MVA Tools

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Los Alamos National Laboratory

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Developing the Technologies and
Infrastructure for CCS

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Presentation Outline

- Benefit to the Program
- Project Overview
  - Goals and Objectives
- Technical Status
- Accomplishments to Date
- Summary
- Appendix
  - Organization Chart
  - Bibliography

Project Overview: Goals and Objectives

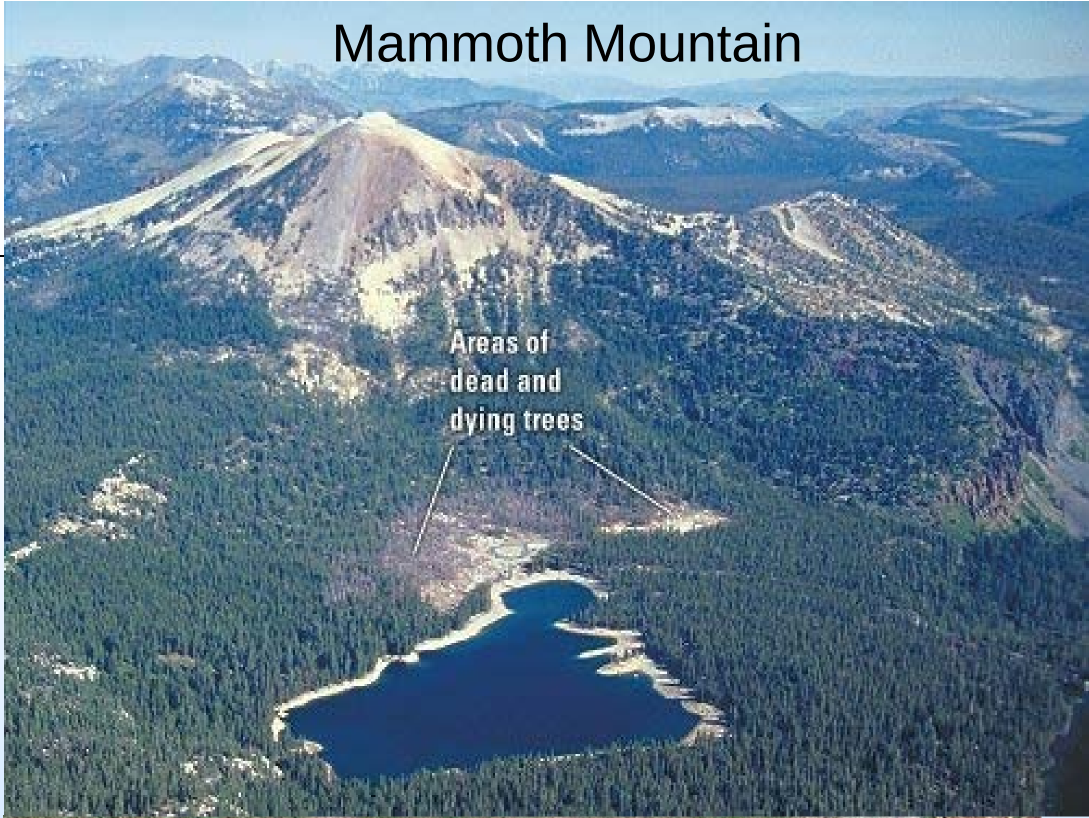
- Surface MVA – Frequency Modulated Spectroscopy
  - Quantitatively identify CO2, H2S and CH4 seepage from geologic sequestration sites
  - Distinguish anthropogenic CO2 from natural CO2 emissions
    - CO2 carbon stable isotope measurements
    - H2S sulfur and CH4 carbon stable isotope measurements
  - Real-time remote and in situ CO2, H2S and CH4 monitoring
- Subsurface MVA – Advanced Seismic Imaging
  - Quantify reservoir geophysical properties changes
  - Design optimal, cost-effective surveys for time-lapse seismic monitoring
  - Monitor potential CO2 leakage through fault zones

Benefit to the Program

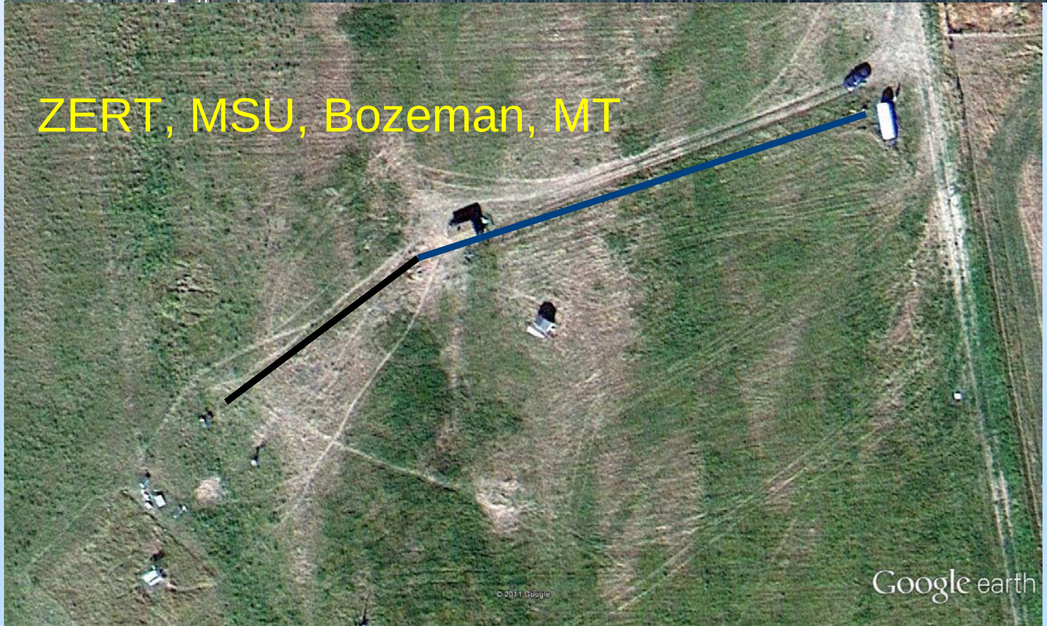
- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
  - Advanced Seismic Reservoir Imaging
- Develop and validate technologies to ensure 99% storage permanence.
  - FMS CO2, H2S, and CH4 Monitoring
  - O2/CO2 Precision Monitoring
  - Advanced Seismic Reservoir Imaging
- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
  - FMS CO2, H2S, and CH4 Monitoring
  - O2/CO2 Precision Monitoring
  - Advanced Seismic Reservoir Imaging
- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.
  - FMS CO2, H2S, and CH4 Monitoring
  - Advanced Seismic Reservoir Imaging

MVA Field Experiments

- 2009 - 2013 Field Experiments
  - Valles Caldera, NM
  - Soda Springs, ID
  - Sevietta Long Term Ecological Research
  - Mammoth Mountain
  - LANL Juniper-Pinion Field Site
- ZERT, MSU, Bozeman, MT
  - Horizontal Well
  - ~2 m Deep
  - Controlled Flow & Release Rate



Mammoth Mountain

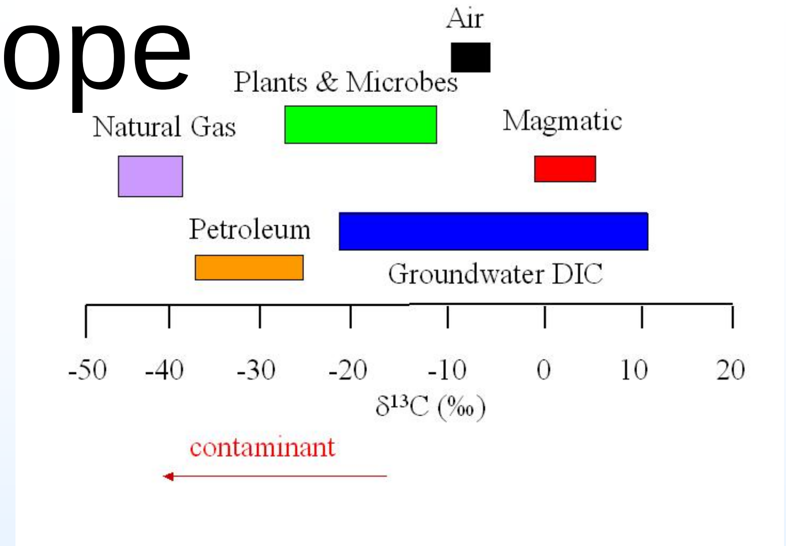


ZERT, MSU, Bozeman, MT

MVA Field Experiments

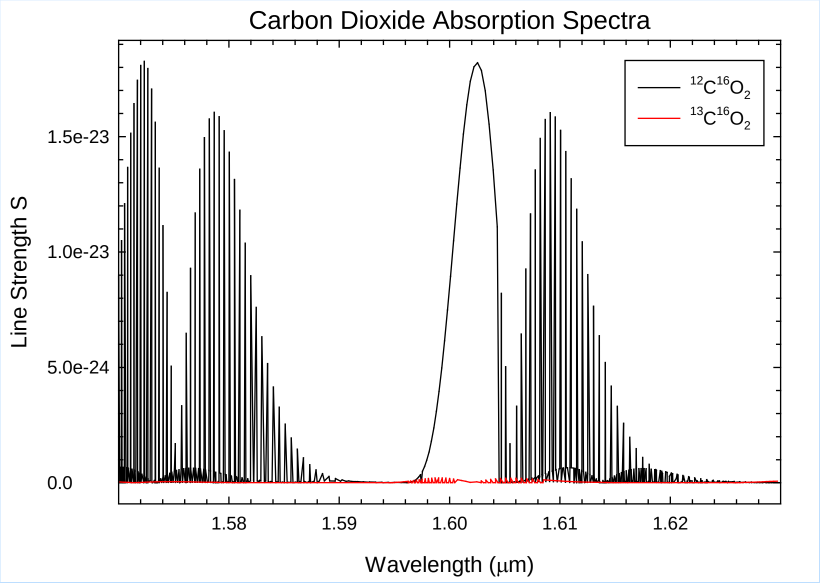
- Frequency Modulated Spectroscopy
  - In situ
  - Remote
  - LIDAR
- In Situ O_2/CO_2
- Flask Collects, Mass Spectroscopy
- Water Stable Isotope Analysis

Carbon Stable Isotope Detection



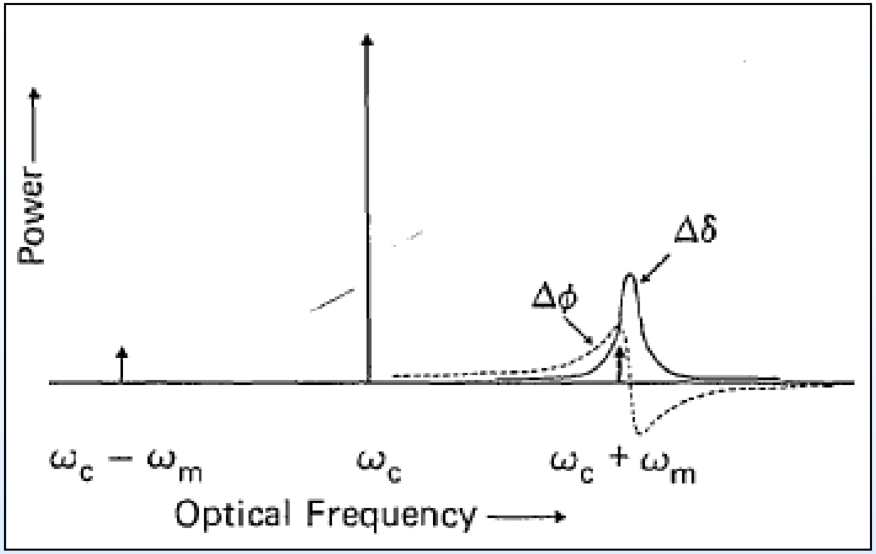
- Detect CO_2 Seepage
  - At Natural CO_2 Emissions
- Generally, the Atmosphere Contains
  - 98.9% $^{12}C^{16}O_2$
  - 1.1% $^{13}C^{16}O_2$
- Absorption Spectroscopy
  - Maximum Line Strength (HITRAN)
  - $^{12}C^{16}O_2$ = 1.83x10-23
  - $^{13}C^{16}O_2$ = 2.10x10-25
- Frequency Modulated Spectroscopy
  - 100x to 1000x more sensitive than absorption spectroscopy

$$\delta^{13}C_{sam} = \left(\frac{13C_{sam}/12C_{sam}}{13C_{std}/12C_{std}} - 1 \right) x1000$$

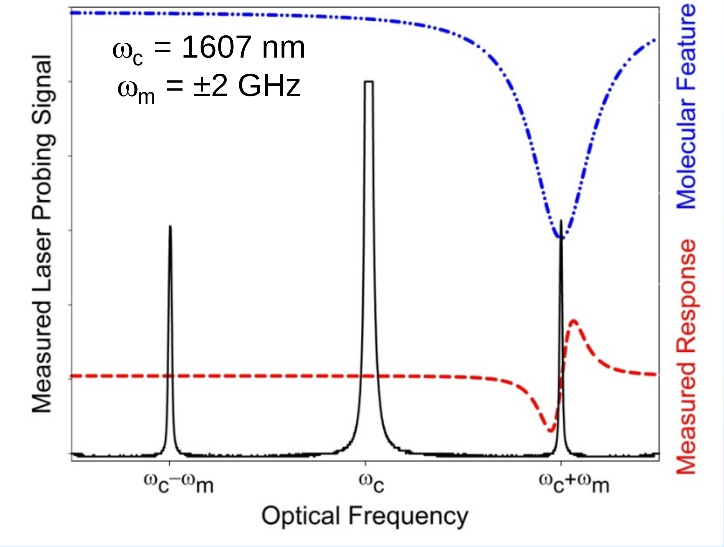


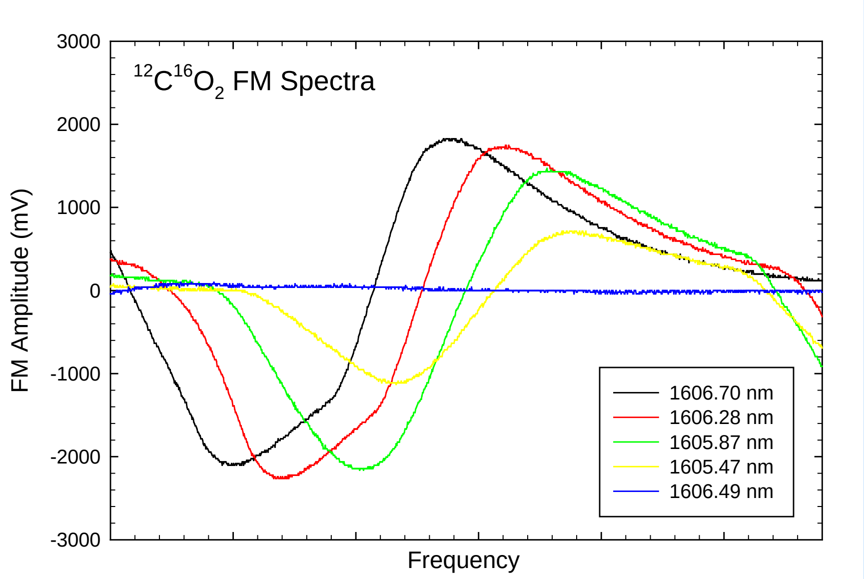
Fundamental Frequency Modulated Spectroscopy

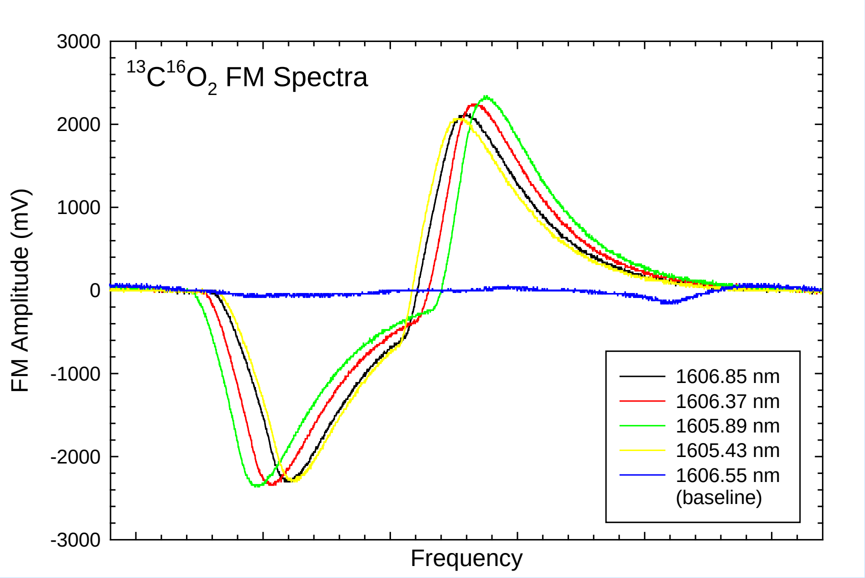
From G.C. Bjorklund Optics Letters, 5, 15, 1980



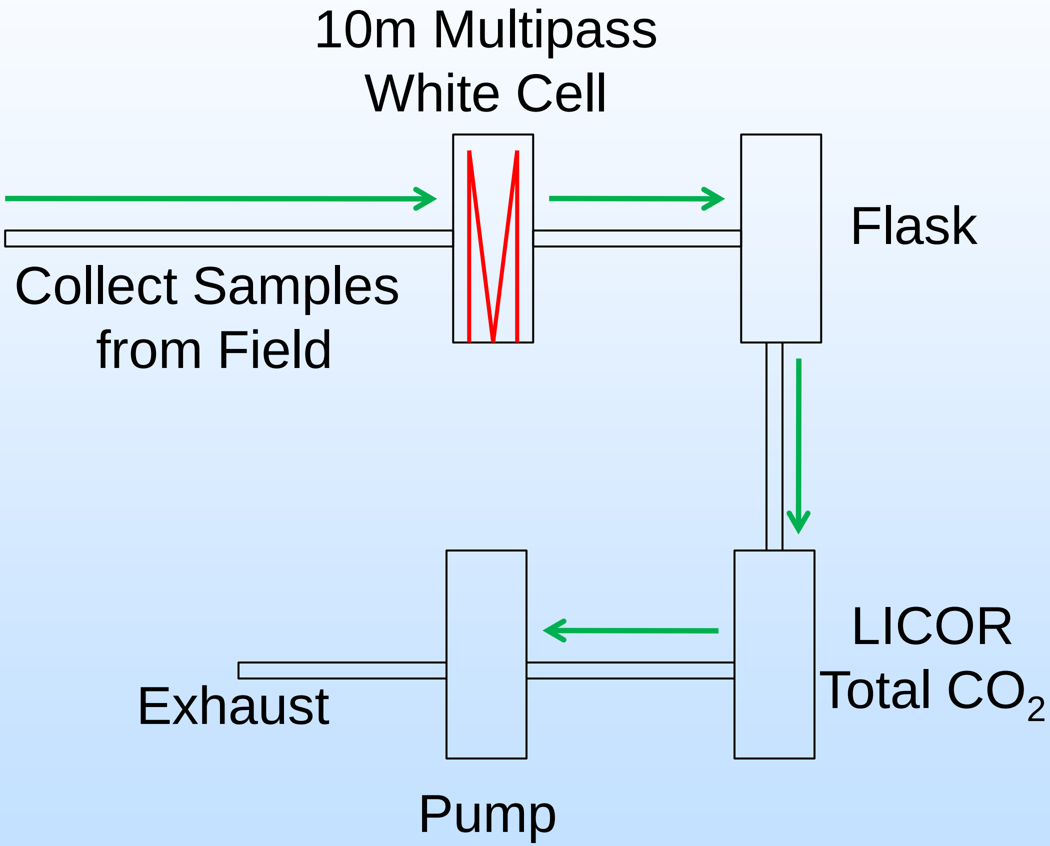
From LANL in situ instrument







In Situ FMS Instrument



10m Multipass White Cell

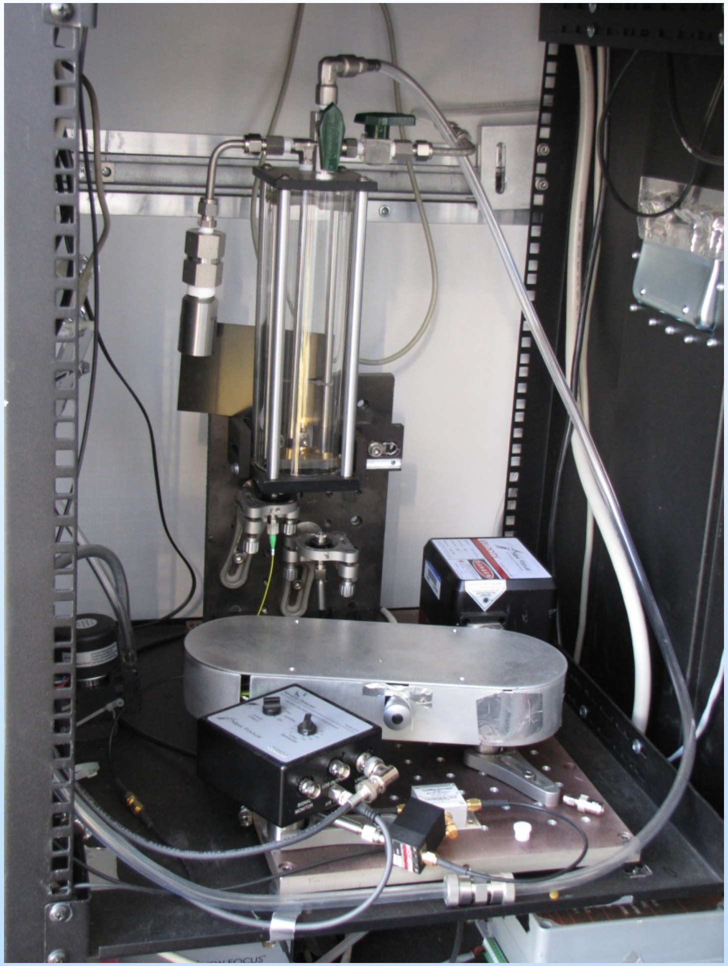
Flask

Collect Samples from Field

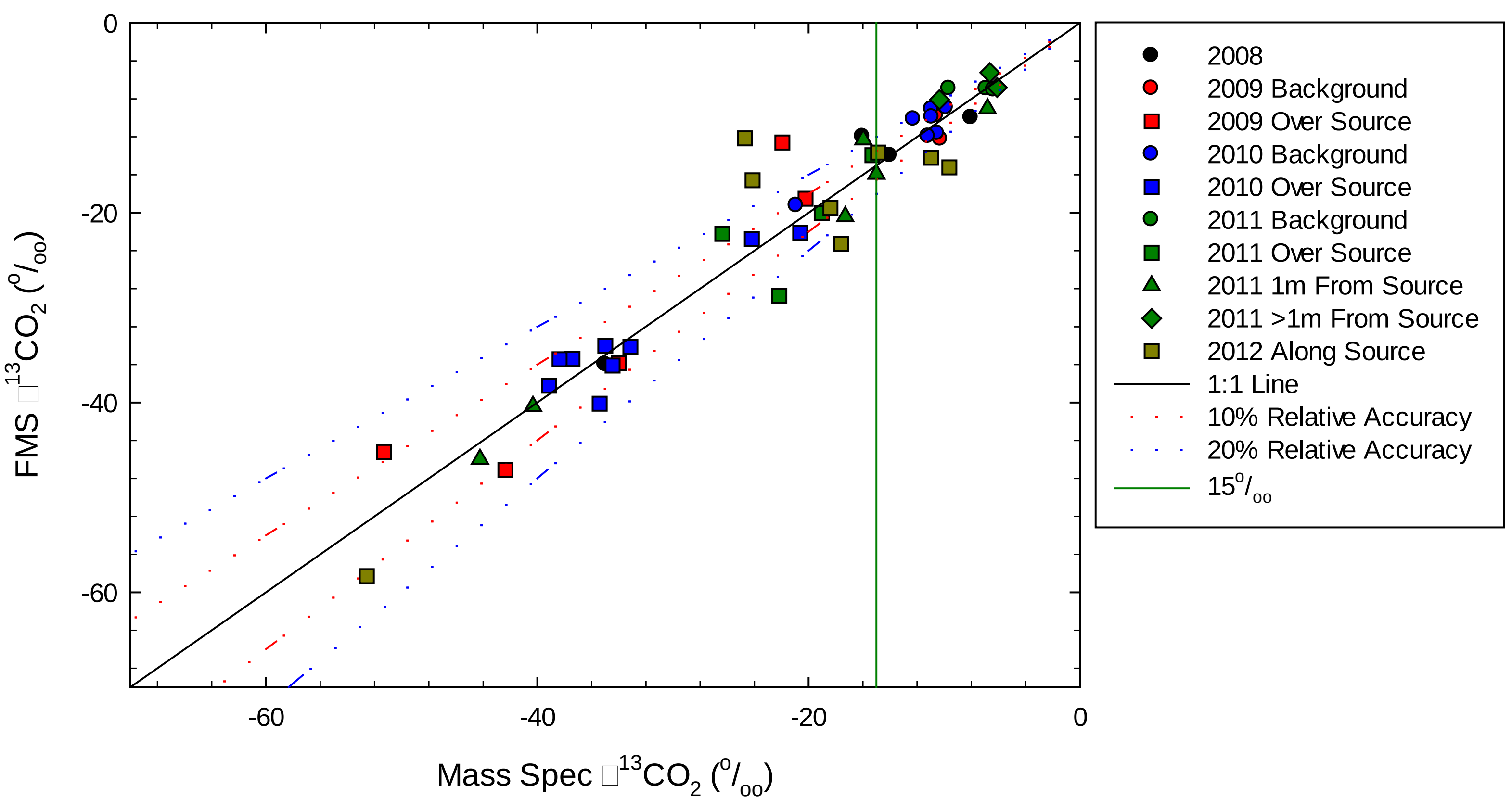
LICOR Total CO_2

Exhaust

Pump



In Situ Observations

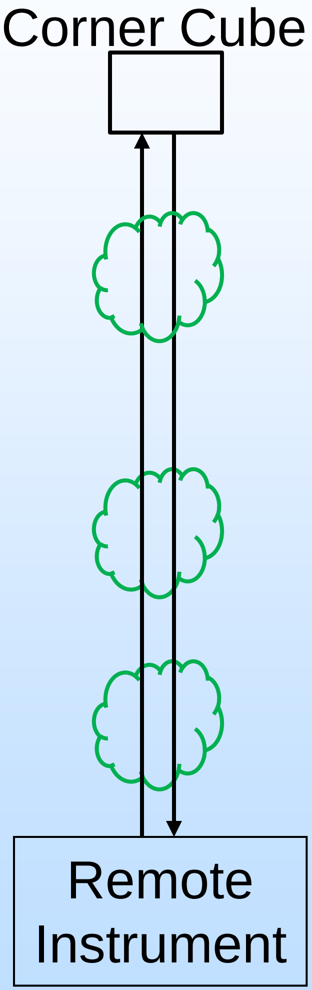


<u>Historical Trends</u>

Background > -15 $^{o}/_{oo}$

Seepage < -15$^{o}/_{oo}$

Remote Instrument



Remote FMS

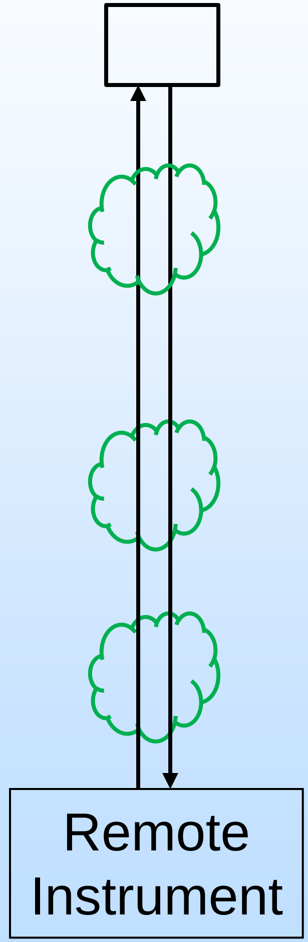
- Stable Isotope Analysis
  - At ZERT,

    2010: $\delta^{13}C \sim -9 - -28\ ^{o}/_{oo}$

    2011: $\delta^{13}C \sim -6 - -28\ ^{o}/_{oo}$

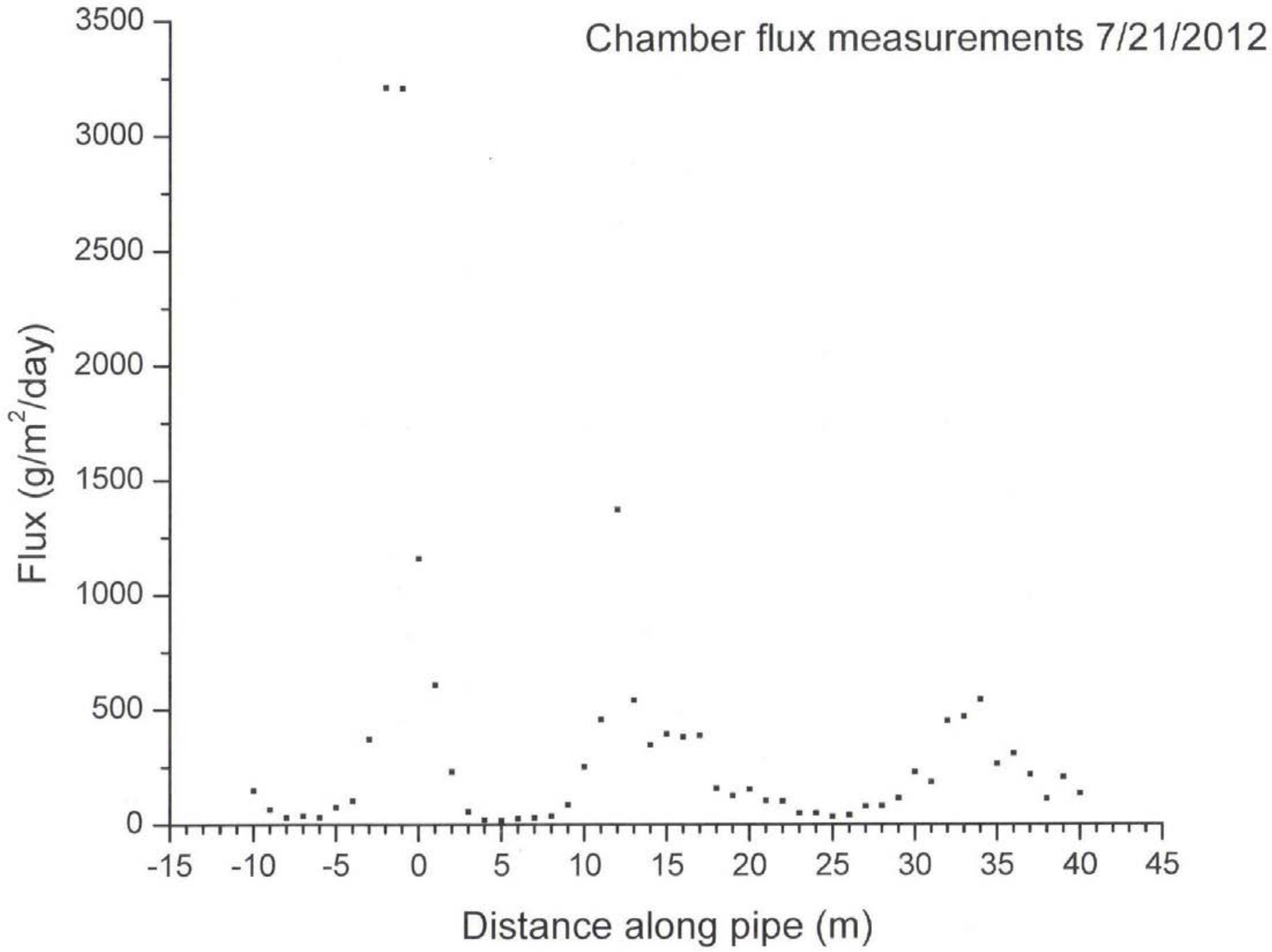
  - Ratio of isotopes to a standard

$$\delta^{13}C_{sam} = \left(\frac{13C_{sam}/12C_{sam}}{13C_{std}/12C_{std}} - 1 \right) x1000$$



Remote Instrument

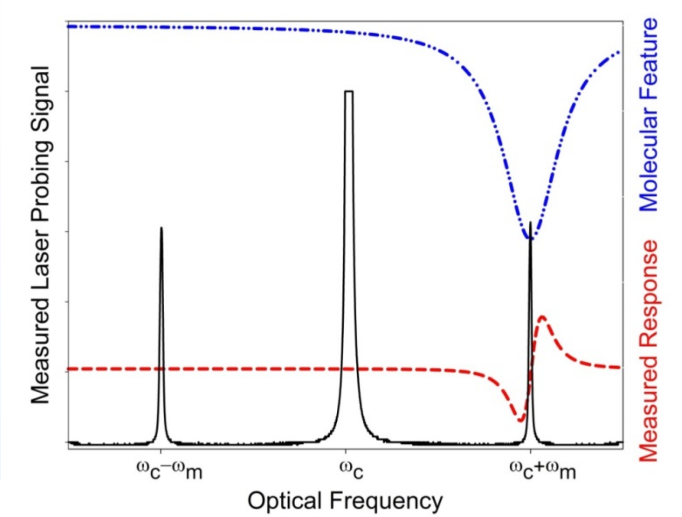
Chamber Measurements Over Source

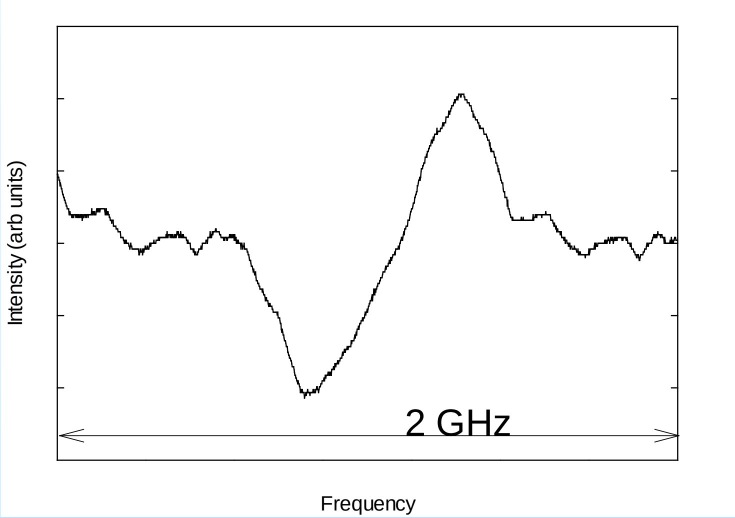


Courtesy Laura Dobeck, Montana State University

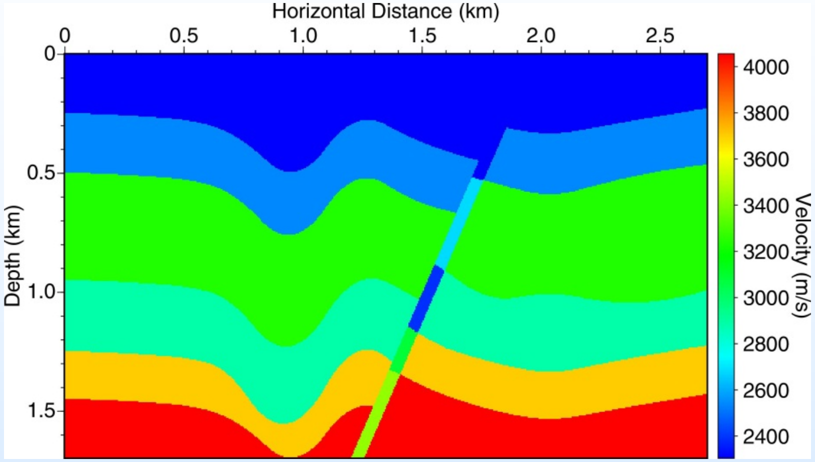
FM-LIDAR

- Direct a CW Laser Across Sequestration Site
- 10ns Modulator Pulse
- Record Time Resolved Return Signal
- Convert Time to Distance

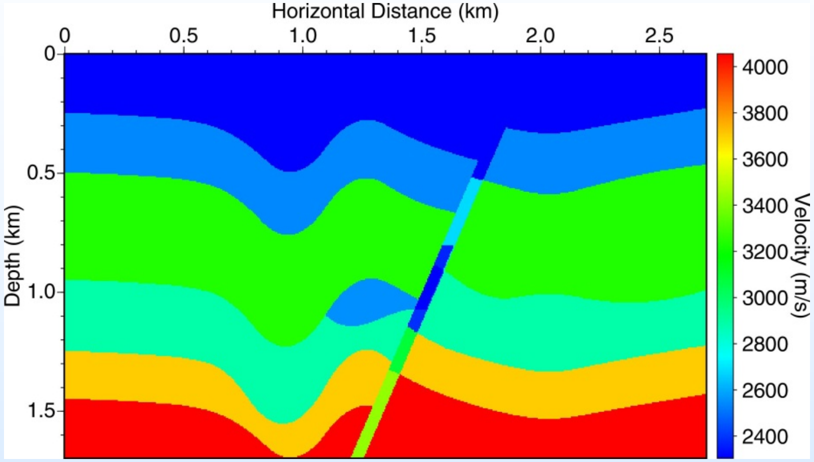




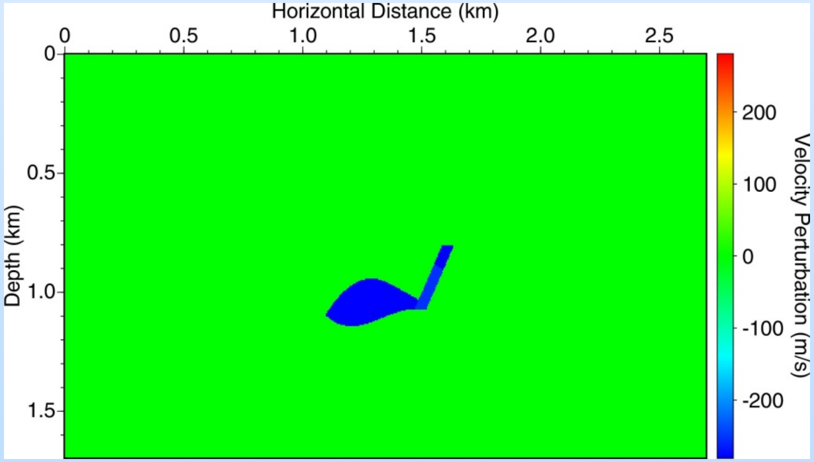
Time-Lapse Models with CO2 Leakage Through a Fault Zone



Initial Model

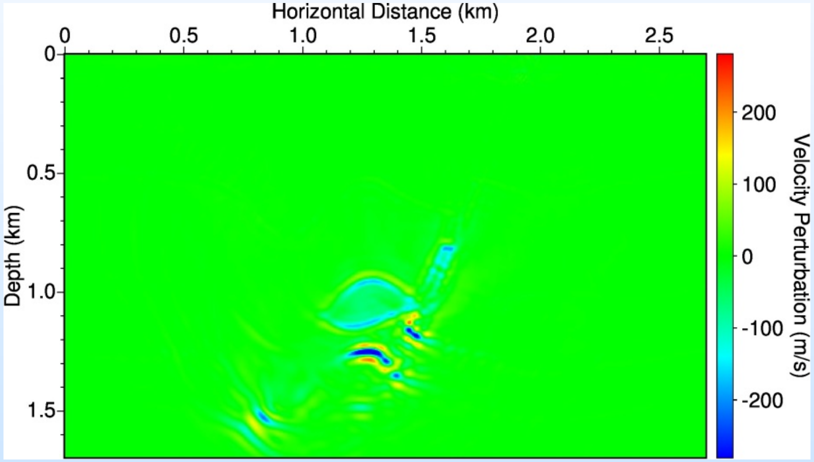


Time-Lapse Model

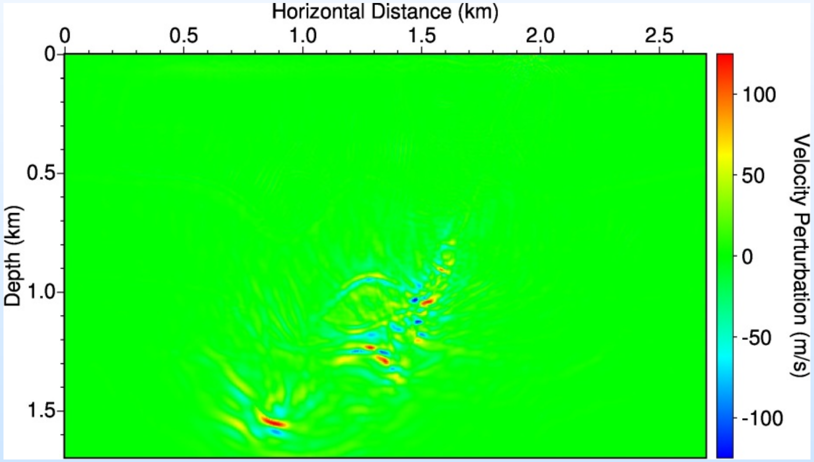


Time-Lapse Change

Conventional Inversion Results of Time-Lapse Changes

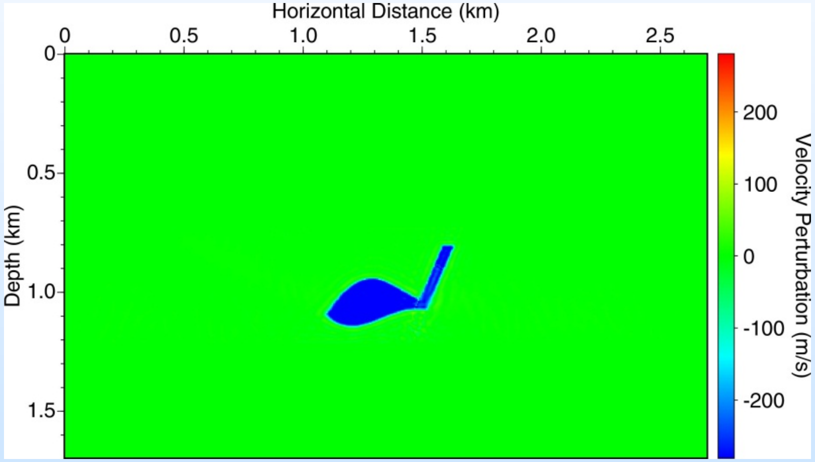


Conventional inversion result of P-wave velocity change

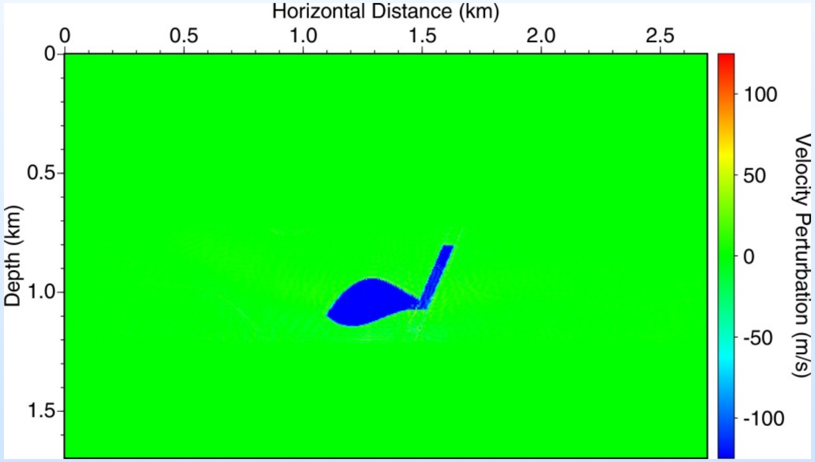


Conventional inversion result of S-wave velocity change

LANL’s Inversion Results of Time-Lapse Changes Using Patchy-Array Data Acquired with Optimal Survey Designs



LANL’s inversion result of P-wave velocity change



LANL’s inversion result of S-wave velocity change

Less than 40% of original full-data are used for this 2D example, indicating that only approximately 15% of original full-data are needed for the 3D case using optimal survey designs.

Accomplishments to Date

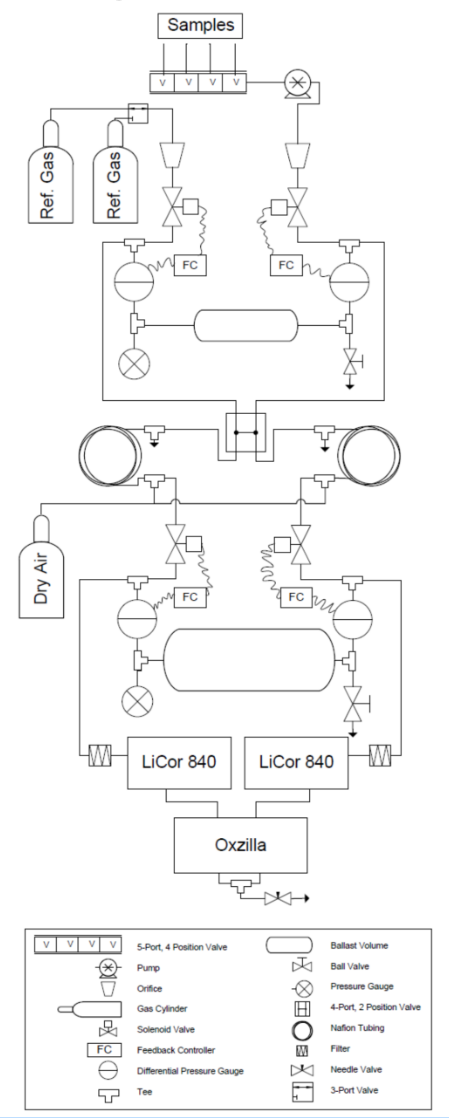
- ✓ Patent 8,390,813 Awarded on March 5, 2013
- ✓ In Situ FMS Instrument Developed
- ✓ Remote FMS Instrument Developed
- ✓ LIDAR FMS Instrument Developed
- ✓ O2/CO2 Instrument Developed
- ✓ Field Demonstration of the Instruments
- ✓ Developed of Novel Seismic Monitoring Methods for Quantifying Reservoir Changes
- ✓ Optimal Designs of Time-Lapse Monitoring Surveys

Summary

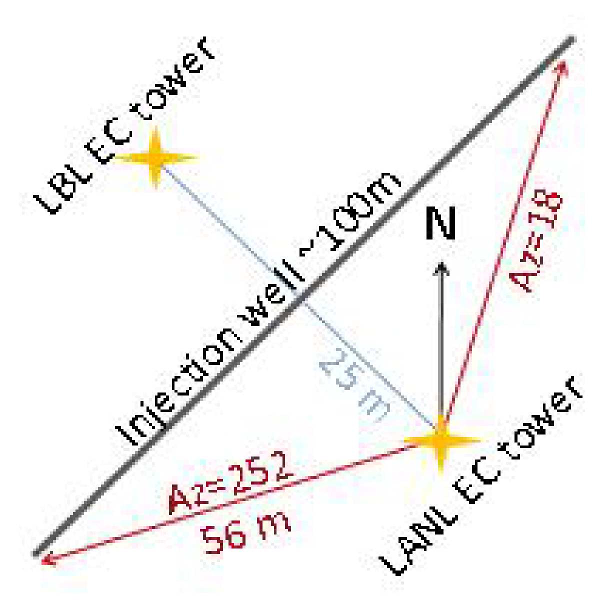
- Key Findings
  - Stable isotopes are a sensitive detector of seepage at the surface
  - O2/CO2 sensitive to diurnal changes in CO2 concentration
  - Joint inversion of time-lapse seismic data significantly improves quantification of reservoir changes
  - Optimal survey designs allow us to accurately and cost-effectively quantify reservoir changes and monitoring CO2 leakage through fault zones
- Lessons Learned
  - Field demonstrations are critical to evaluate the instruments
  - Repeatability of time-lapse surveys is crucial for reliable monitoring
- Future Plans
  - Extend CO2 stable isotope instrument to detect H2S and CH4
  - Apply seismic imaging methods to large scale storage system

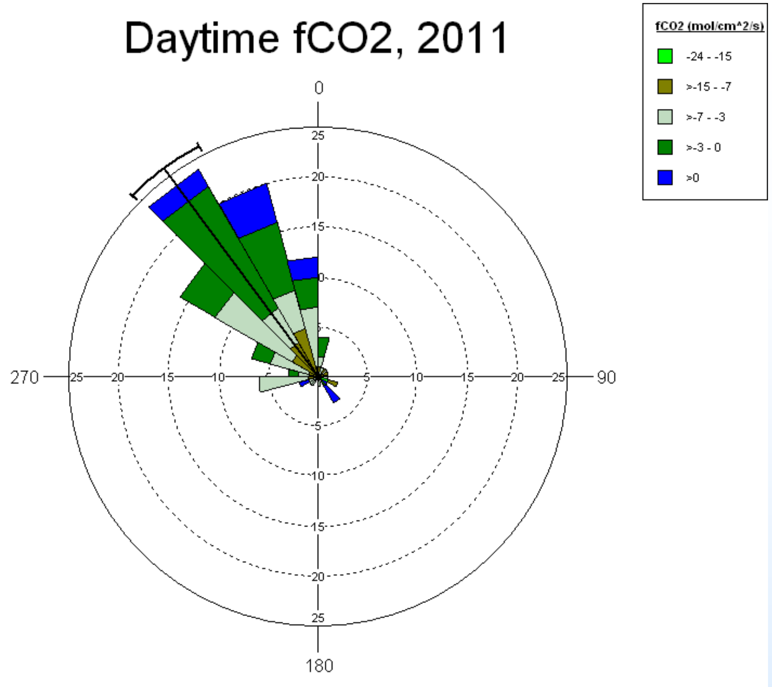
Appendix

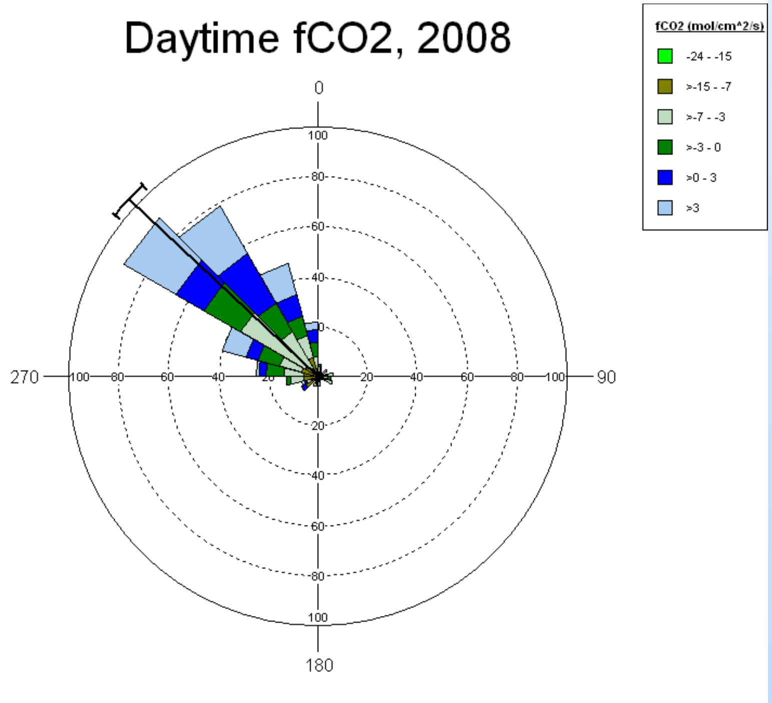
High Precision Oxygen/CO2 Measurements



High Precision Oxygen/CO2 Measurements

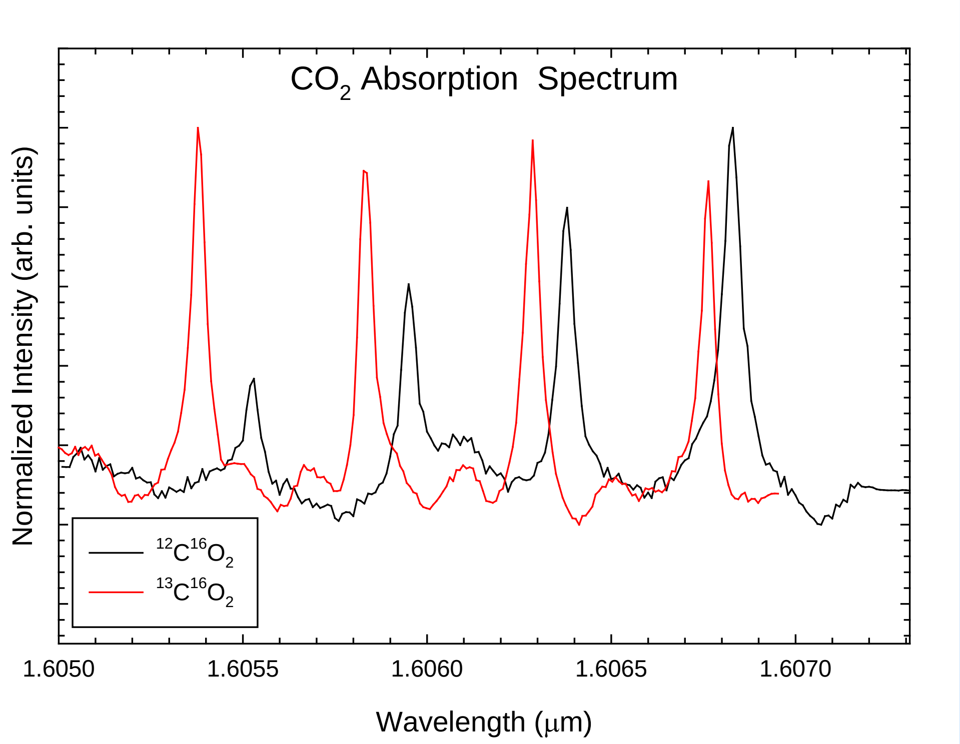



Daytime fCO2, 2011


Daytime fCO2, 2008

Frequency Modulated Spectroscopy

- Why 1570 – 1630nm range?
  - Telecom Electronics (1550nm)
  - Absorption Cross Section for Remote (hundreds of meters)
  - No spectral interferences.
    - H_2O or CO
- Why 1604 – 1609nm range?
  - $^{13}C^{16}O_2$ Peaks between $^{12}C^{16}O_2$ Sub-Bandheads.
  - $^{12}C^{16}O_2$ Peaks ~10x $^{13}C^{16}O_2$



Quantitative Seismic Monitoring

- Developed a suite of novel elastic-waveform inversion methods for building subsurface seismic velocity models (e.g. baseline model)
- Developed a suite of novel elastic-waveform ***joint*** inversion methods for quantifying reservoir geophysical properties changes
- Developed a new numerical method for optimal designs of time-lapse seismic surveys
- Studied effective and reliable monitoring for potential CO2 leakage through fault zones

Organization Chart

- MVA Project PI – Sam Clegg
  - Frequency Modulated Spectroscopy (FMS)
    - Sam Clegg – FMS Development Lead
    - Kristy Nowak-Lovato – FMS Instrument Development
    - Julianna Fessenden – Stable Isotope Geochemist
    - Ron Martinez– Technician
  - O2/CO2
    - Thom Rahn – O2/CO2 Instrument Development Lead
  - Advanced Seismic Imaging
    - Lianjie Huang - Advanced Seismic Imaging Lead
  - Field Work Coordination
    - Julianna Fessenden
    - Kristy Nowak-Lovato – FMS Instrument Development

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- Peer Reviewed Publications (1/2)

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  - Julianna E. Fessenden and Samuel M. Clegg, Carbon Dioxide Stable Isotope Detection of Geological Sequestration Seepage, 2008 AGU Meeting.
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  - Samuel M. Clegg, Seth D. Humphries, Julianna E. Fessenden, Laura M. Dobeck, Lee H. Spangler, Seepage CO2 Detection using ZERT Controlled Release site in Bozeman, MT, 2009 AGU Meeting.
  - Seth D. Humphries, Julianna E. Fessenden, and Samuel M. Clegg, Geological Sequestration Seepage Identification with Carbon Stable Isotopes, 2009 CCS Conference.
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