ARPA-E Methane Detection Workshop

April 23, 2013, Fort Collins, CO

Report out from March 29, 2012 ARPA-E Emerging Ideas Workshop on Ubiquitous Methane Sensing

"Sensors and Networks Integrated for Finding Emissions Remotely" (SNIFFER)

Phil Larochelle

arpa·e

Full Presentations from Workshop available on ARPA-E Website:

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Emerging Ideas Workshops→
“Ubiquitous Methane Leak Sensing…”

Methane Emissions from the U.S. Natural Gas Industry and Leak Detection and Measurement Equipment

March 29, 2012

Roger Fernandez
U.S. EPA

Leak Survey Methods

- Leak detection tools
  - Infrared cameras
  - Catalytic oxidation/thermal conductivity detector
- Leak measurement tools
  - Acoustic leak detector and quantifier
  - Hi Flow Sampler
  - Calibrated vent bag
  - Vane/hot wire anemometers
  - Ultrasonic flow meter
  - Turbine meter

The technologies mentioned in this presentation are those that Natural Gas STAR Partners have reported using from own projects and experience. EPA is not endorsing a particular technology or brand.

Future Wish List

Remote sensing equipment that MEASURES emissions

Companies are working on this but equipment completion date is unknown the Energy to Lead

GTI – Addressing Methane Emissions

Kiran Kothari and Jack Lewnard
Gas Technology Institute

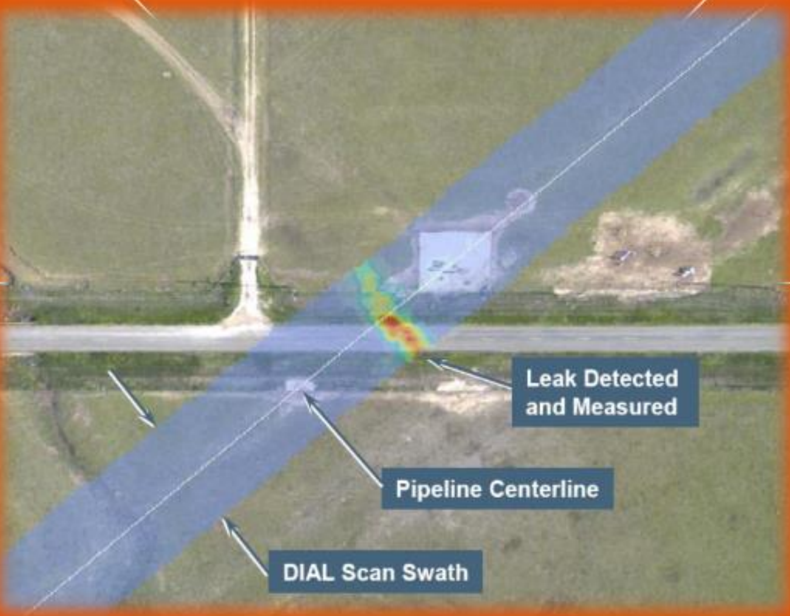
ARPA-E Emerging Ideas Workshop

March 29, 2012

gti

Identifying Solutions: Example Methane RD&D Projects

- Commercial leak detection tools based on filtered infra-red detection
  - Optical Methane Detector
  - Portable Methane Detector
  - Ethane Detector
- LLC Remote Leak Survey Tool
- Isotopic Discrimination - GYRO
- MEMs Methane Sensor



ITT EXELIS

ANGEL Services

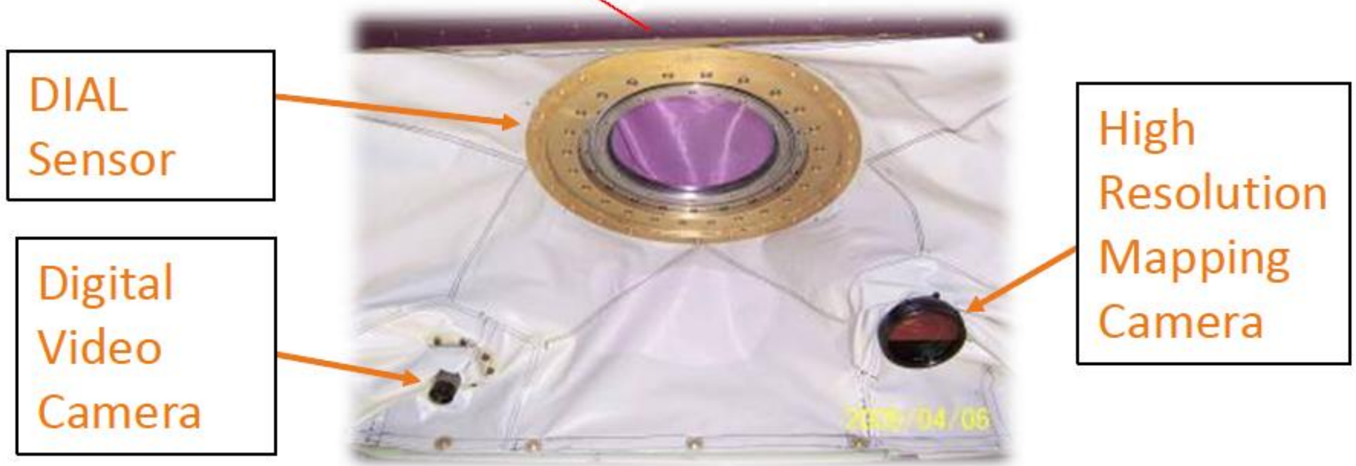
(Airborne Natural Gas Emission LIDAR)

Technology Development & Industry Experience

Dan Brake – Extended Enterprise
Sharon Abbas – Environmental Intelligence

ITT ANGEL Services

Aircraft and Sensor Suite



ITT ANGEL Services - *We Can.*

Low power and lightweight UAV sensors for methane and other petrochemical tracers

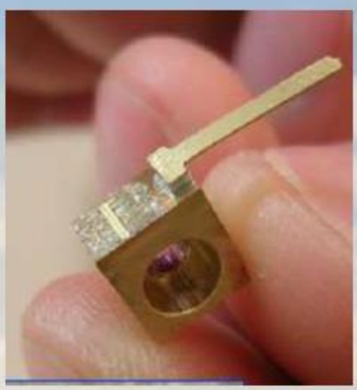
Mark A. Zondlo

Amir Khan, Lei Tao, David Miller, Kang Sun, Minghui Diao

Dept. of Civil and Environmental Engineering
Princeton University

ARPA-E Workshop:
Ubiquitous methane leak etection through novel sensors and sensing platforms

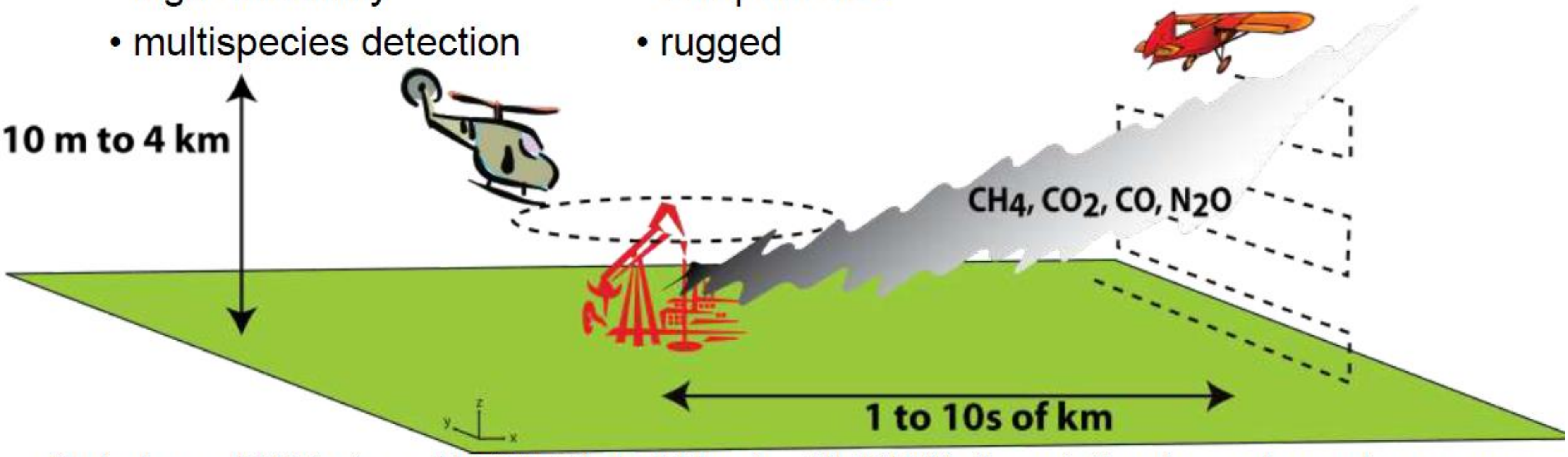
29 March 2012, Washington, DC



Why laser-based sensors for methane on UAVs?

Performance
- high sensitivity
- fast response (<< 1 Hz)
- high selectivity
- multispecies detection

Physical specifications
- low power (~ 1 W)
- low mass (~ kg)
- compact size
- rugged



Only large UAVs (e.g. NASA Global Hawk, SIERRA) fly existing laser-based sensors

To fully utilize UAV capabilities, need low power, light weight, compact sensors for smaller, cheaper, easier-to-deploy UAVs and UAV fleets

Our key innovations: ***Vertical cavity surface emitting lasers***
Open-path spectroscopy
Multiharmonic in-line stability system

Vertical cavity surface emitting lasers (VCSELs)

<u>Characteristics</u>

- Inexpensive for mass production
- Very large tuning range
- Low power draw (15 mW)
- Near-infrared

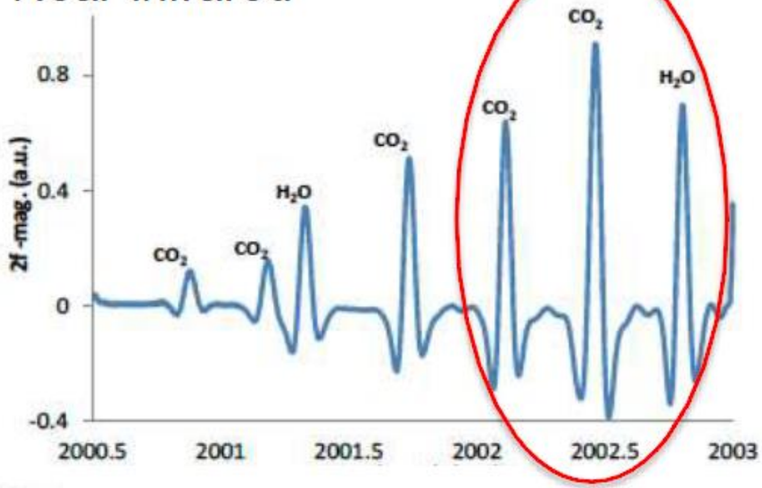
<u>Attributes for sensing</u>

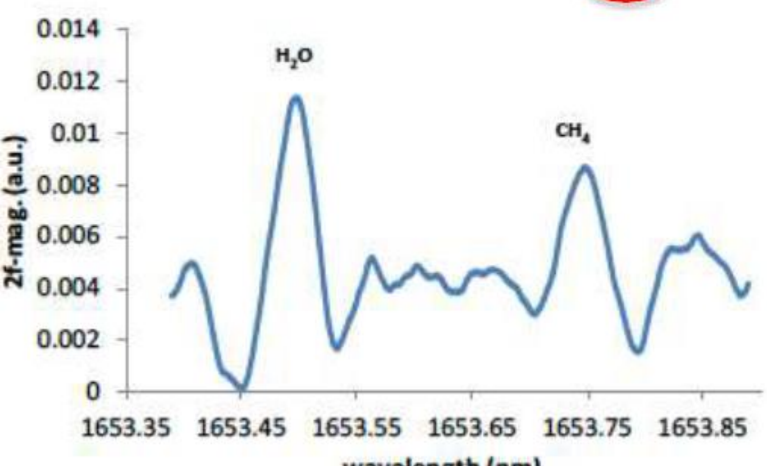
Inexpensive ($5/laser in large qty.)

Multispecies detection at high S/N

Low power, lightweight sensors

Spectrally clean absorption lines





Above: VCSEL hygrometer for NSF Gulfstream-V aircraft, >700 flight hours, 0-15 km, polar regions to tropics (Zondlo et al., *J. Geophys. Res.*, 2010)

Quantum cascade lasers: simultaneous N_2O, CO, and C_2H_2

<u>Characteristics</u>

- probes fundamental ro-vi bands
- mid-infrared spectral region
- fully cryogenic-free

<u>Attributes for sensing</u>

- high sensitivity, simple designs
- most key atmospheric species
- long-term operation

N_2O precision at 1 Hz = 0.06 ppbv

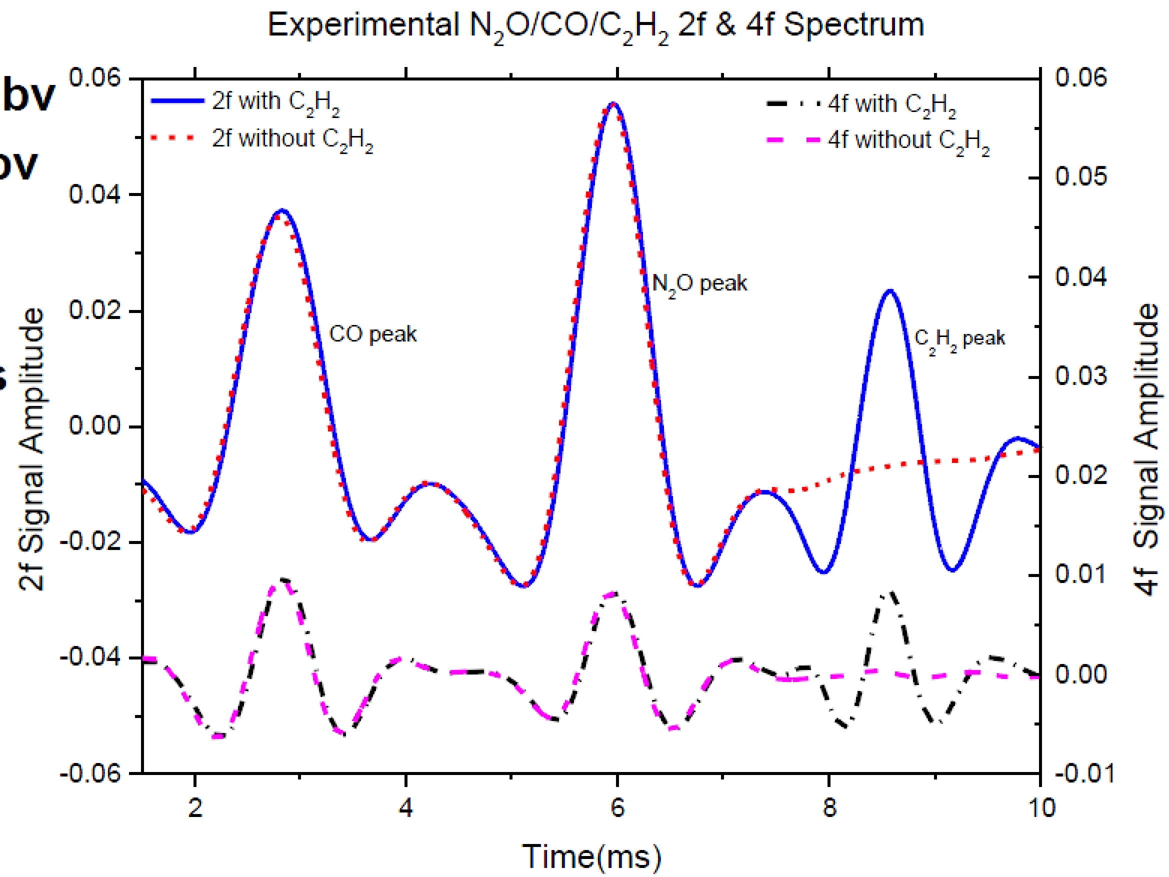
CO precision at 1 Hz = 0.12 ppbv

Multiharmonic in-line maintains calibration of <0.4 ppbv N_2O over 24 hours

y

10 kg, 40 W, 35 x 18 x 15 cm

Tao et al., *Appl. Phys.* B, 2012b



- **CO distinguishes CH_4 from combustion, uncombusted leaks**
- **N_2O, C_2H_2 plume tracers when released at source (emissions)**

In-situ and Standoff Gas Detection Using Laser Spectroscopy

Kumar Patel

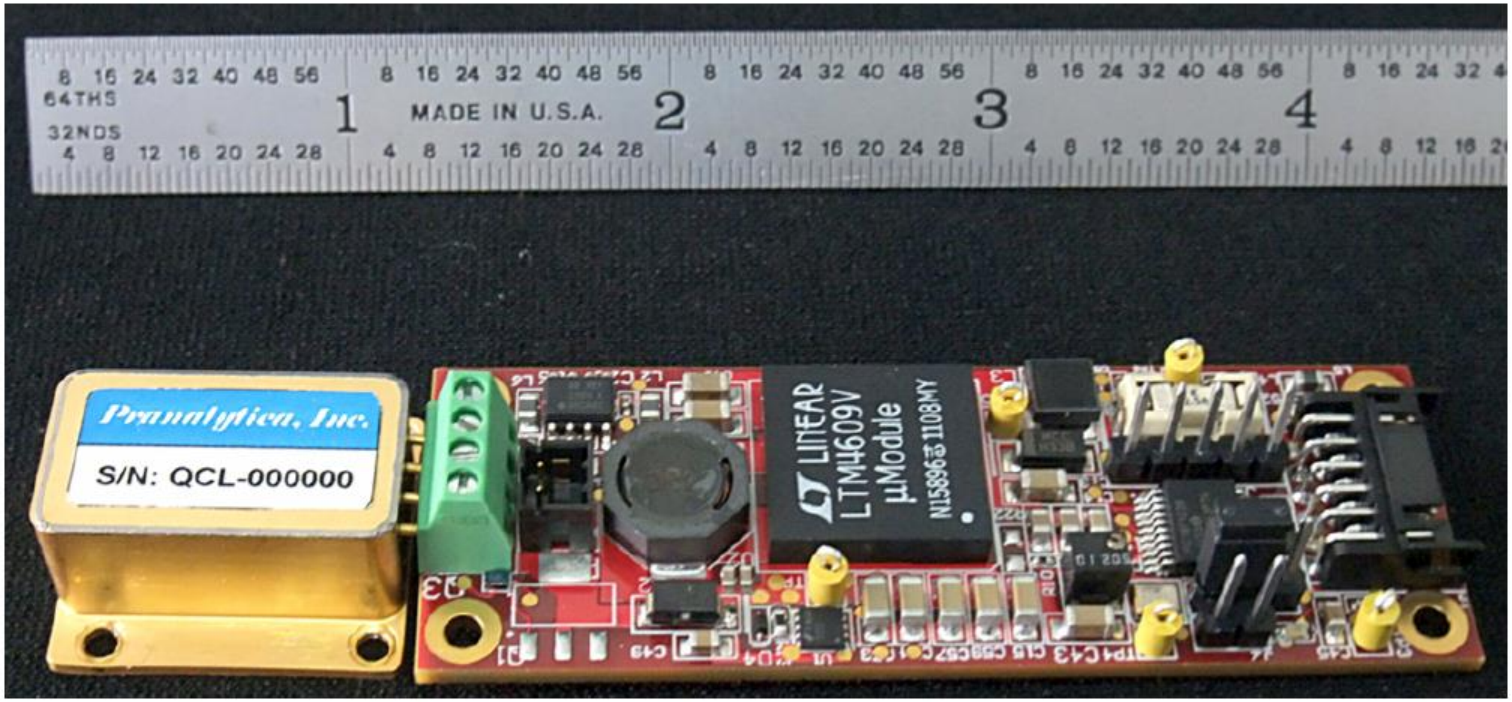
Presentation at

ARPA-E Workshop

Ubiquitous Methane Leak Detection Through Novel Sensors and Sensing Platforms

March 29, 2012

Ultra Small, Ultra Light QCL Package



Total weight < 2 Oz; WPE 10%

Meets MIL-STD VIB/SHOCK/TEMP requirements

Pranalytica *In-Situ* Gas Sensors

GAS	SENSITIVITY	GAS	SENSITIVITY
Acetic acid	200 ppt	Nitric acid	1 ppb
Acrolein	500 ppt	Nitric oxide	1 ppb
Ammonia	100 ppt	NO_2	0.5 ppb
Arsine	1 ppb	Ozone	500 ppt
1,3-butadiene	500 ppt	Phosphine	1 ppb
DMMF	500 ppt	Silane	200 ppt
Ethylene	200 ppt	SF_6	1 ppt
Formaldehyde	1 ppb	Toluene	1 ppb
Methane	100 ppt	Xylene	1 ppb

PRINCETON UNIVERSITY LASER SENSING LABORATORY
PULSE

ARPA-E Workshop 2012
Washington, DC
March 29, 2012

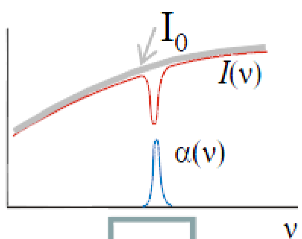
Optical heterodyne detection in the mid-infrared: capabilities and new molecular sensing applications

Gerard Wysocki

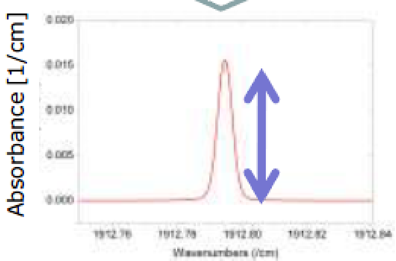
Electrical Engineering Dept., Princeton University, Princeton NJ

email: gwysocki@princeton.edu; web: pulse.princeton.edu

Absorption vs. Dispersion Sensing

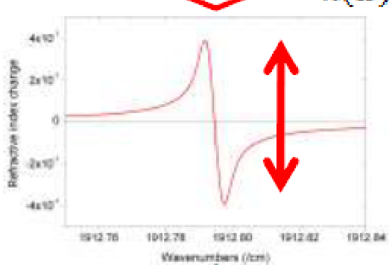


Baseline correction



Kramers-Kronig:

$$n(\omega) = 1 + \frac{c}{\pi} \int_0^{\infty} \frac{\alpha(\omega')}{\omega'^2 - \omega^2} d\omega'$$



Dispersion measurement

???

- Well understood Beer-Lamberts Law, but….
- **intensity fluctuations=measurement error**
- In direct LAS signal is measured with **baseline**
- **Above 10% absorption** the Beer-Lambert law becomes highly **non-linear**

EASY

for 1% of NO in N_2 mixture at 5 Torr and 15 cm optical path:

- Peak absorption → **~20%** → **easy**
- Peak-to-peak refractive index change → **~ 8 × 10^{-7}** → **challenging**

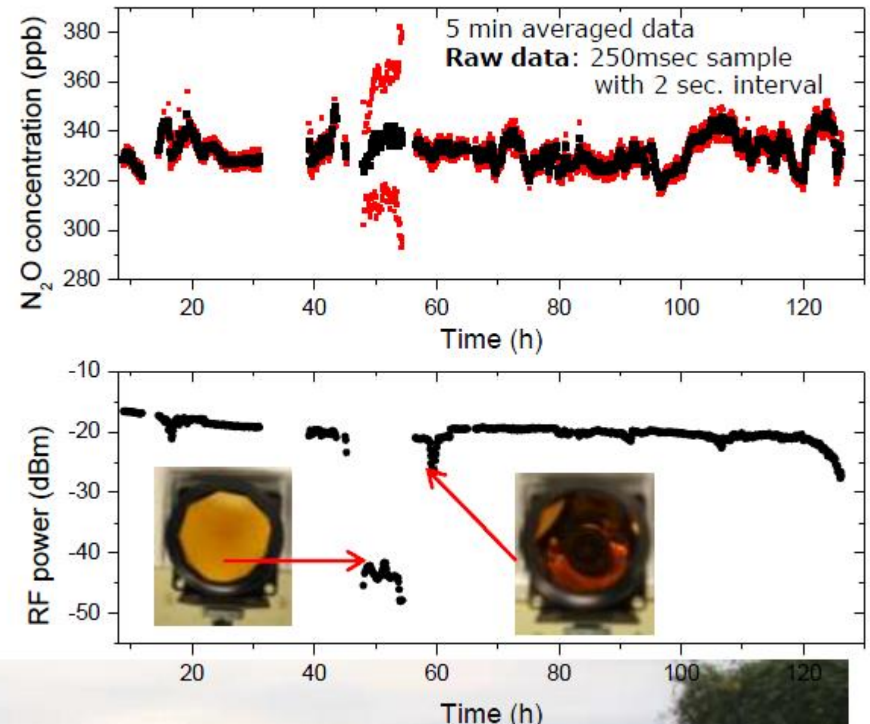
CHALLENGING

- Useful signal encoded in phase of light

→ **immune to intensity fluctuations**.

- **No baseline**
- Dispersion changes **linearly with concentration**

Dispersion-based sensor deployment (Baltimore, MD)




BOEING
INSITU
ScanEagle
Unmanned
Aircraft System
Gary Viviani
V.P. InSitu

ScanEagle EO Unmanned Air Vehicle

Advanced Unmanned Systems | **ScanEagle**

Wingspan	**10 ft**
Length	**4 ft**
Diameter	**7 in**
Max Gross Weight	**44 lbs**
Max Container Dim	**7 x 2 x 1.5 ft**
Max Container Wgt	**112 lbs**
Max Level Speed	**75 kts**
Cruise @ max wt	**48 kts**
Ceiling @ max wt	**19,500 ft**
Endurance	**>20 hours**

Sensor Turret System

- Electro-Optical Camera
  - Streaming color video
  - 25:1 Optical Zoom
  - Image Stabilization
- Infrared Camera
  - Uncooled
  - Long-Wavelength
  - 18 deg FOV
  - 30 Frames per Second
  - Image Stabilization

Laser-based Standoff Methane Detectors

ARPA-E WORKSHOP:
Ubiquitous Methane Leak Detection through Novel Sensors and Sensing Platforms

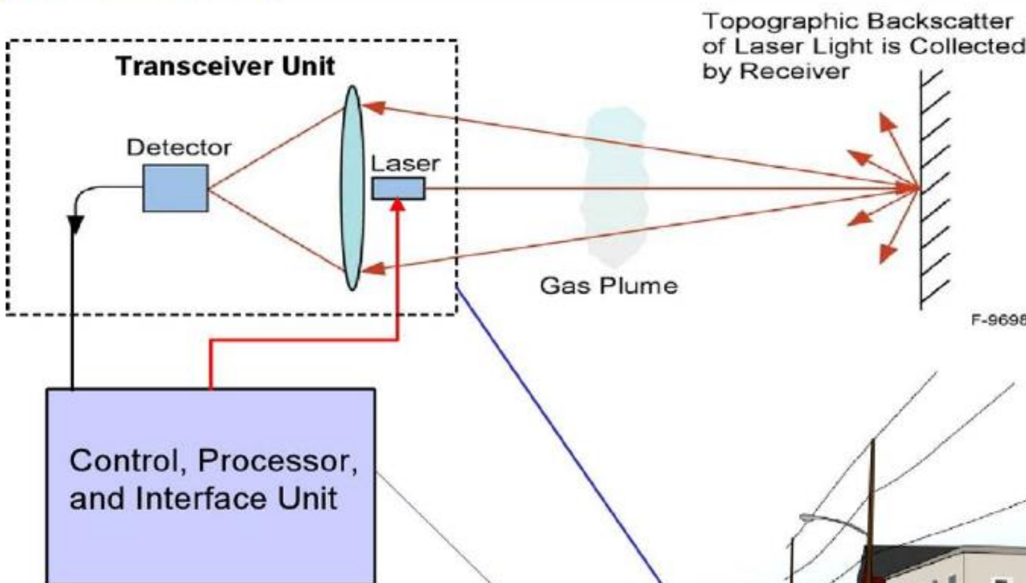
Washington, DC
29 March 2012

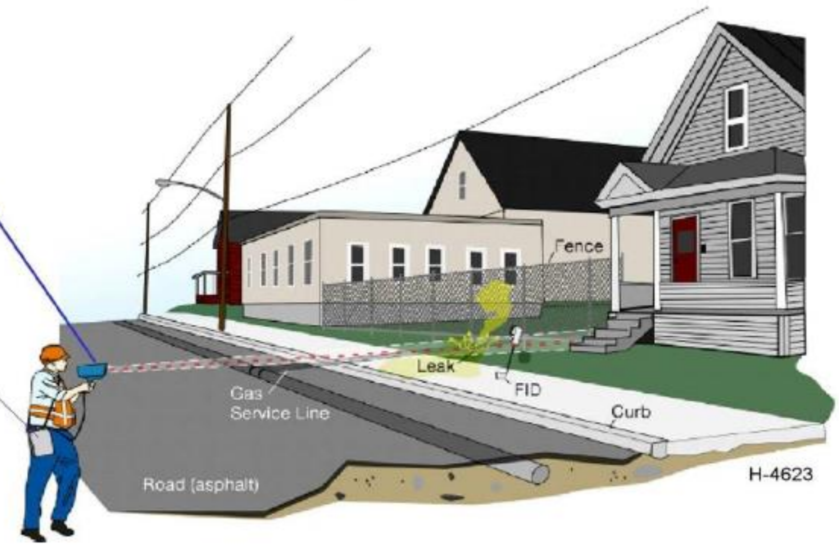
Dr. Mickey Frish
Manager, Industrial Sensors
Physical Sciences Inc.
Andover, MA
frish@psicorp.com

Portable Standoff TDLAS Product:
The Remote Methane Leak Detector (RMLD™)

Physical Sciences Inc.

VG12-042





- **Like a flashlight, laser beam Illuminates a surface up to 100 feet distant**
- **Senses target gas between surveyor and illuminated surface**

- ***>1500 in use for natural gas (CH_4) distribution pipeline leak surveying***

HEATH CONSULTANTS

Physical Sciences Inc.

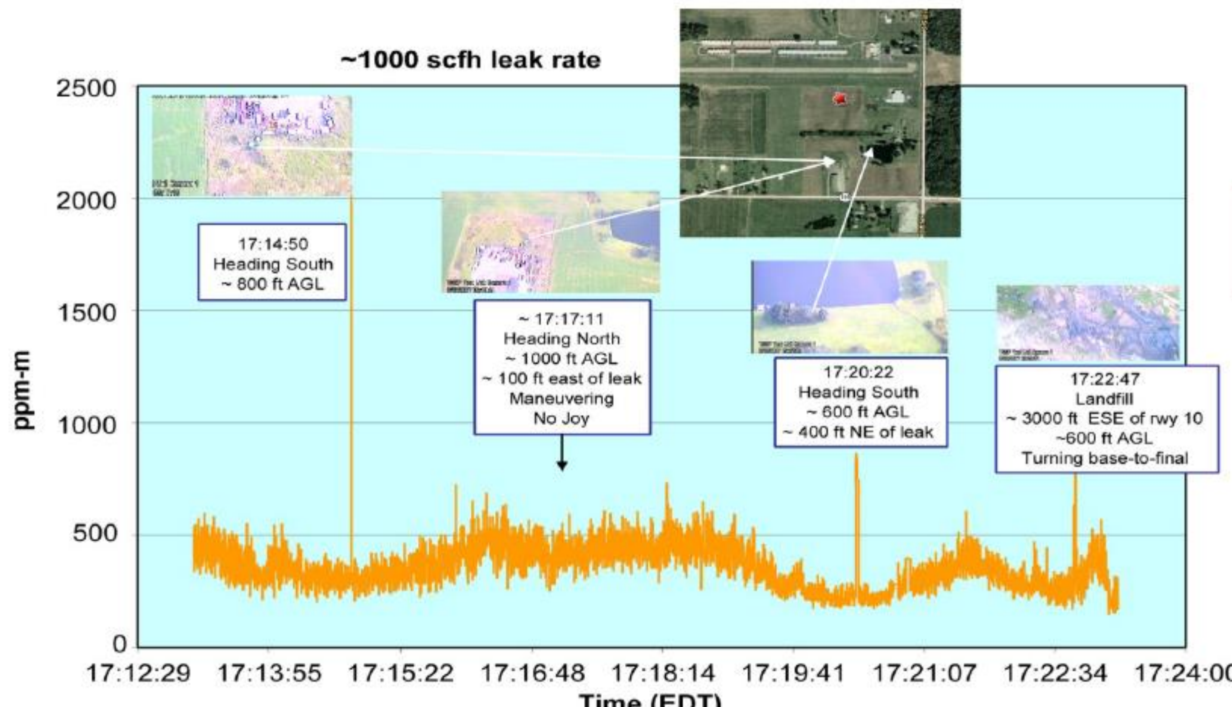
Aerial RMLD™

VG12-042

Fixed-wing

Helicopter

Mini-UAV



Leak detection from fixed-wing aircraft

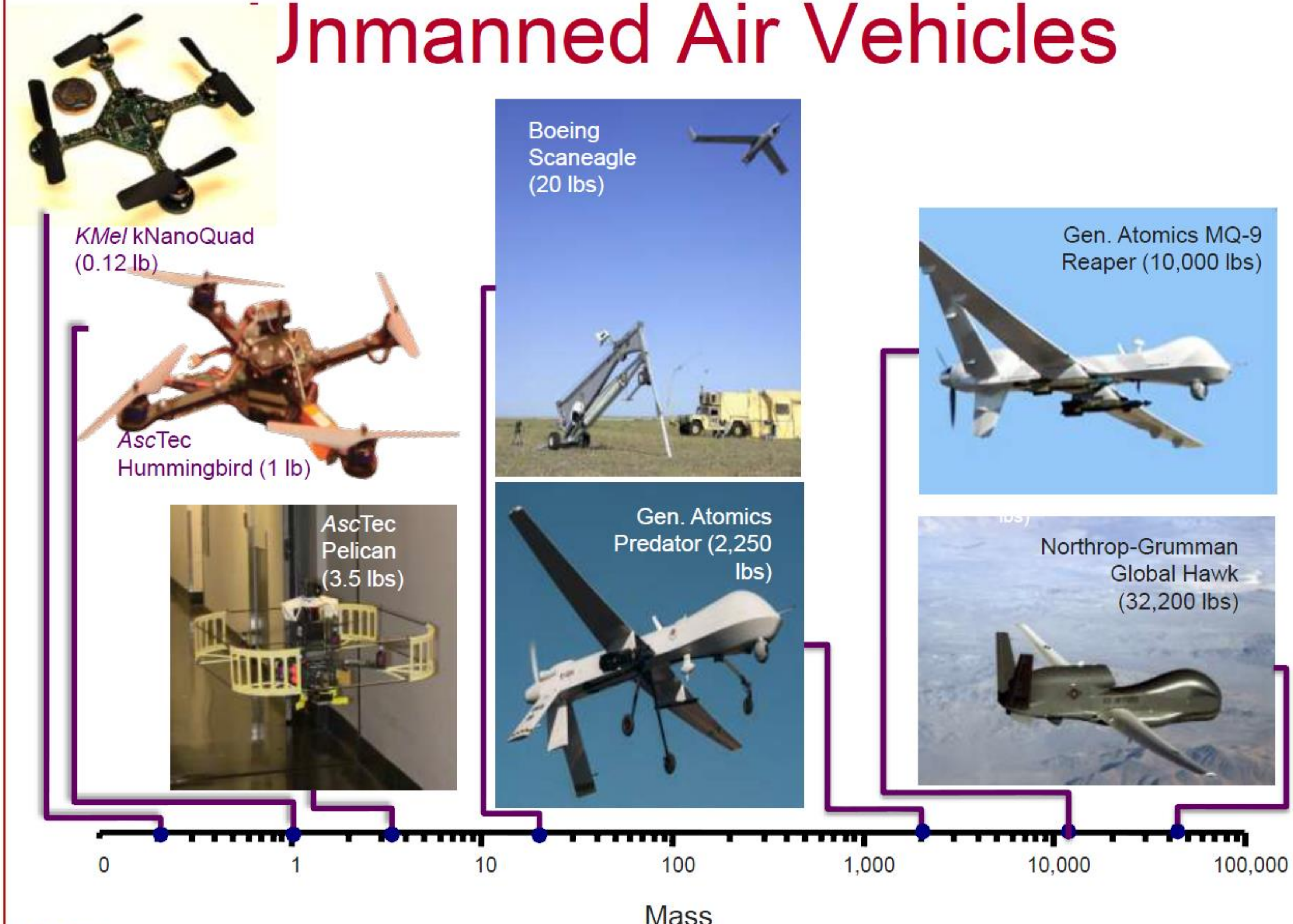
HEATH CONSULTANTS

Swarms of Micro Aerial Vehicles for Active Sensing and Monitoring

Vijay Kumar
UPS Foundation Professor
Departments of Mechanical Engineering and Applied Mechanics
and Computer and Information Science
Member of the GRASP Laboratory
University of Pennsylvania

www.seas.upenn.edu/~kumar

Unmanned Air Vehicles



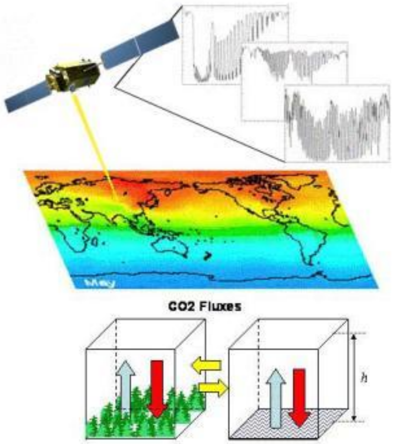
Images from www.af.mil

Conclusions

- Many sensor options available
  - In situ sensors with high precision
  - Remote sensors, limited range, precision
- Many sensing platforms available
  - Airborn sensor platforms demonstrated
  - Unmanned aircraft (drones) intelligently controlled
  - "Unmanned" aerial vehicles are not so unmanned
- Questions unanswered
  - Is this a technology challenge?
  - What metrics are needed to drive adoption?

A Possible Vision of Ubiquitous Methane Sensing did Emerge

Start with satellite/high altitude/low resolution data



Narrow area down with low altitude flights

Measure/ mitigate with handheld inspection, drive by, or swarms of intelligent drones