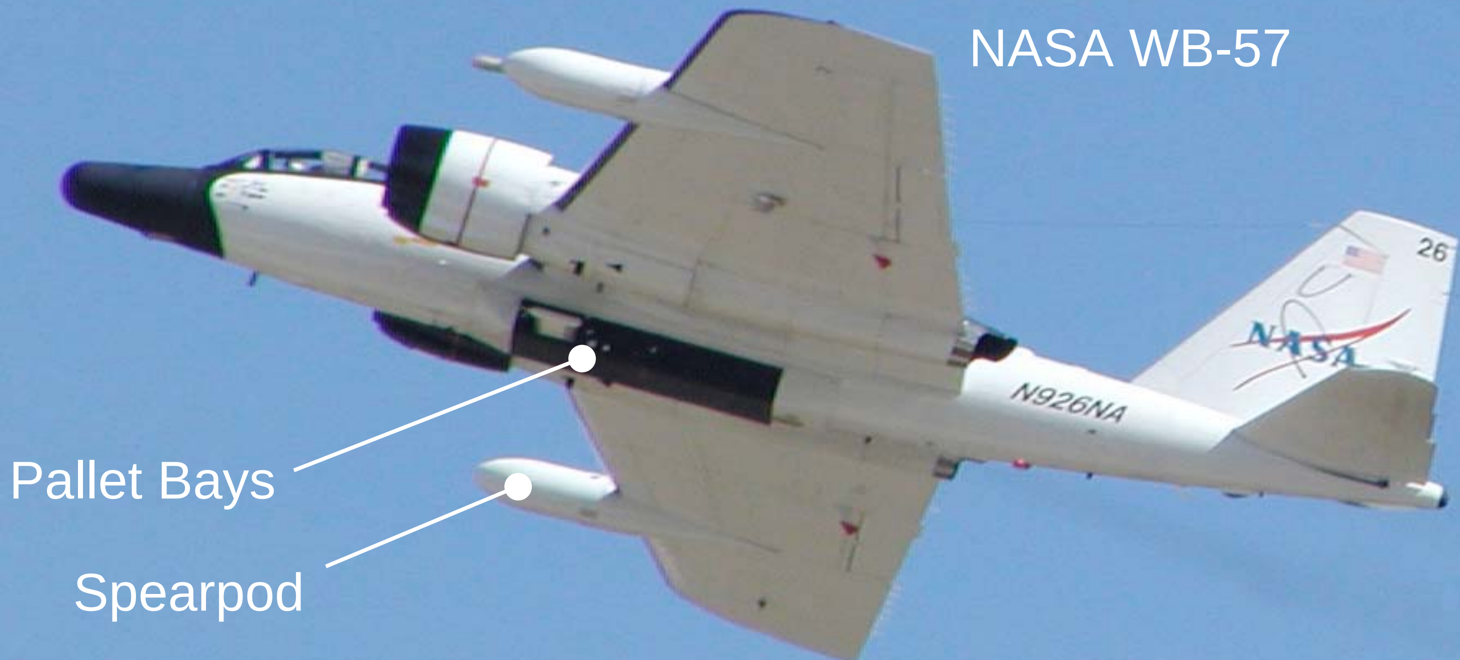
The Scalable Signal Processing Board (SSP) is a 16 Bit DAQ Device With On-The-Fly DSP and Ethernet Interface



- 16 Bit, 100 MHz, AD9446 ADC with 79 dB SINAD (13 ENOB)
- Xilinx Vertex–4 FPGA for DAQ Control and DSP Engine
- <500 fs Clock Jitter (measured)


DRIVER
LASER
CELL
DET
A/D
CPU
QCLI
TE
C
QCL
DFB
CPU
ELECTRONICS
TILDE
HHH
SS
P
Detectors
Herriott Cell

Preparing Two TDL Instruments for NOVICE Mission in Houston, TX -- Summer 2008

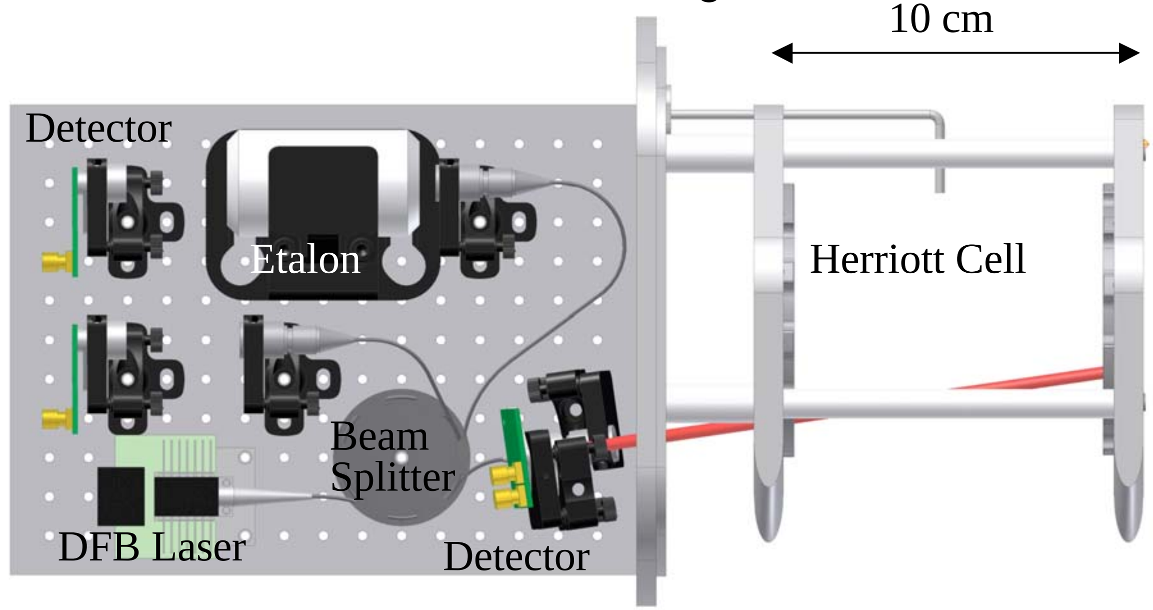


Results will be compared with those of
other tracer instruments (Wofsy, Podolske, Lowenstein)

DRIVER — LASER — CELL — DET — A/D — CPU

Harvard Herriott Hygrometer (H_3)

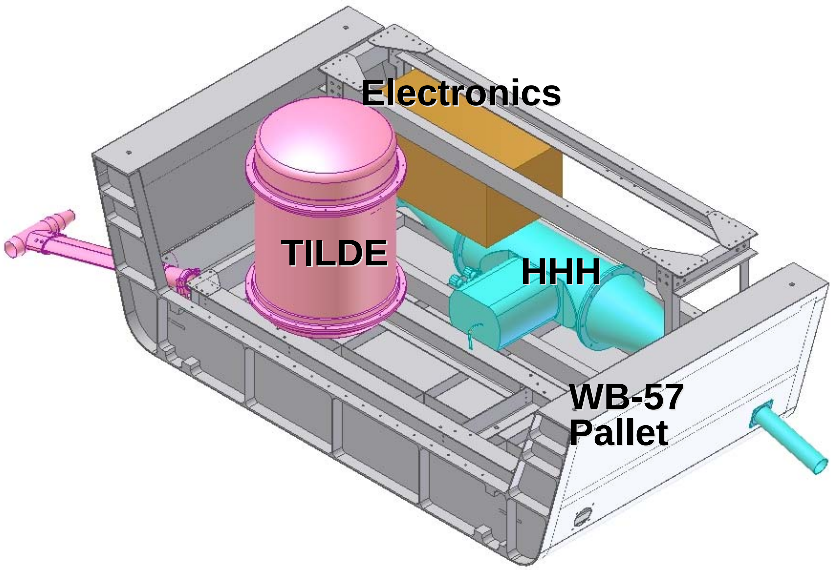
- Measures H_2O in Stratosphere (UAV)
- 1.39 μm DFB Laser
- 2nd Path for Residual H_2O Correction
- 3rd Path for Si Etalon

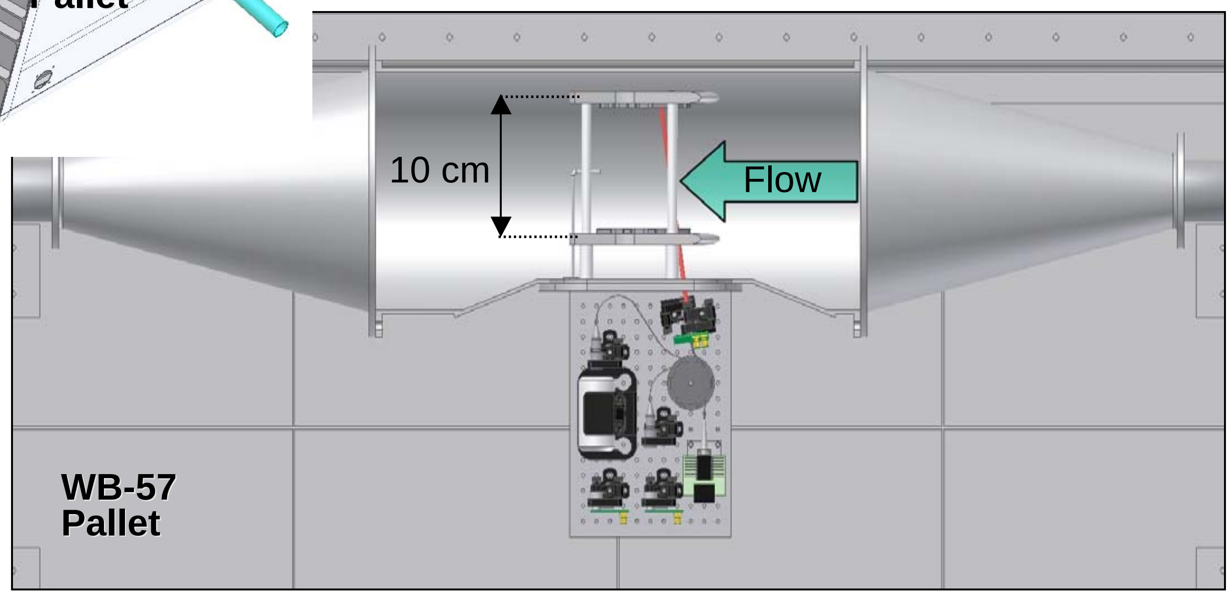


	Accuracy (± %)	Precision (± ppmv, 10-s, 5 ppmv)	Threshold (ppmv)
Theoretical	3-5, UT-LS	0.004	0.004
Target	3-5, UT-LS	0.05	0.1
Achieved	6, 35 ppmv	0.63	0.63

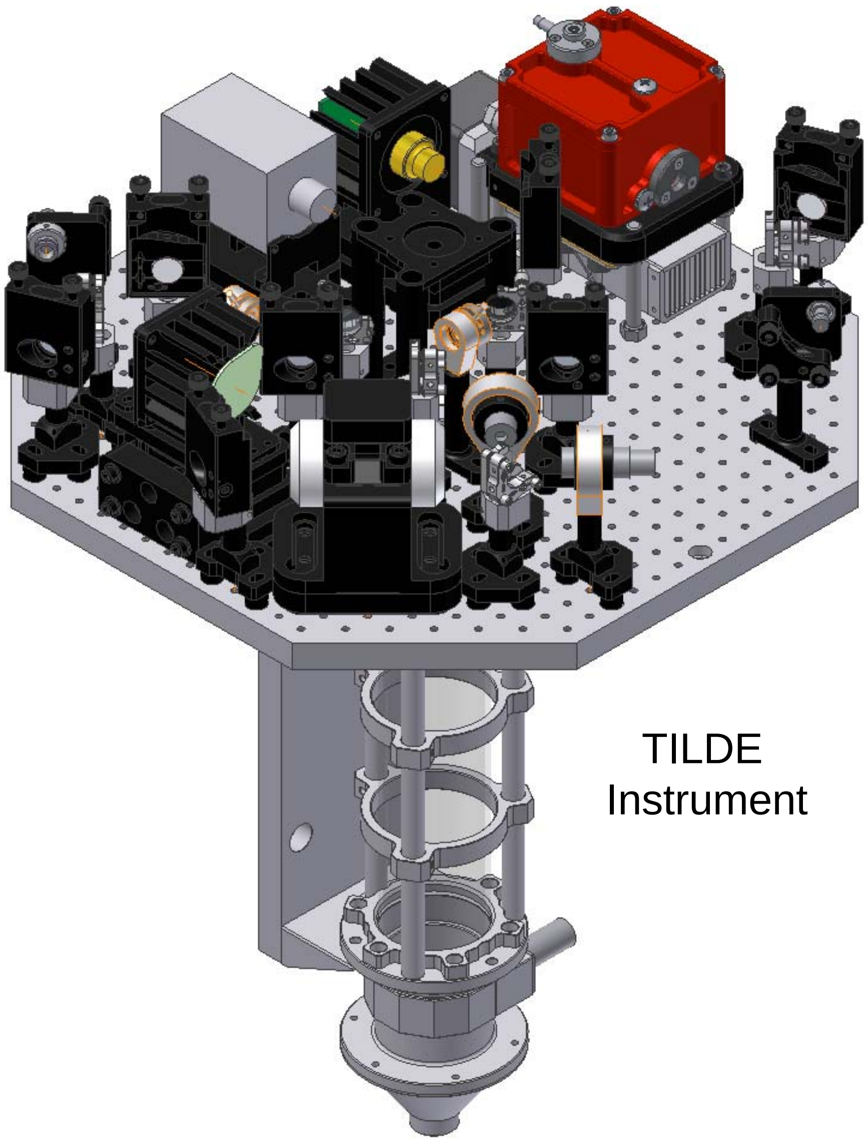
DRIVER — LASER — CELL — DET — A/D — CPU

H_3 Integration





DRIVER – LASER – CELL – DET – A/D – CPU

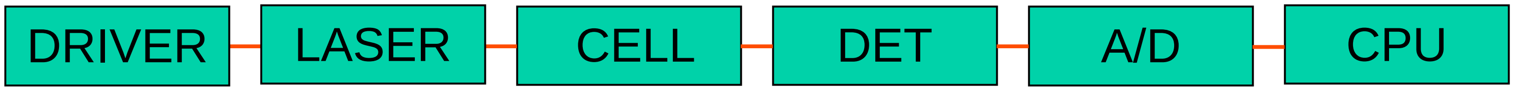


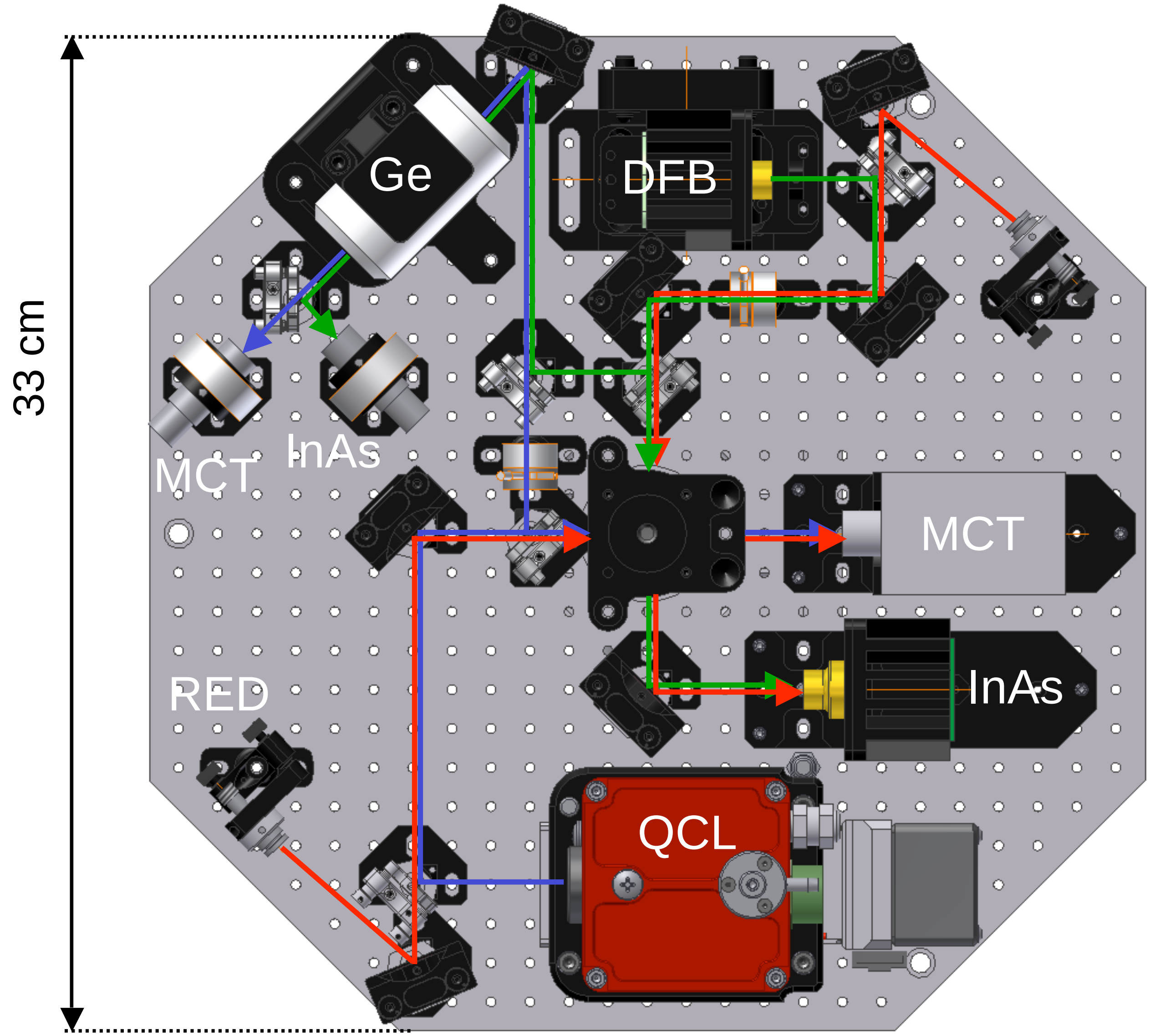
TILDE Instrument

Tunable Infrared Laser Diode Experiment. (TILDE)

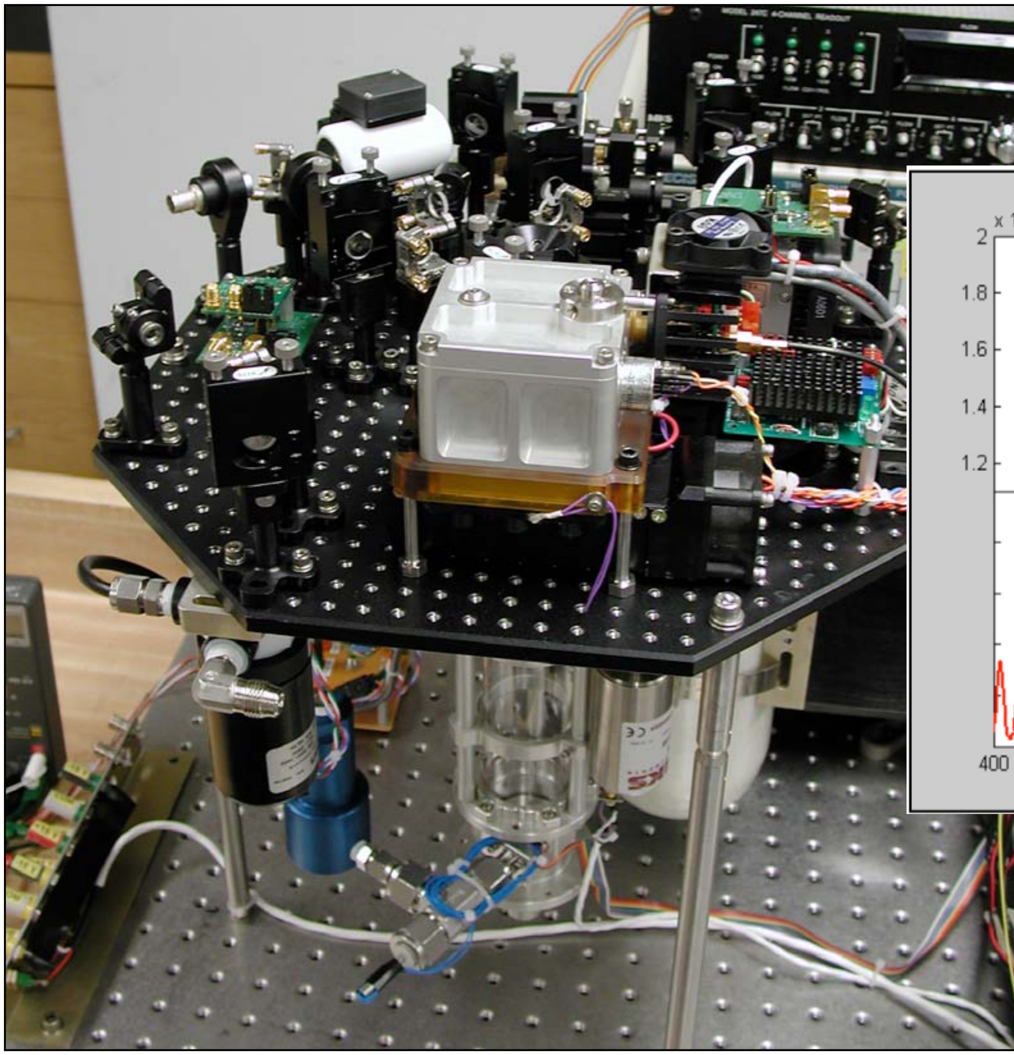
General Characteristics

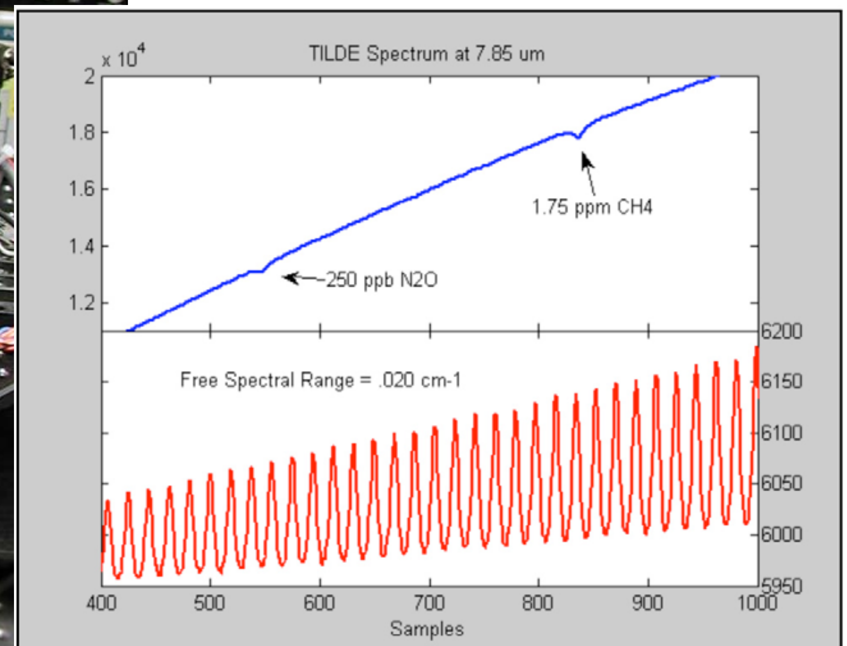
- Measures H_2O, CO_2, CH_4, N_2O (+ $^{13}CO_2/^{12}CO_2$)
- 2 TE Cooled *cw* Lasers: 2.7 μm DFB, 7.9 μm QCL
- 2 TE Cooled Detectors/2 Uncooled Detectors
- Precision: CO_2 → 0.1 ppm
  N_2O → 5 ppb
  CH_4 → 10 ppb


DRIVER
LASER
CELL
DET
A/D
CPU

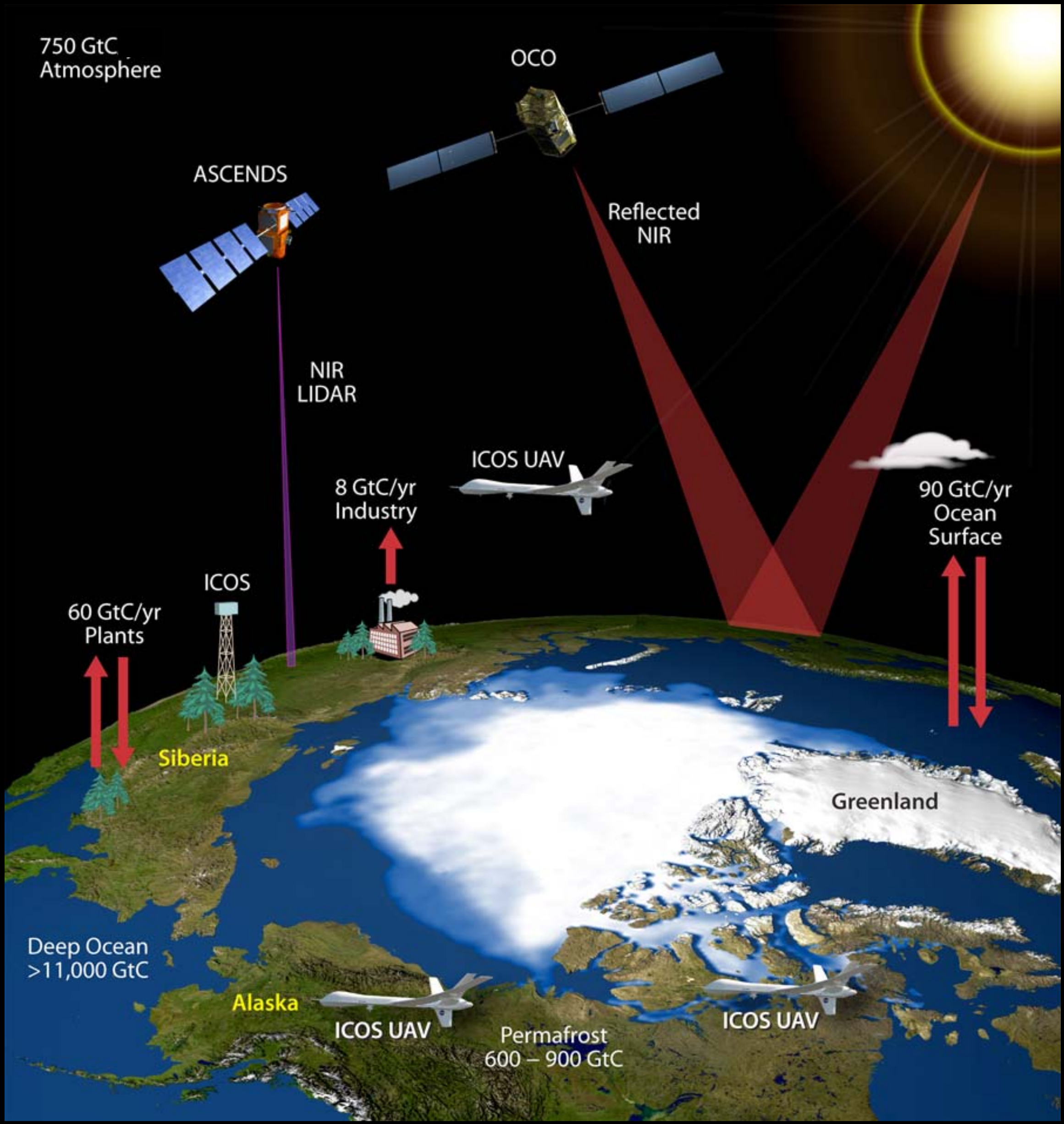

33 cm
Ge
DFB
MCT
InAs
MCT
RED
InAs
QCL

TILDE PROTOTYPE

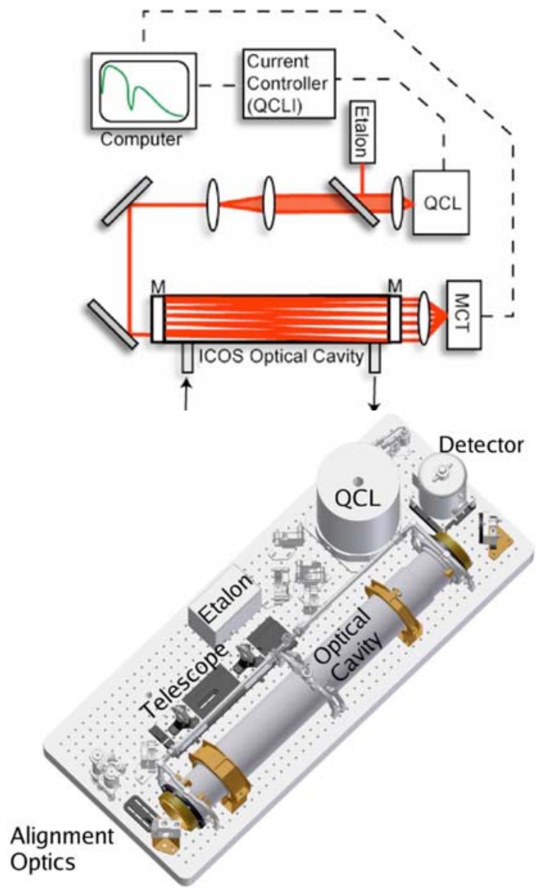




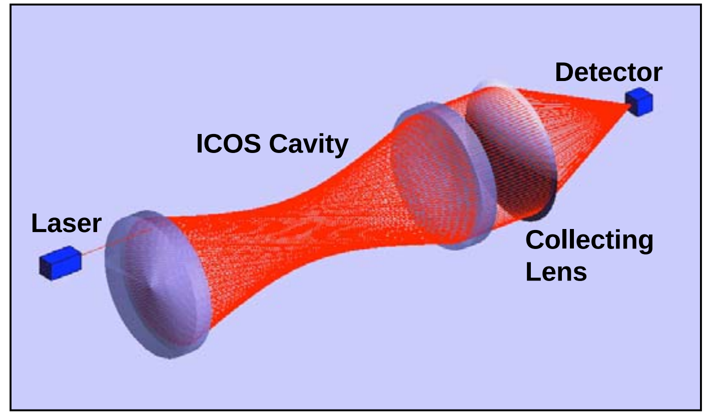
TDLAS and the Arctic: Miniaturized ICOS

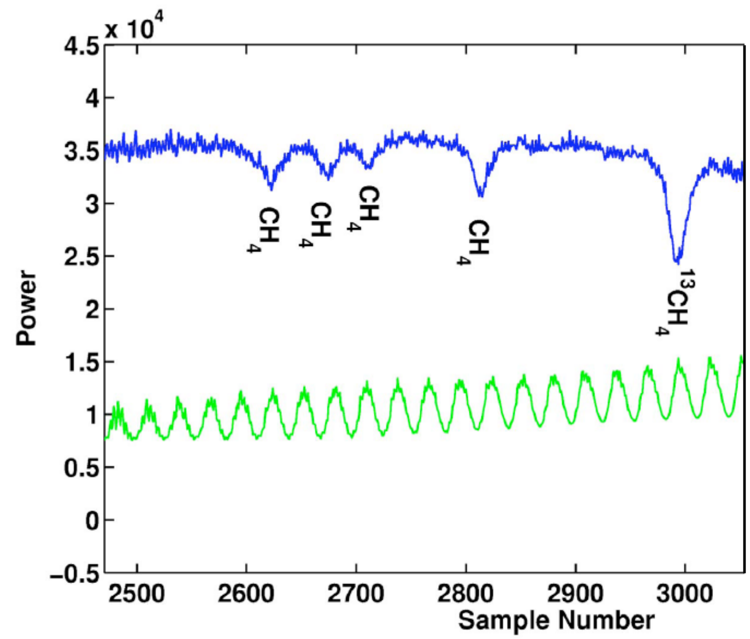


TDLAS and the Arctic: Miniaturized ICOS



OA-ICOS Ultra-
Sensitive Detection





Thank you.

Science: Jim Anderson,David Sayres and Jessica Smith

Electrical Eng.: Joe Demusz, Marco Rivero, Terry Martin

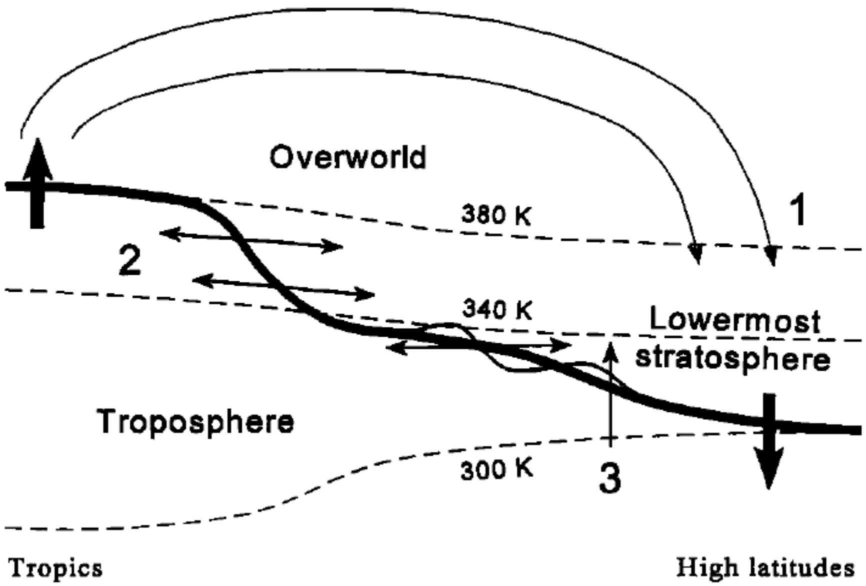
Mechanical Eng.: Chris Tuozzolo, Mike Greenberg

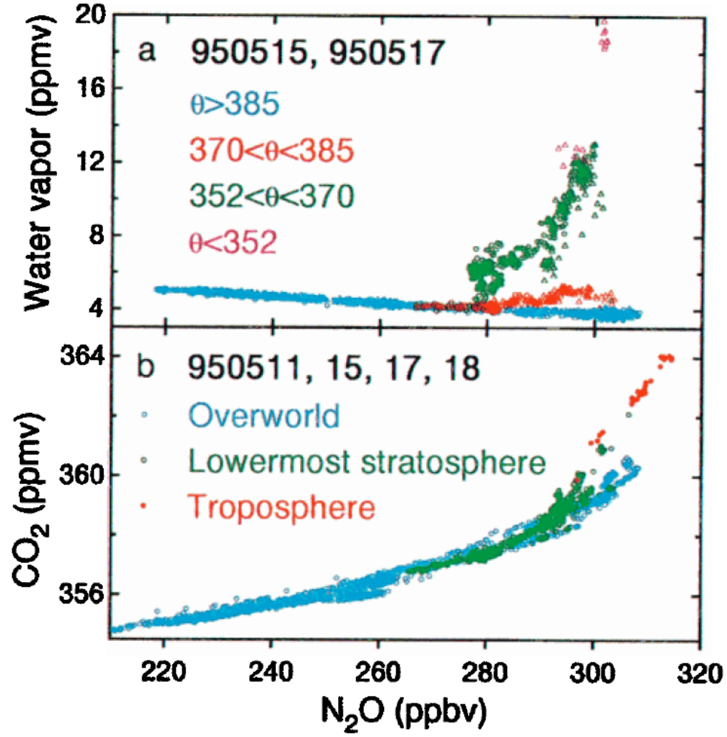
Laser/Optical Design: Josh Paul, Larry Lapson

Other: Lenny Solomon, Bruce Daube, Rodrigo Jimenez

Funding: NASA IIP Program

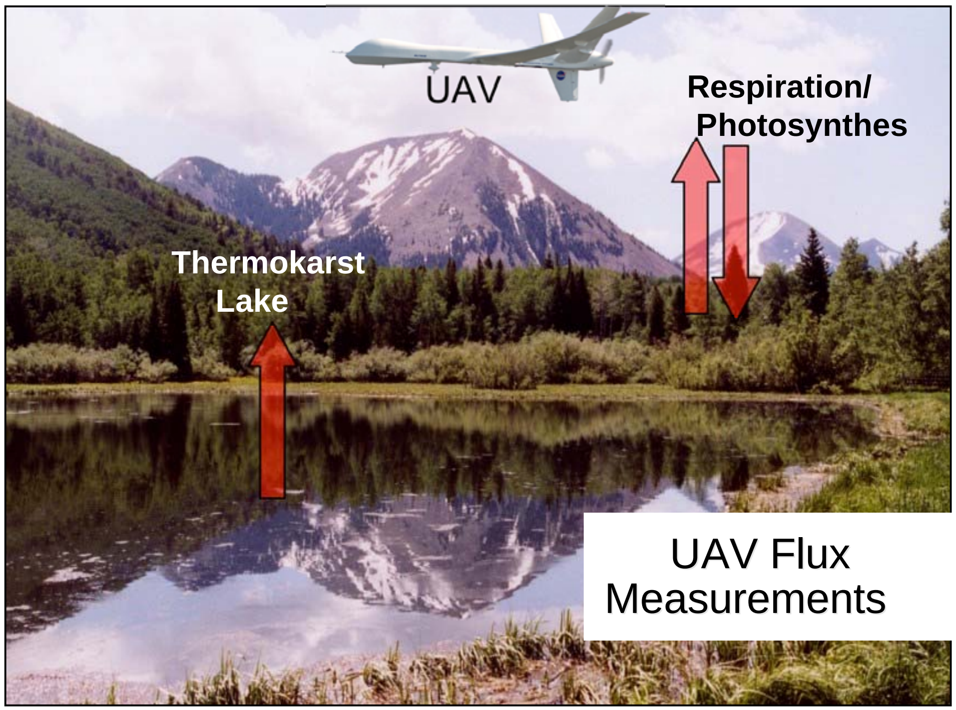
Upper Troposphere/Lower Stratosphere (UT/LS) Transport





E. J. Hintsa, *et. al.*, GRL, 25 (14), 1998.

TDLAS and the Arctic: Miniaturized ICOS



- Need Flux Measurement Technology
- Need to Measure $^{13}CO_2/^{12}CO_2$, $^{13}CH_4/^{12}CH_4$
- High Precision: $\delta^{13}CH_4 < .05‰$ (1σ, 1s)