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Diode lasers, DFG and Molecules: Development and applications of trace gas sensors

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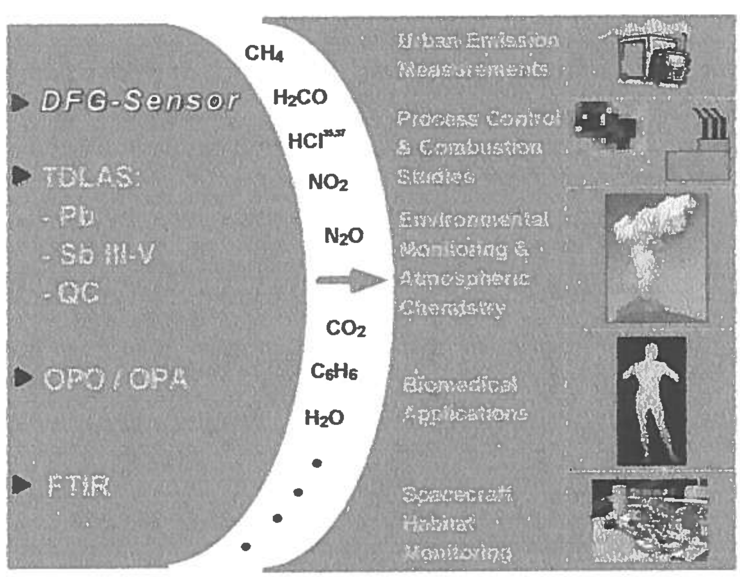
http://www.rice.edu/~lasersci

- Motivation
- Concept and operation of mid-IR gas sensors
- Trace Contaminant Control on the ISS
- Masaya volcano field campaign
- DFG 2000 and summary

Motivation



▸ Diode lasers, DFG and Molecules

Diode Lasers:

Desirable characteristics for spectroscopy

- Stable/reproducible frequency, easy to modulate (Hz-MHz)
- Narrow linewidth (<MHz)
- Room temperature operation
- Compact and rugged

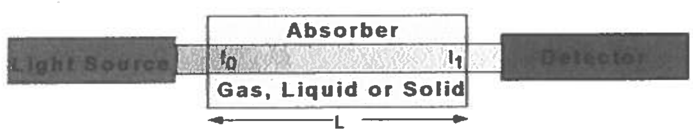
DFG: Difference Frequency Generation

- NIR diode lasers can be shifted into the spectroscopically important 3-5 μm region

Molecules:

- Strongest absorptions in the spectroscopic 'fingerprint' 2-20 μm region
- Detected to date: 13 species including CH_4, H_2O, N_2O, NO_2, NO, NH_3,H_2CO, CO, CO_2, HCl, CH_3OH, SO_2, C_6H_6

▸ Absorption Spectroscopy



Beer's Law

$$I_1(\nu)=I_0 \cdot e^{-\alpha(\nu)\cdot L}$$

$\alpha(\nu)$-absorption coefficient (cm^{-1}), L- path length (cm), ν - frequency (cm^{-1})

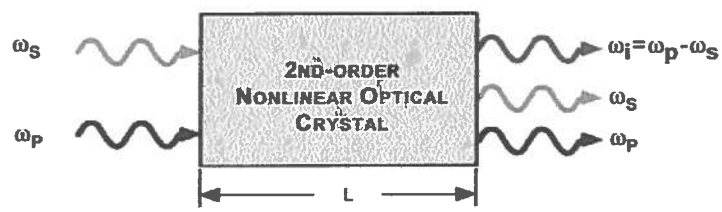
Molecular Absorption Coefficient

$$\alpha(\nu)=C\cdot\frac{S}{\Delta\nu}\cdot g(\nu)$$

C-gas concentration (cm^{-3}), S - absorption line strength (cm), $\Delta\nu$ – linewidth (cm^{-1})

g (ν) - line shape function: Gaussian, Voigt, or Lorentzian profile

▸ Difference Frequency Generation



POWER: $P = C \cdot P_{PUMP} \cdot P_{SIGNAL} \cdot L$

$C \sim 500\ \mu W / cm \cdot W^2$

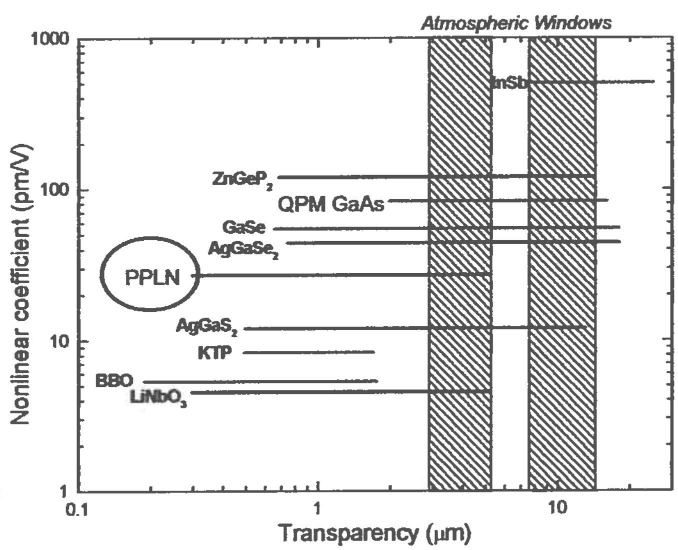
3 μW for 6 and 500 mW pump LDs

0.7 mW for 0.6 W and 1.6W pump

Advantages of Bulk PPLN:

- cost effective
- custom design: multichannel crystal
- QPM from 2.5-5 μm
- alignment insensitive

▸ Applicable NLO Crystals



▸ Key Enabling DFG Technologies

MID-IR Source:

Fiber Coupled Single Frequency Diode Lasers:
DFB:
-1515 nm to 1620 nm
2 - 25mW

Alpha DFB / DBR
or fiber laser
1030 nm - 1110 nm
10 mW - 500 mW

+

Yb-Fiber Amplifier:
0.5 - 10 W
typ: 1W

Er/Yb-Fiber Amplifier:
0.04 - 10 W
typ: 0.5W

+

Frequency Conversion to MID-IR:
~3.5 µm
µW to mW

QPM PPLN
L 30 µm

Detection:

Single-Line Absorption Spectroscopy:
Multipass Cell:
L = 18m to 100 m

TE cooled
HgCdTe-detectors
NEP ~5pW Hz $^{1/2}$

+

Real-time Data Acquisition and Control:
-Analog / Digital PCMCIA Card

-Notebook PC

-LabVIEW 5.0 Software

+

Calibration and Reference:
- Wavemeter
- Cal Reference Gas Cells
- Hitran Database

▸ Design Issues

→ CENTER WAVELENGTH:
DETERMINED BY CHOICE OF TARGET GAS MOLECULE

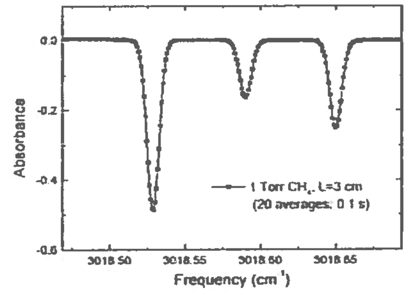
→ TUNING RANGE: COARSE 200 cm^{-1} (~200NM IN MIR)

-TWO TUNABLE DIODE LASERS

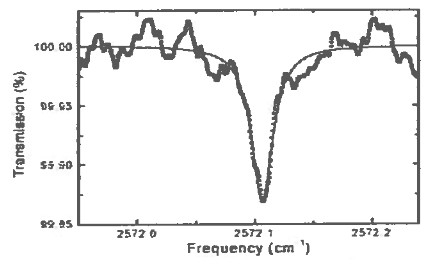
-MULTIGRATING QPM PPLN

Spectroscopic Performance: Selectivity and Sensitivity

- High resolution doppler limited CH_4 spectra at 3.3 microns
- DFG linewidth of present system ~40 MHz

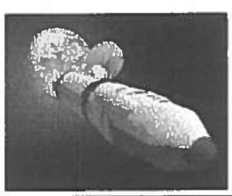


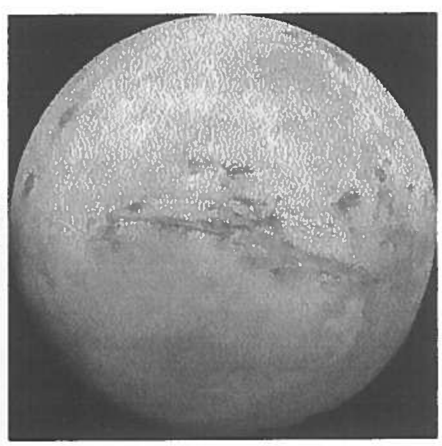
- Ambient N_2O (c=315 ppb)
- Sampling pressure: 88 Torr
- Optical path length: 18 m
- Averaging time: 2 s
- Sensitivity: $2x10^{-4}$



National Aeronautics and Space Administration

Advanced Life Support

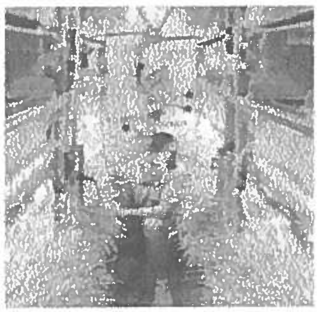


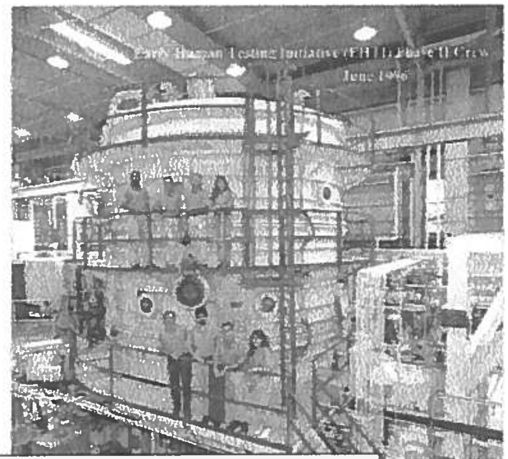


National Aeronautics and Space Administration

Lunar - Mars Life Support Project

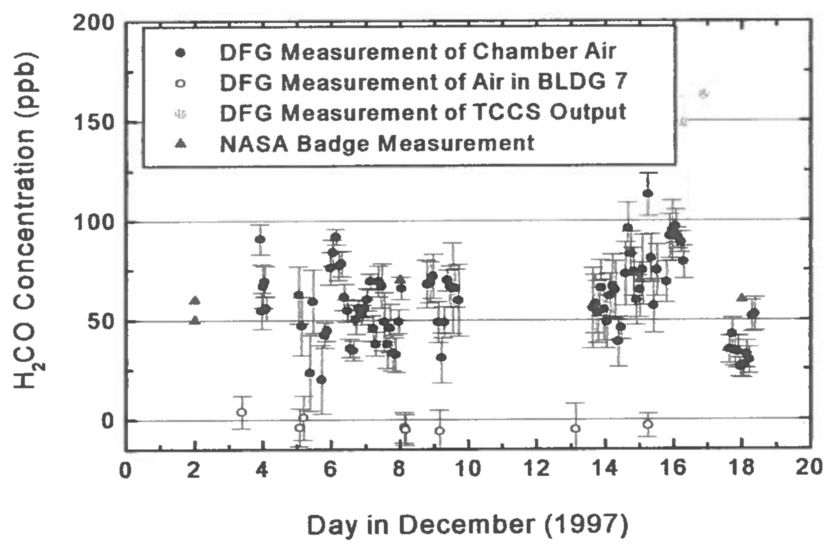
Phase I: 15-day, 1-Person Test
March 1995



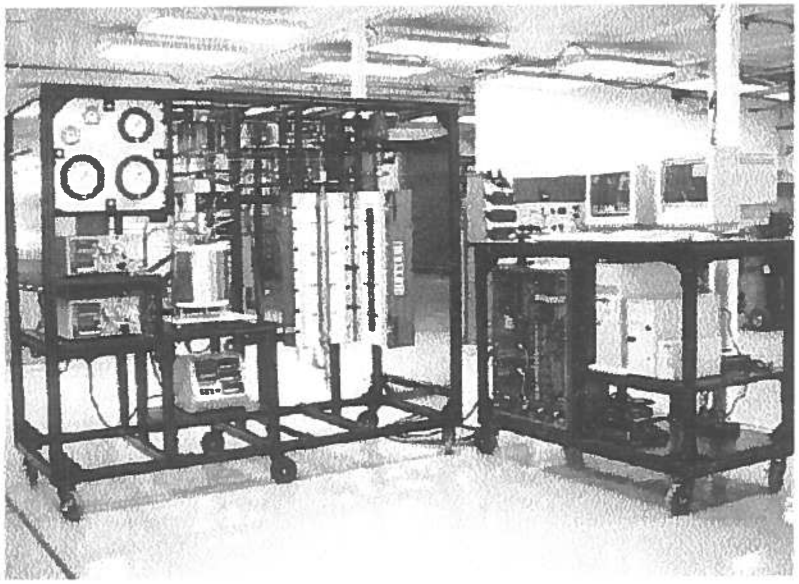


Phase II: 30-day, 4-Person Test - June 1996
Phase IIA ISS: 60-day, 4-Person Test - January 1997
Phase III: 90-day, 4-Person Test - September 19, 1997

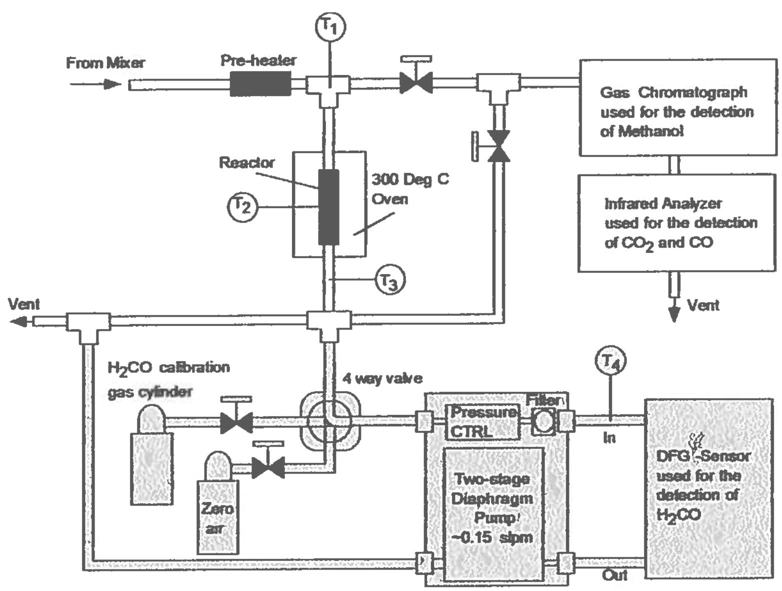
▶ H2CO Concentration Measurements
NASA Lunar Mars Life Support Test Phase III



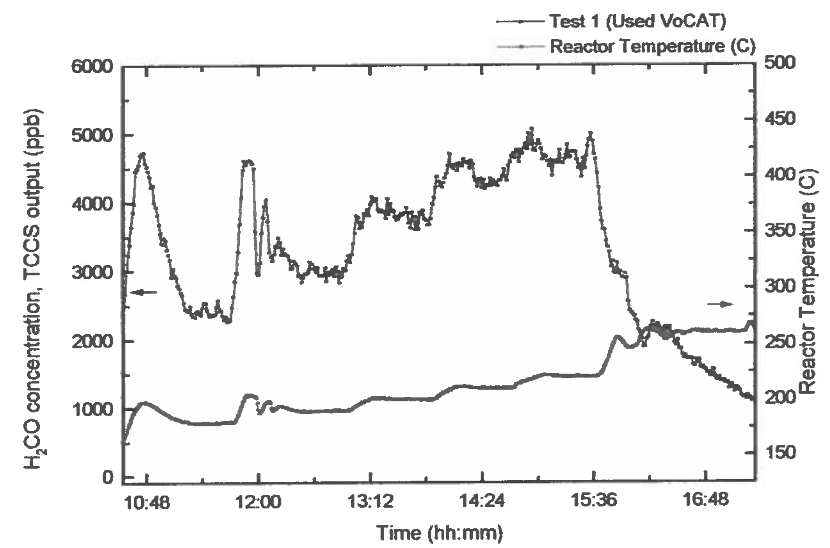
▶ TDA Trace Contaminant Control System

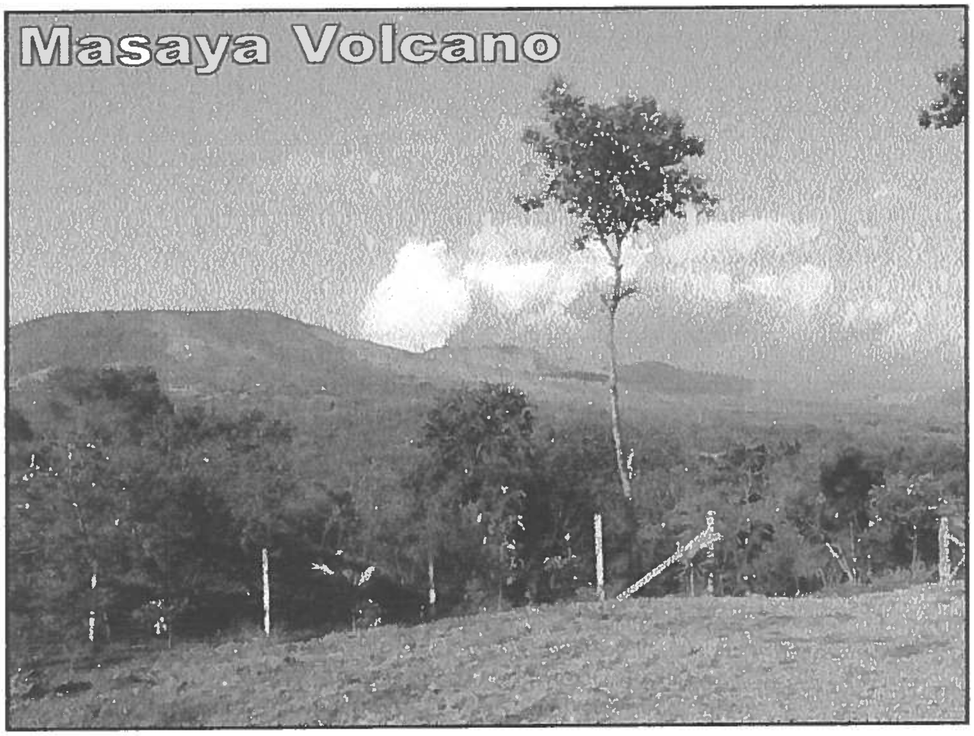


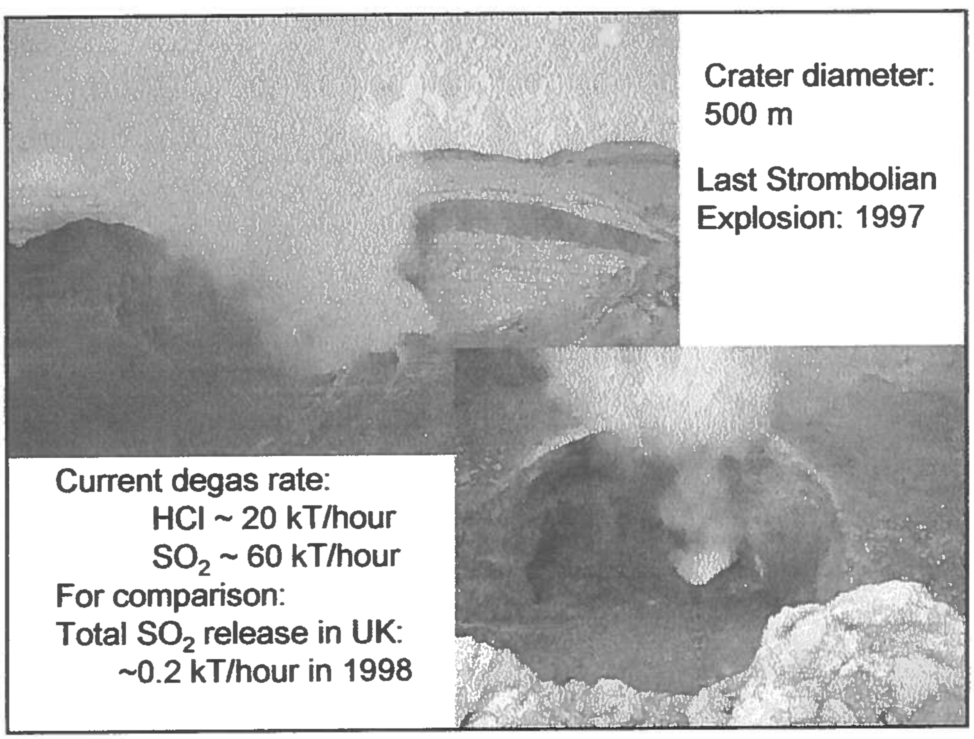
▶ Schematic of TCCS-DFG System



▶ H2CO concentration in NASA TCCS System




Masaya Volcano


Crater diameter: 500 m
Last Strombolian Explosion: 1997
Current degas rate:
HCl ~ 20 kT/hour
SO_2 ~ 60 kT/hour
For comparison:
Total SO_2 release in UK:
~0.2 kT/hour in 1998

▸ Masaya field campaign goals and challenges

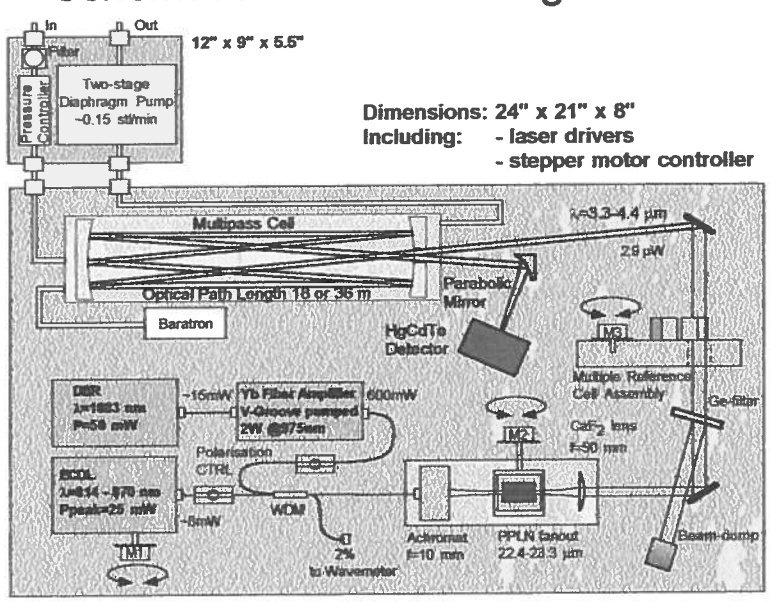
Goals:

- Multi-species detection of volcanic gases using diode laser based sensors - proof of concept
- Correlation of measured gas concentrations with open path FTIR based gas sensor (in collaboration with Clive Oppenheimer, University of Cambridge, UK)

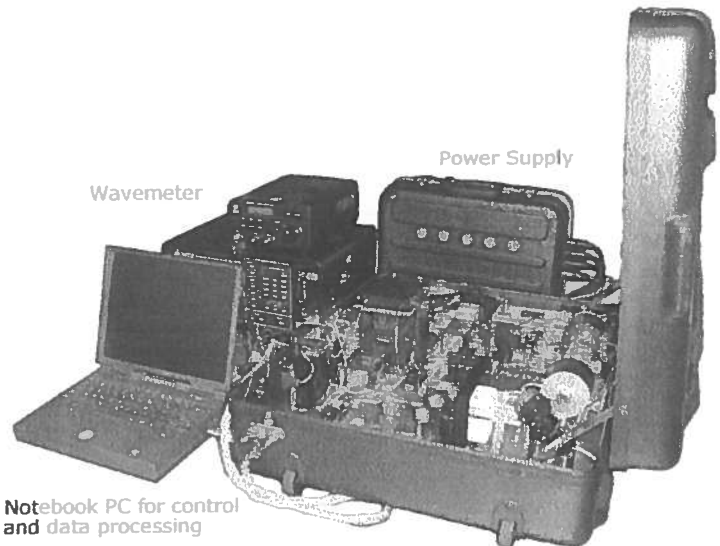
Challenges:

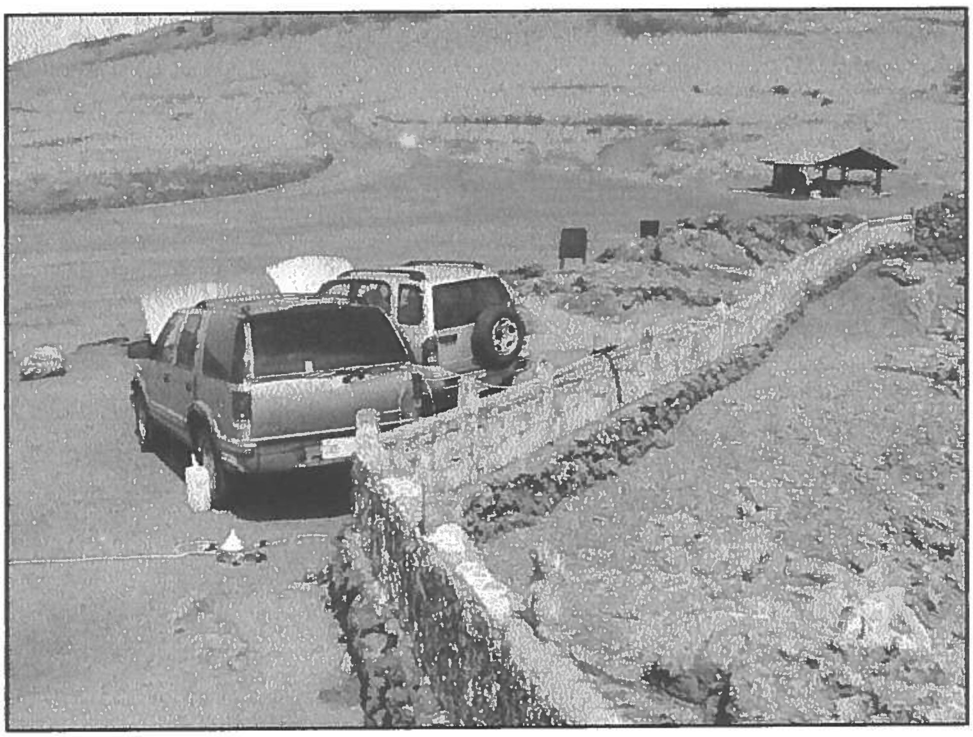
- Shipping logistics
- Customs
- Environmental conditions: 90 - 100 °F, acid rain

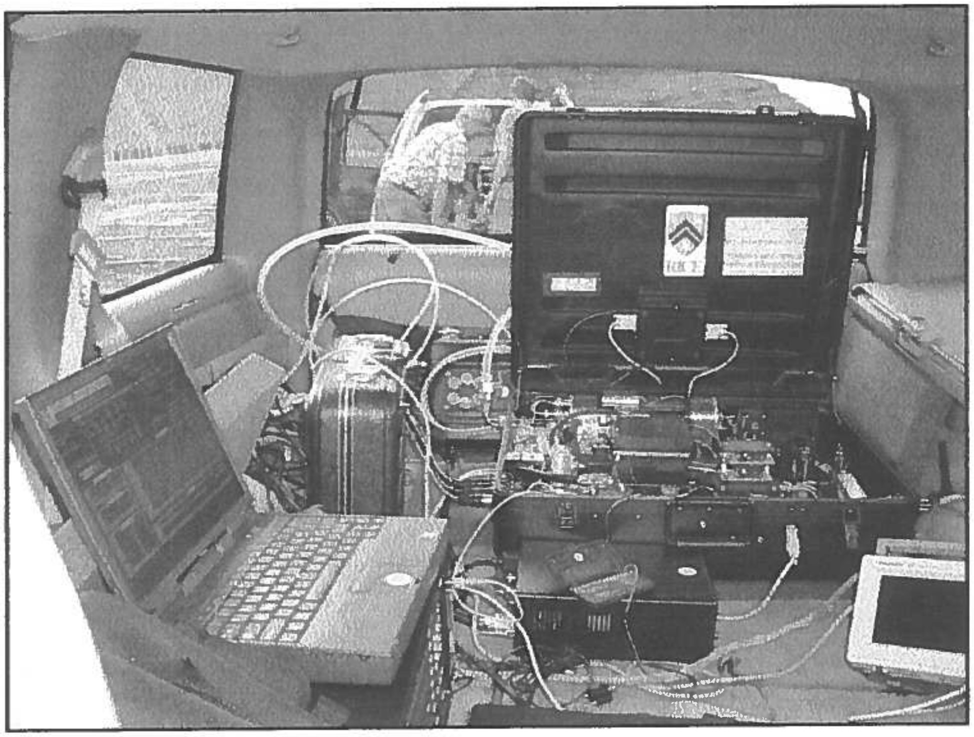
▸ Schematic of DFG based gas sensor

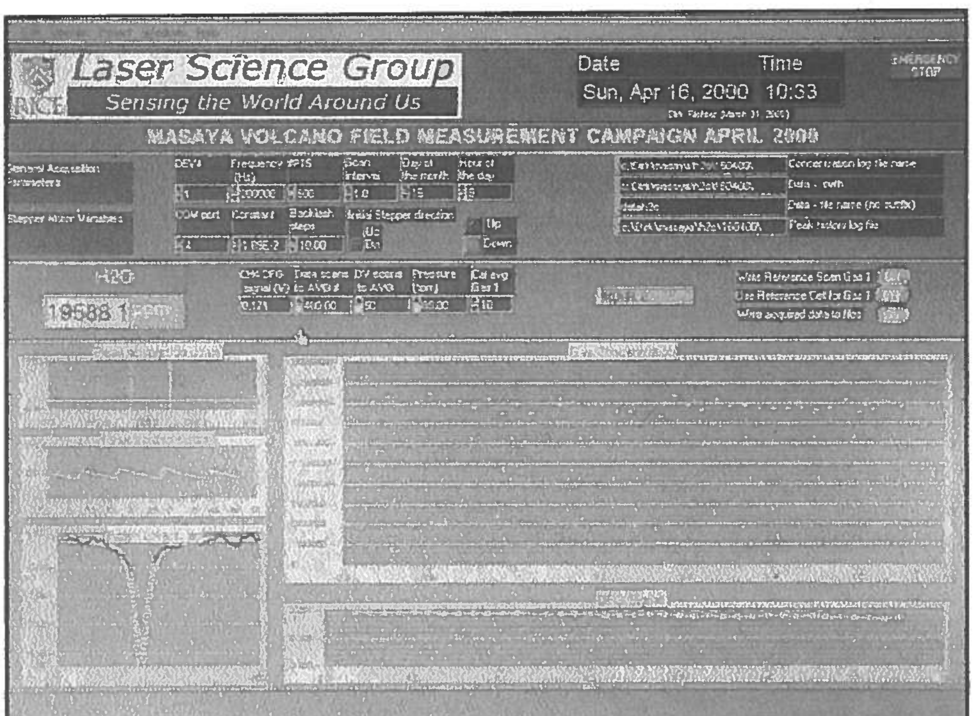


Widely tunable DFG based gas sensor system

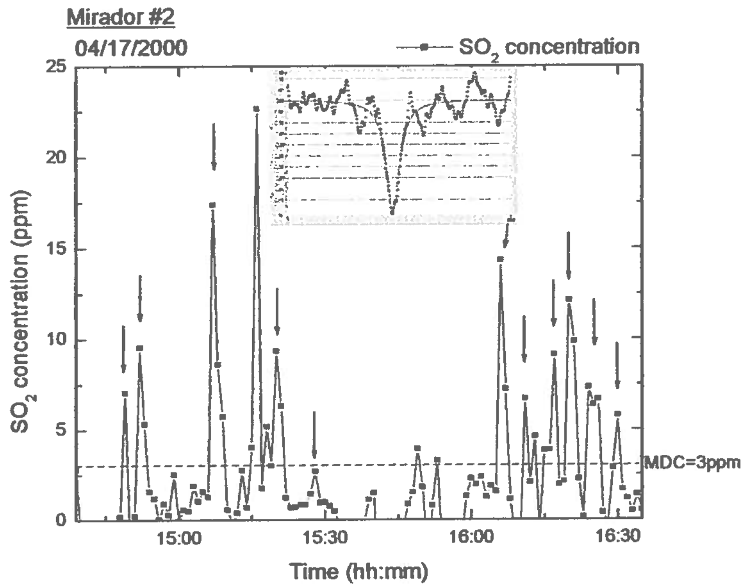







Laser Science Group
Sensing the World Around Us
Date
Time
Sun, Apr 16, 2000
10:33
MASAYA VOLCANO FIELD MEASUREMENT CAMPAIGN APRIL 2000
H2O

▶ Detection of SO_2 at 4.2 μm



▶ Accomplishments

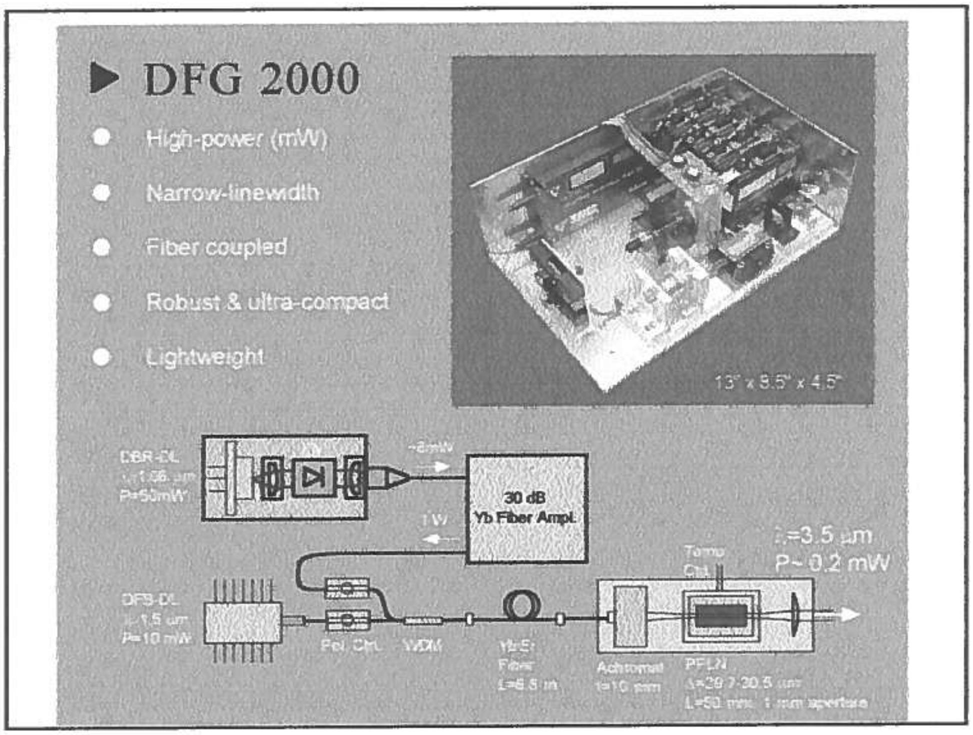
- Successful deployment and operation of two
- DFG based gas sensors at Masaya volcano

- Highly Selective Detection of
- CO2, SO2, $H^{35,37}Cl$, CH4, H2O

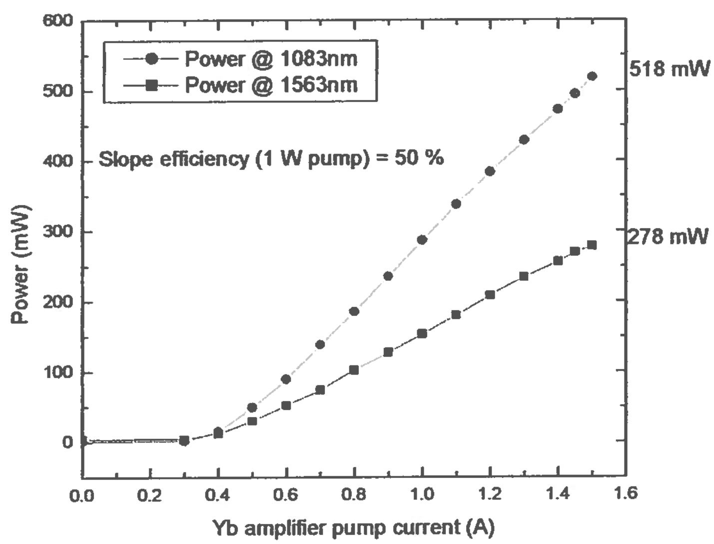
▶ Future improvements:

- Temperature management
- ⇒ Solid state Peltier air-conditioner

- Modular assembly, more compact
- ⇒ Source and detector (extractive or open path)



▶ Yb - Er/Yb Dual Fiber Amplifier Power Output



Summary

- Fiber based DFG gas sensors
- Single and multi-species detection
- Highly sensitive and selective
- Robust field portable technology

Mature technology, ready for use in:

Laboratory, field, industrial and airborne applications

Acknowledgements

RICE

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