Beyond Inspections:

How Remote Monitoring is Altering Air Emission Measurements

NCASI Eastern Regional Meeting
Atlanta, Georgia
June 4-6, 2018

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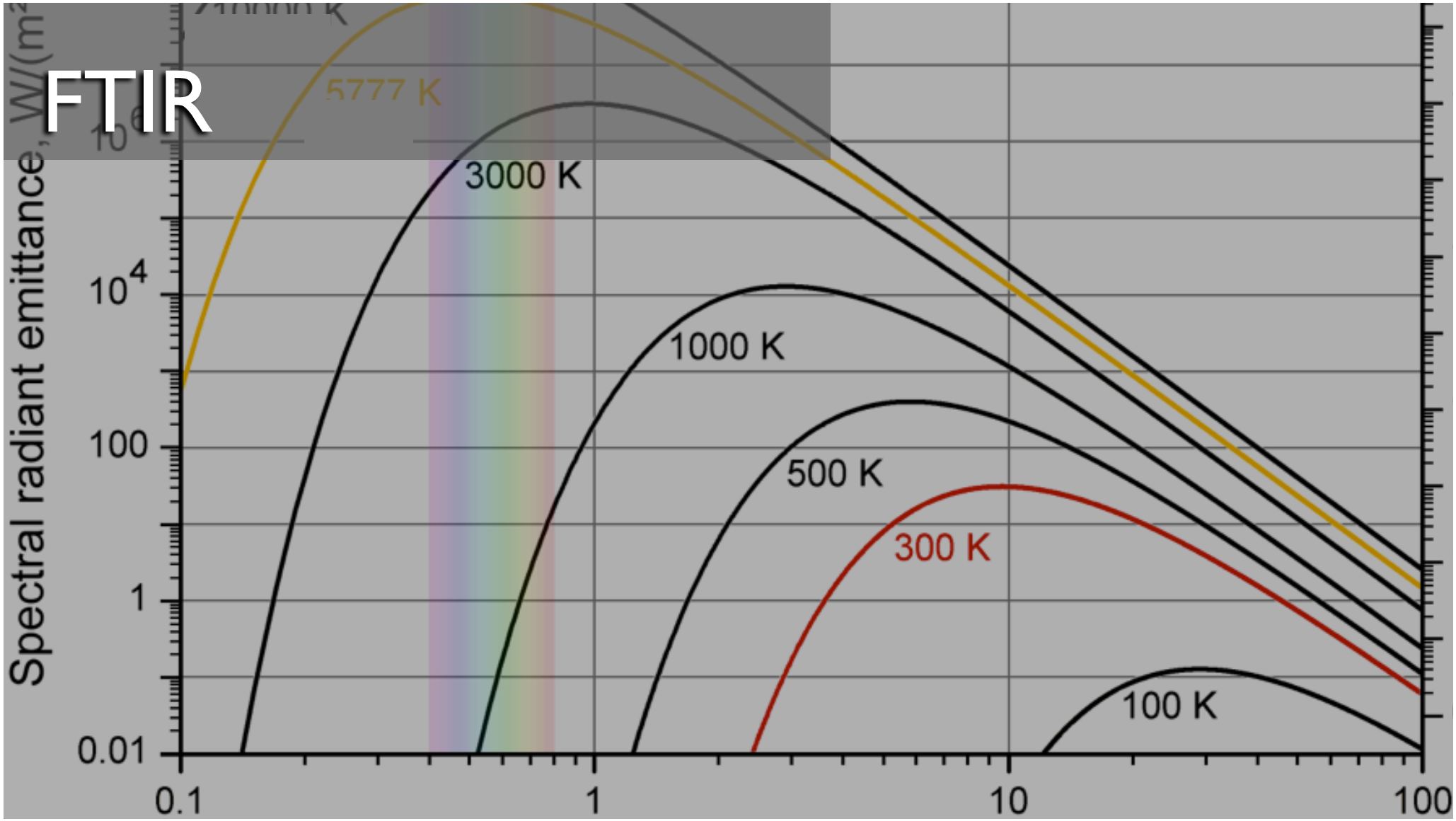
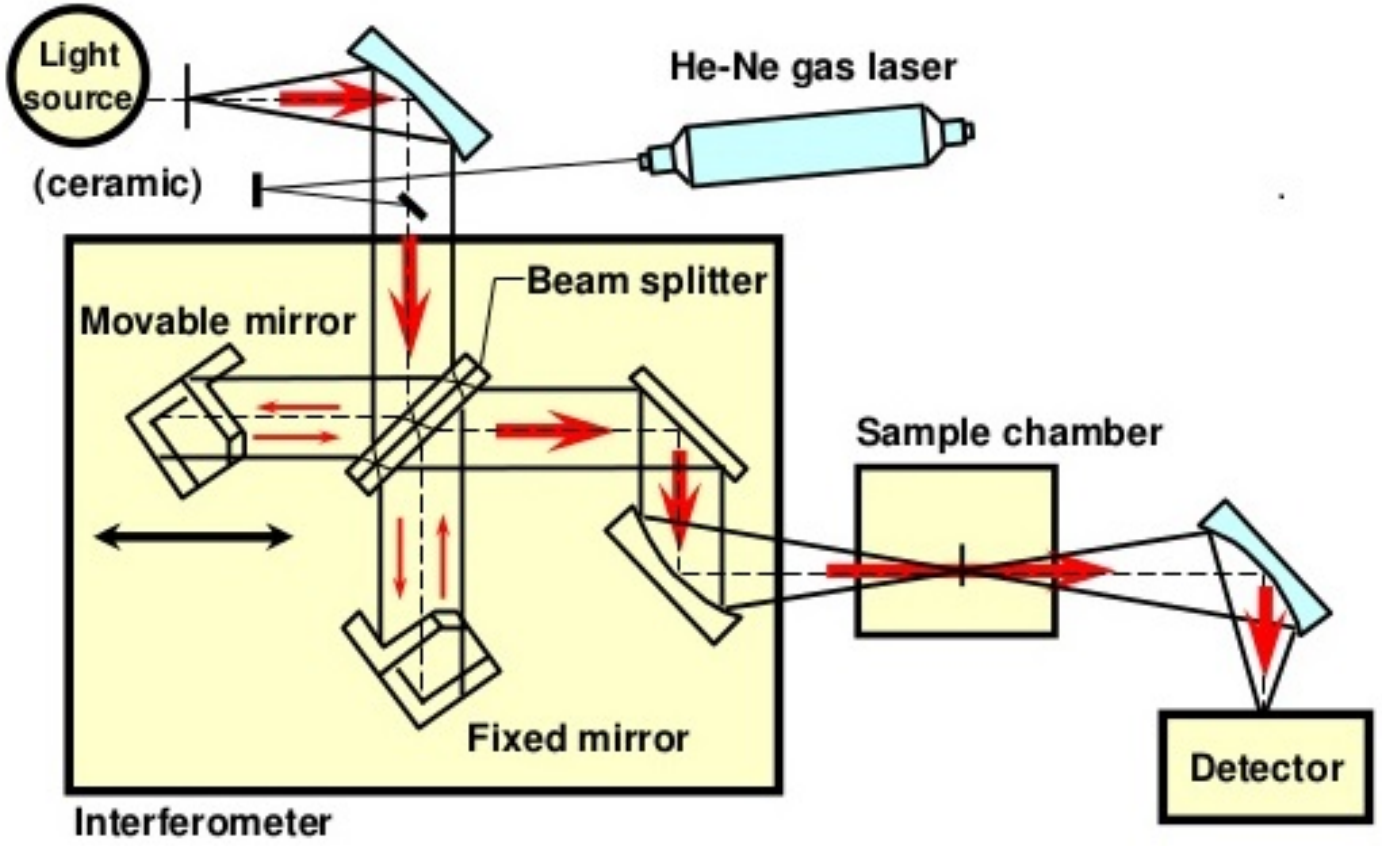
Clean Air Engineering

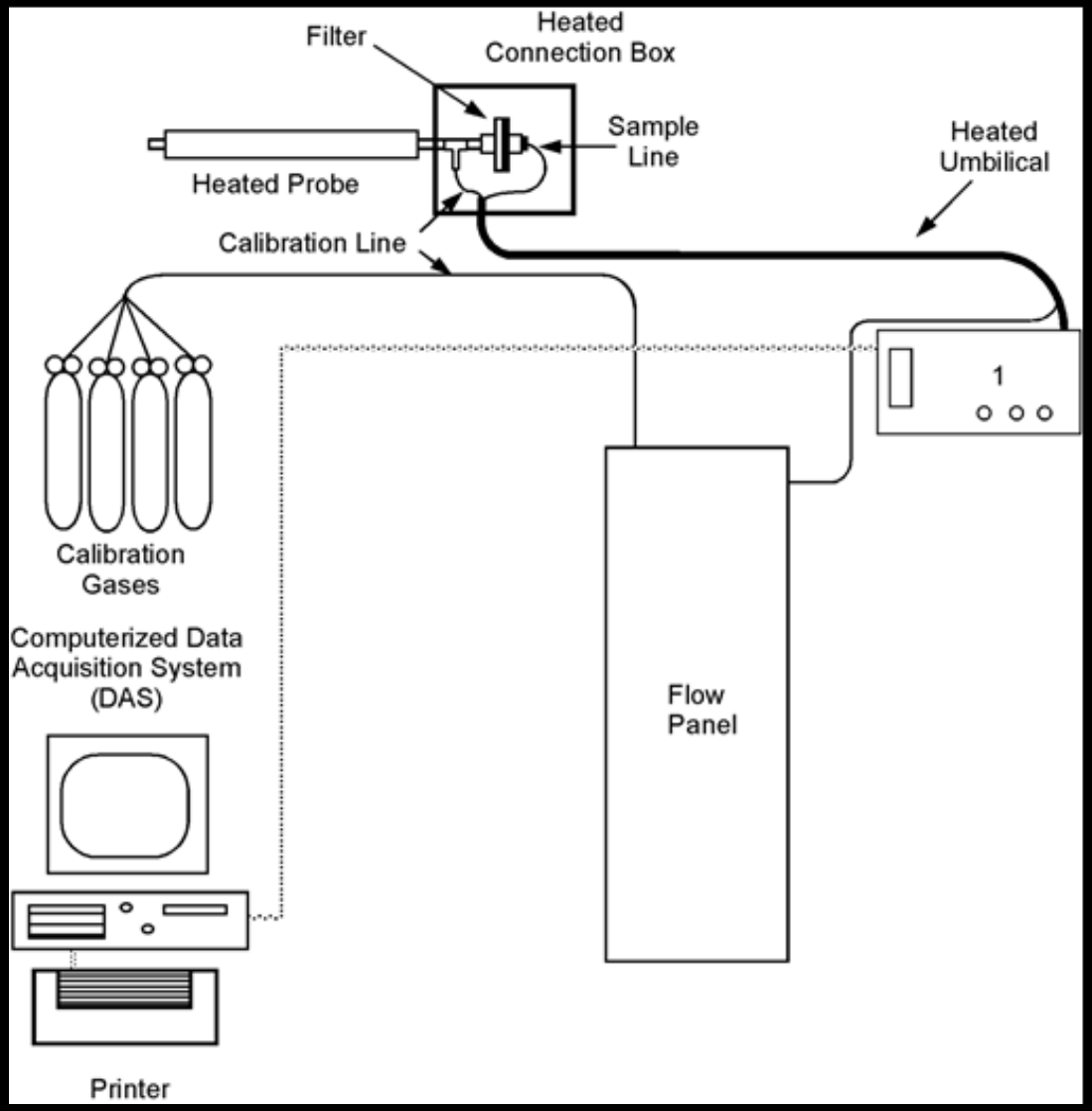

FTIR
Spectral radiant emittance, W/(m
5777 K
3000 K
1000 K
500 K
300 K
100 K
10^4
100
1
0.01
0.1
1
10
100

FTIR - WORKING



Extractive CEMS

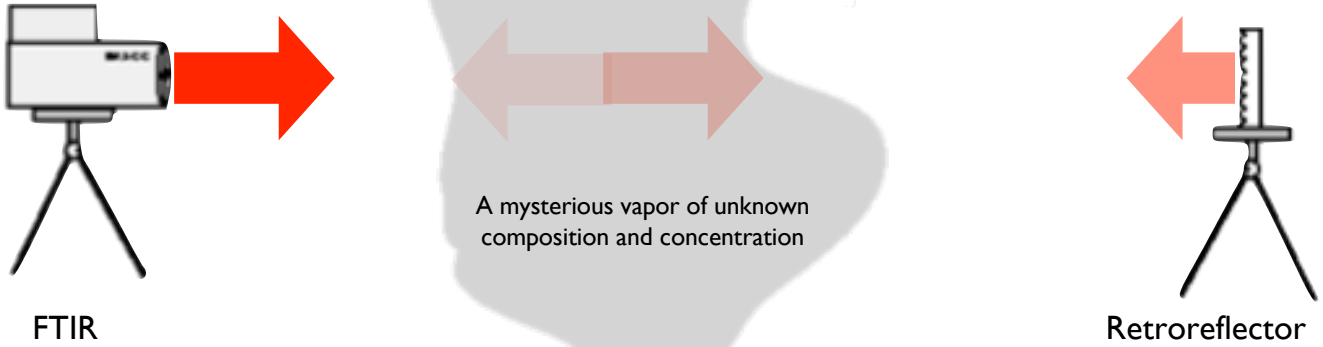
EPA Method 320



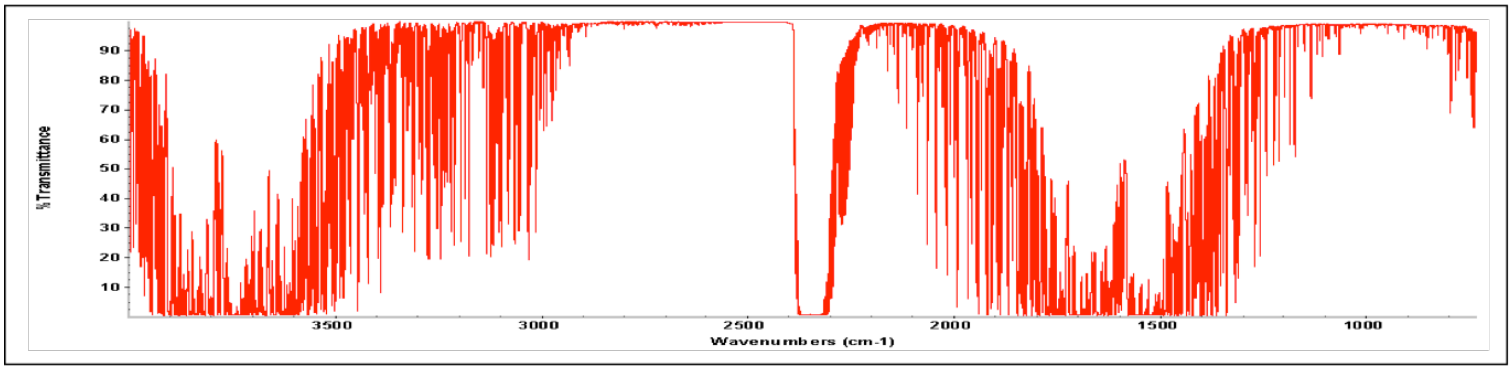
Open-Path FTIR Monitoring

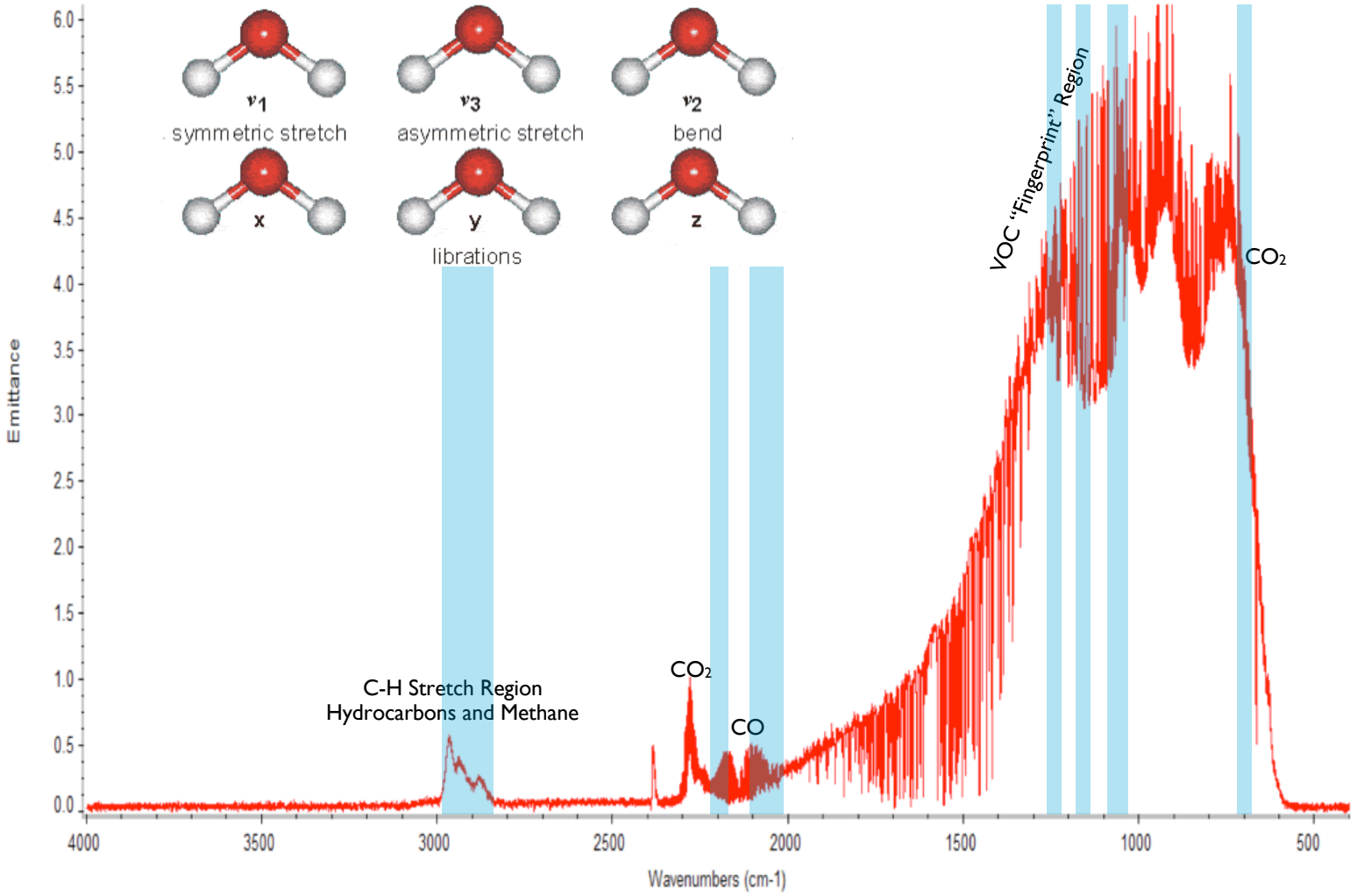
- Characterize fugitive emissions
- Multiple paths allow determination of plume size and direction of motion
- Low ppb detection limits on many compounds

Open Path FTIR



Transmission Spectrum




ν_1
symmetric stretch
ν_3
asymmetric stretch
ν_2
bend
x
y
z
librations
VOC "Fingerprint" Region
CO_2
C-H Stretch Region
Hydrocarbons and Methane
CO_2
CO
Emittance
Wavenumbers (cm-1)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4000
3500
3000
2500
2000
1500
1000
500

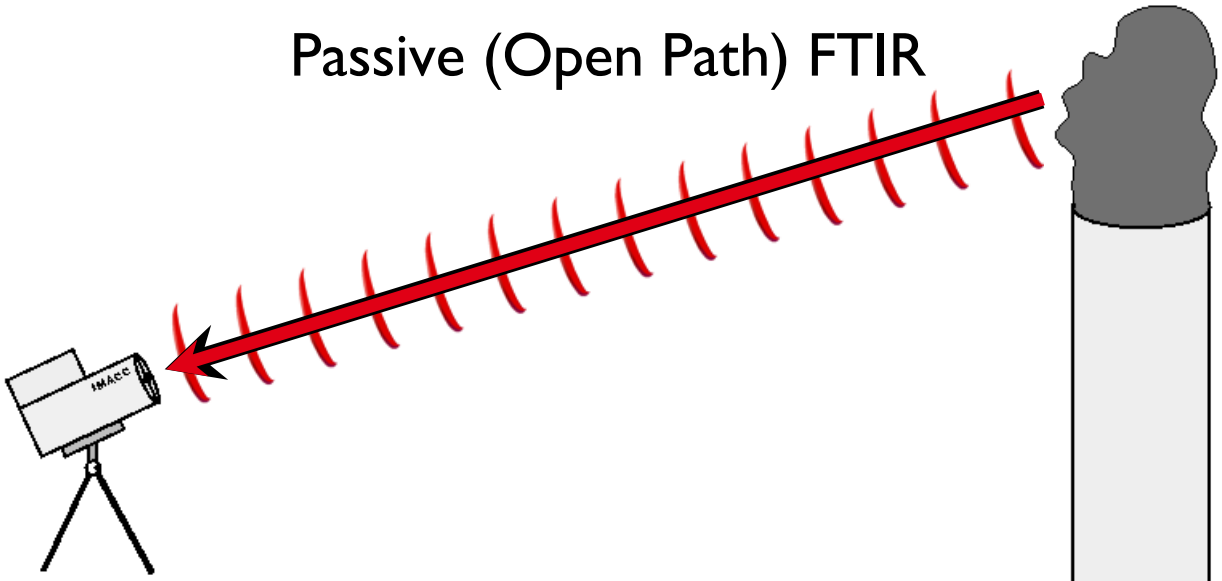

Flare Testing

Flare Combustion Efficiency

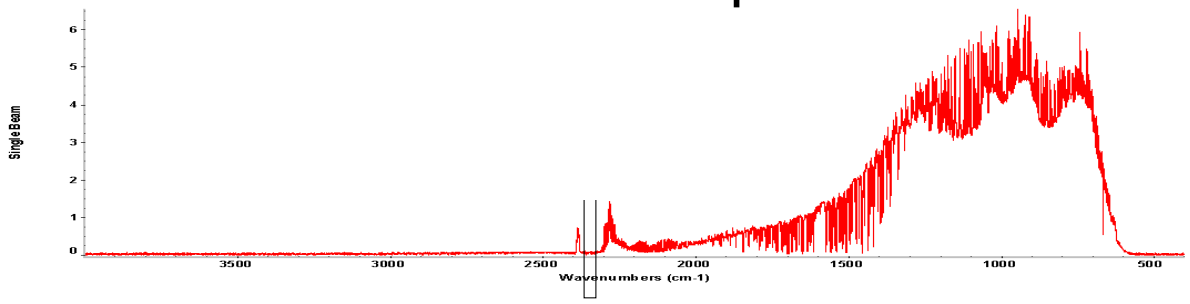
How efficiently does the flare convert hydrocarbons to carbon dioxide?

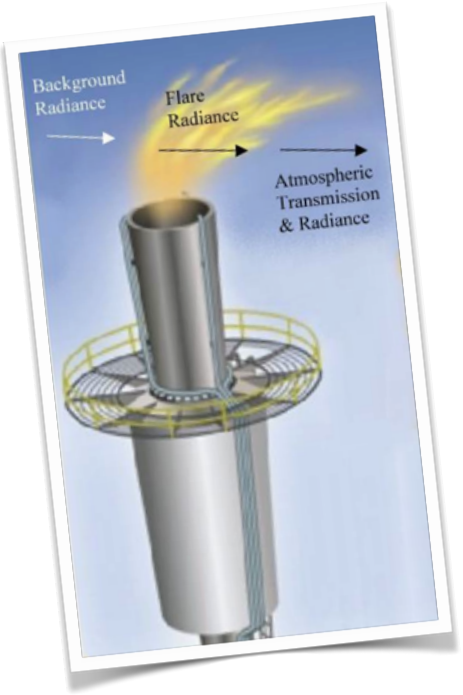
$$\frac{\text{Concentration of } CO_2 \text{ in the plume}}{\text{Concentration of } CO_2 + CO + HC}$$

Passive (Open Path) FTIR



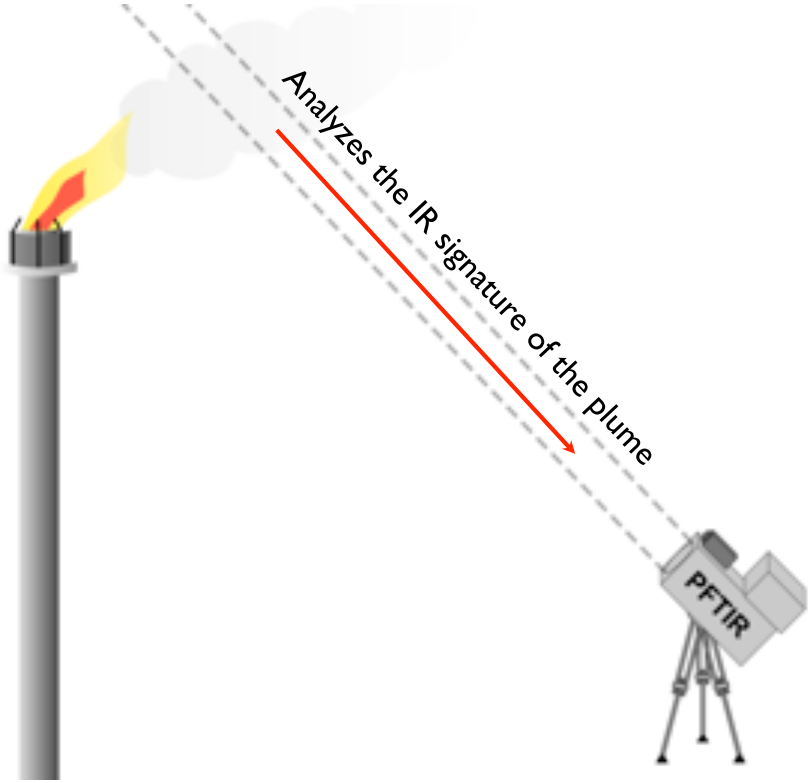
Radiance/Emission Spectrum





Total radiance to the instrument consists of many components.

Flare radiance is the only signal of concern.



Passive FTIR
No Active IR Source


Where
we aim

Fantastic. Why don't you use PFTIR for every source?

PFTIR has a limitation…


The plume has to be hot!


CleanAir
ENGINEERING

DRONE

Noun

1. a low continuous humming sound or a dull monotonous tone

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2. a stingless male bee (as of the honeybee) that has the role of mating with the queen and does not gather nectar or pollen.

3. a person who lives on the labor of others; parasitic loafer.

4. any unmanned aircraft or ship that is guided remotely


QF-004
AF
83
110


NY
AF
85
500

Beyond Inspections

CUI support

Mapping and site integration

3D Modeling and scanning

LDAR – seal gap measurements

Emergency response

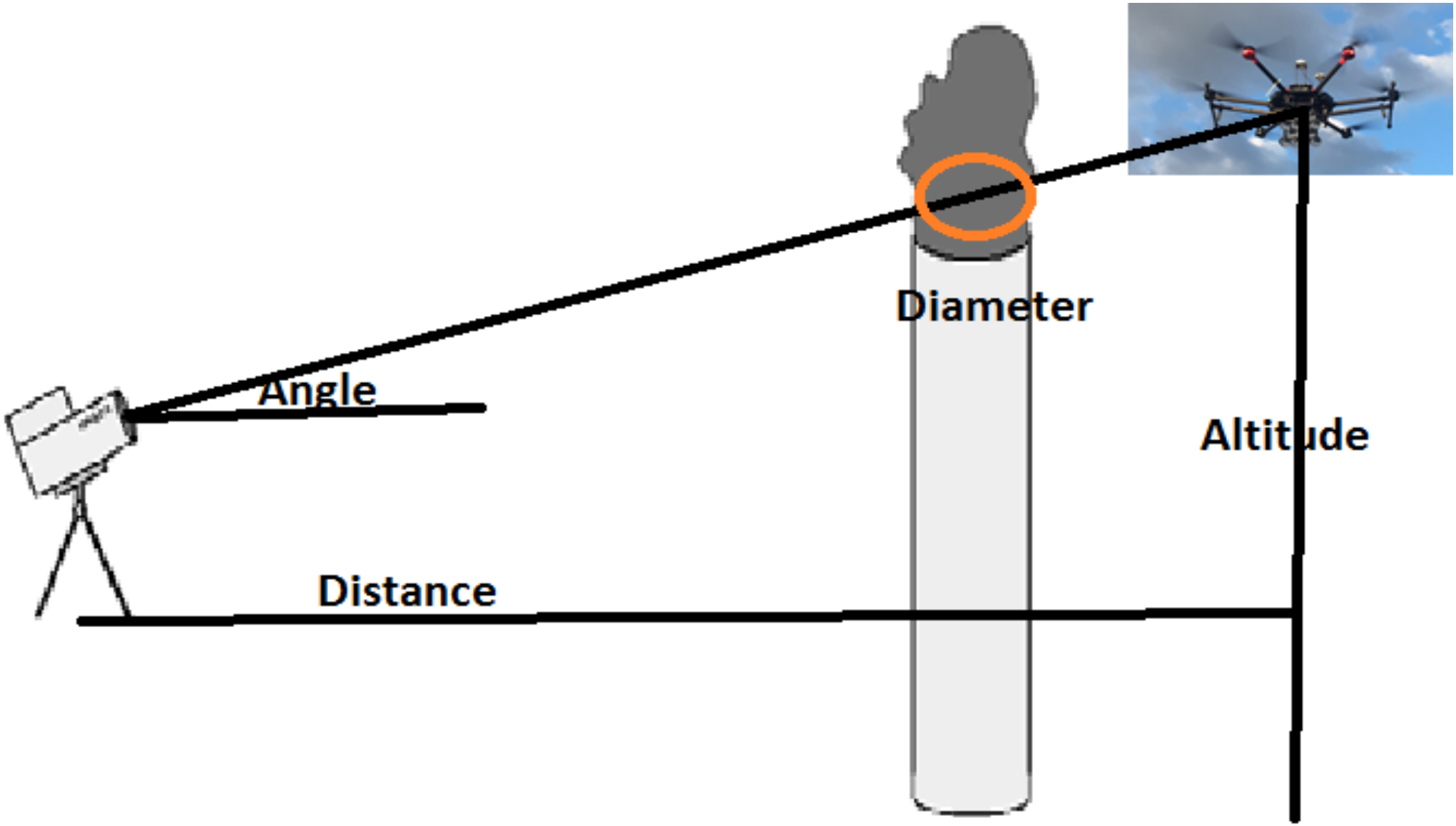
Emission testing


IMACC

I don’t have to test any enclosed flares. Why should I care?

What can we measure with FTIR?

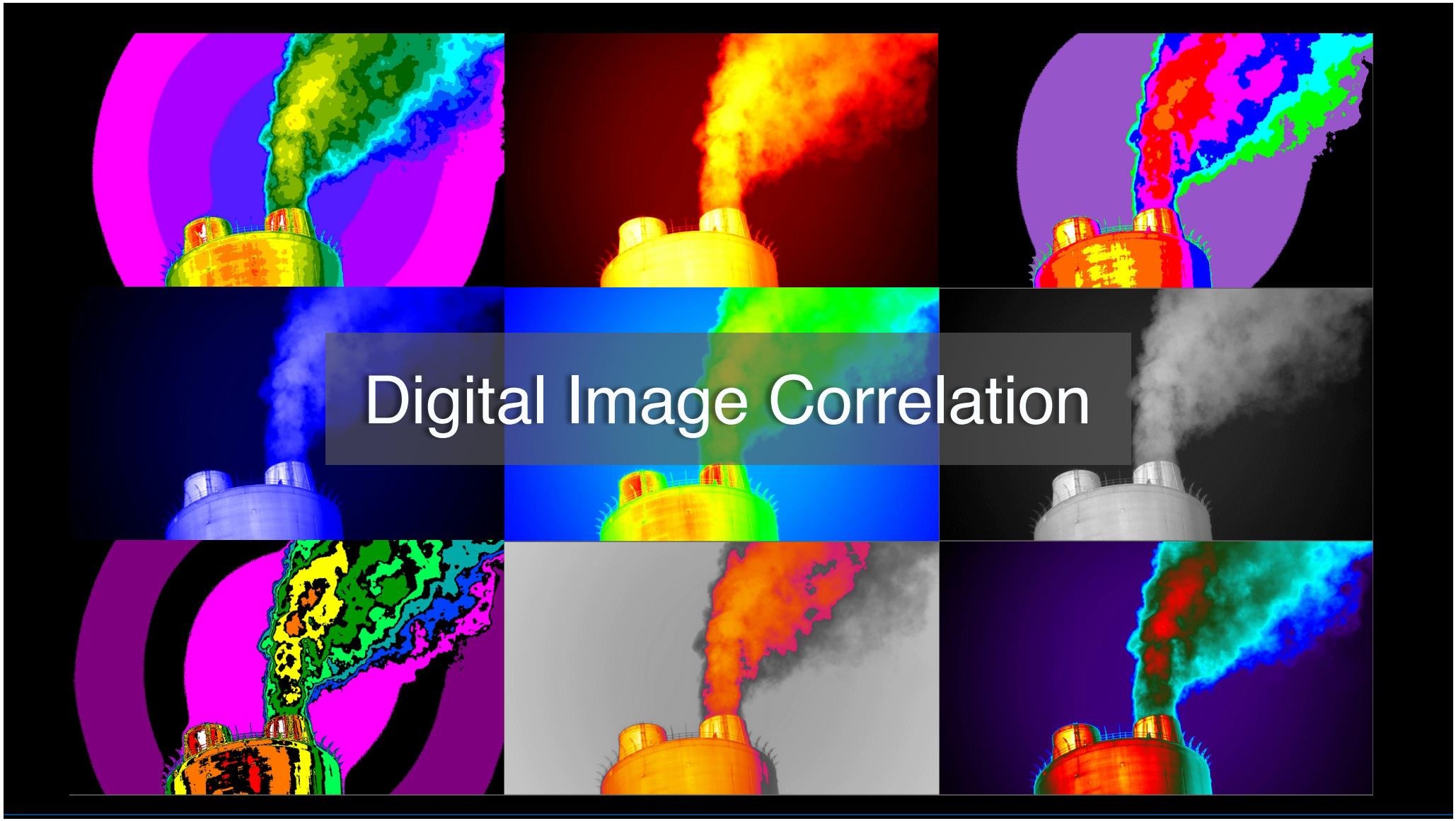
- ✓ CO_2 - Method 3, 3A-B
- ✓ H_2O - Method 4
- ✓ SO_2 - Method 6, 6A-C
- ✓ NOx - Method 7, 7A-E
- ✓ CO - Method 10, 10A-B
- ✓ VOCs - Method 18
- ✓ THC - Method 25, 25A-E
- ✓ HCl - Method 26, 26A
- ✓ NH_3 - CTM-027
- ⊘ PM - Method 5, 5F, 201A, 202


Diameter
Angle
Altitude
Distance

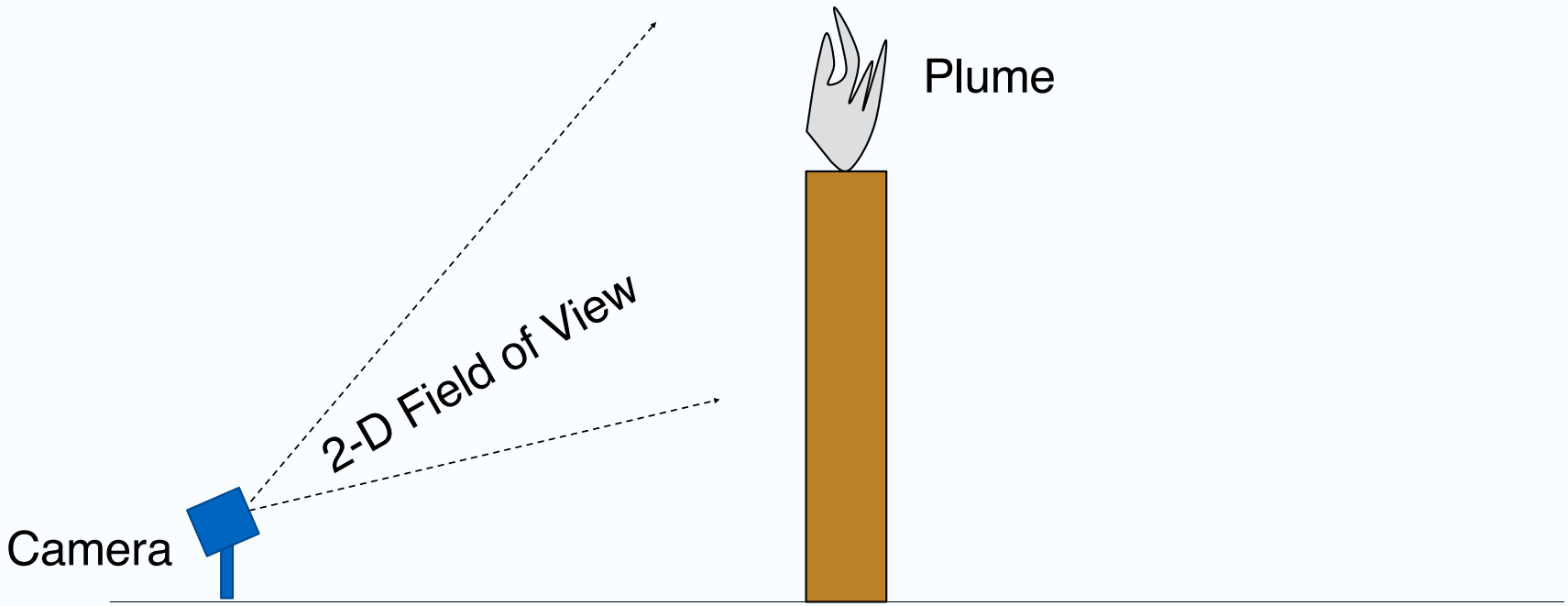
What About Mass Emissions Measurement?

Gas Composition

Gas Flow Rate

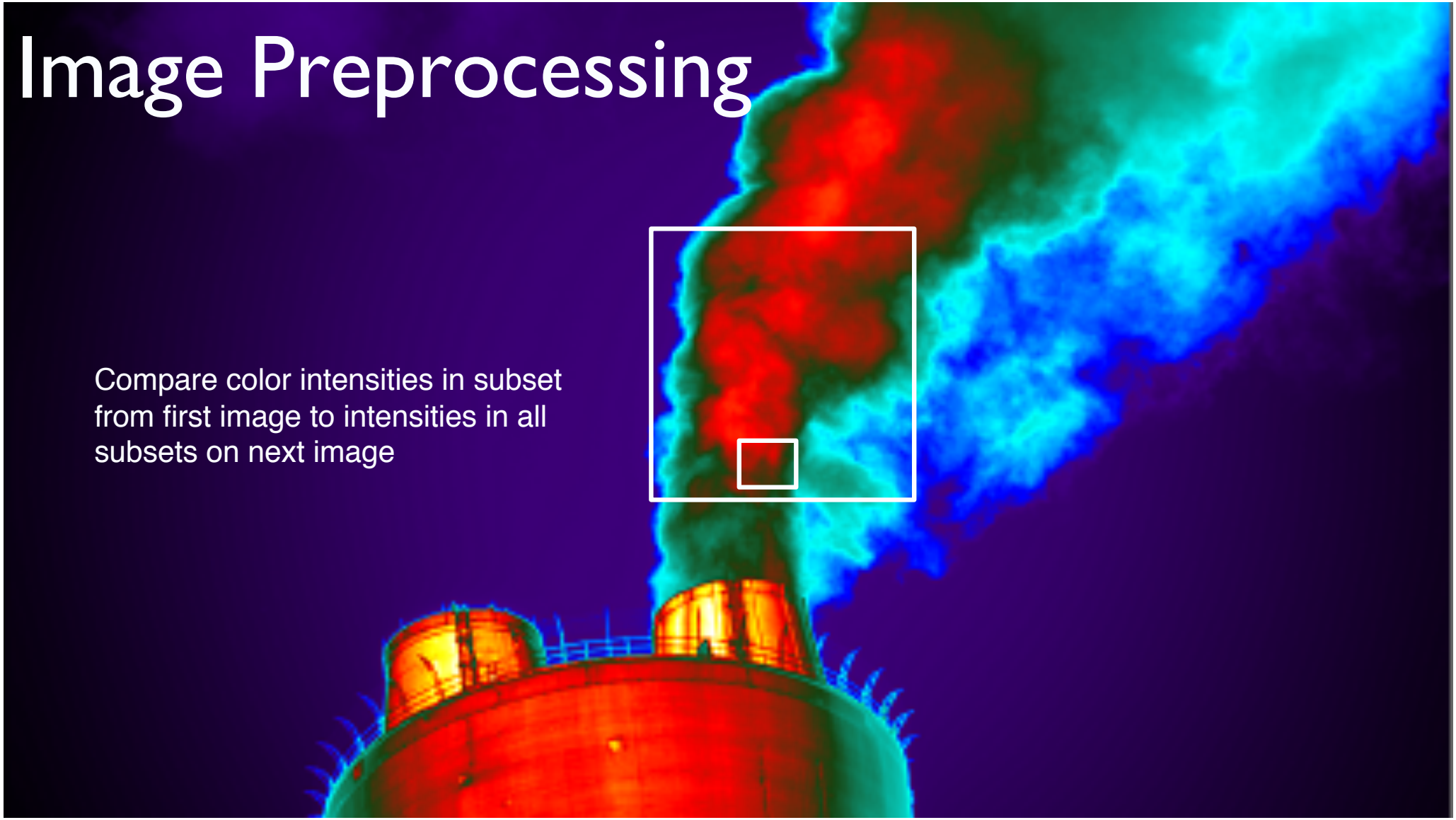

Digital Image Correlation

Remote Velocity Measurement



1. Take Pictures
2. Analyze Pictures
3. Calculate Plume Velocity

Image Preprocessing



Digital Image Correlation

Image 1

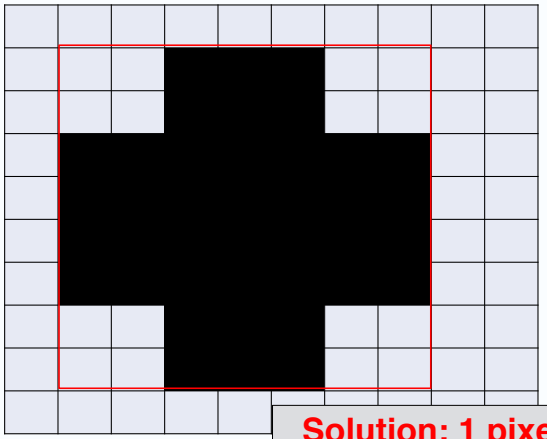
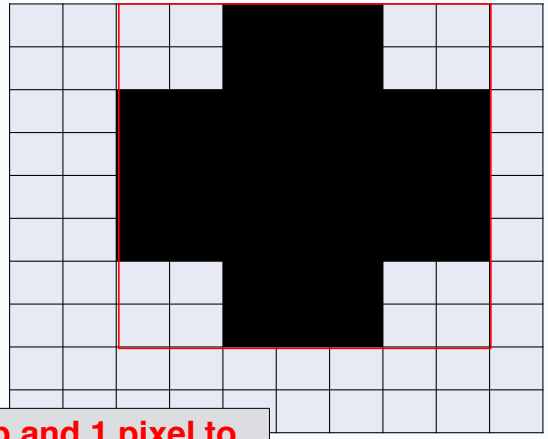


Image 2



Solution: 1 pixel up and 1 pixel to the right

0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	1	0	0	0	0
0	0	0	1	1	1	0	0	0	0
0	1	1	1	1	1	1	1	0	0
0	1	1	1	1	1	1	1	0	0
0	1	1	1	1	1	1	1	0	0
0	1	1	1	1	1	1	1	0	0
0	0	0	1	1	1	0	0	0	0
0	0	0	1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0

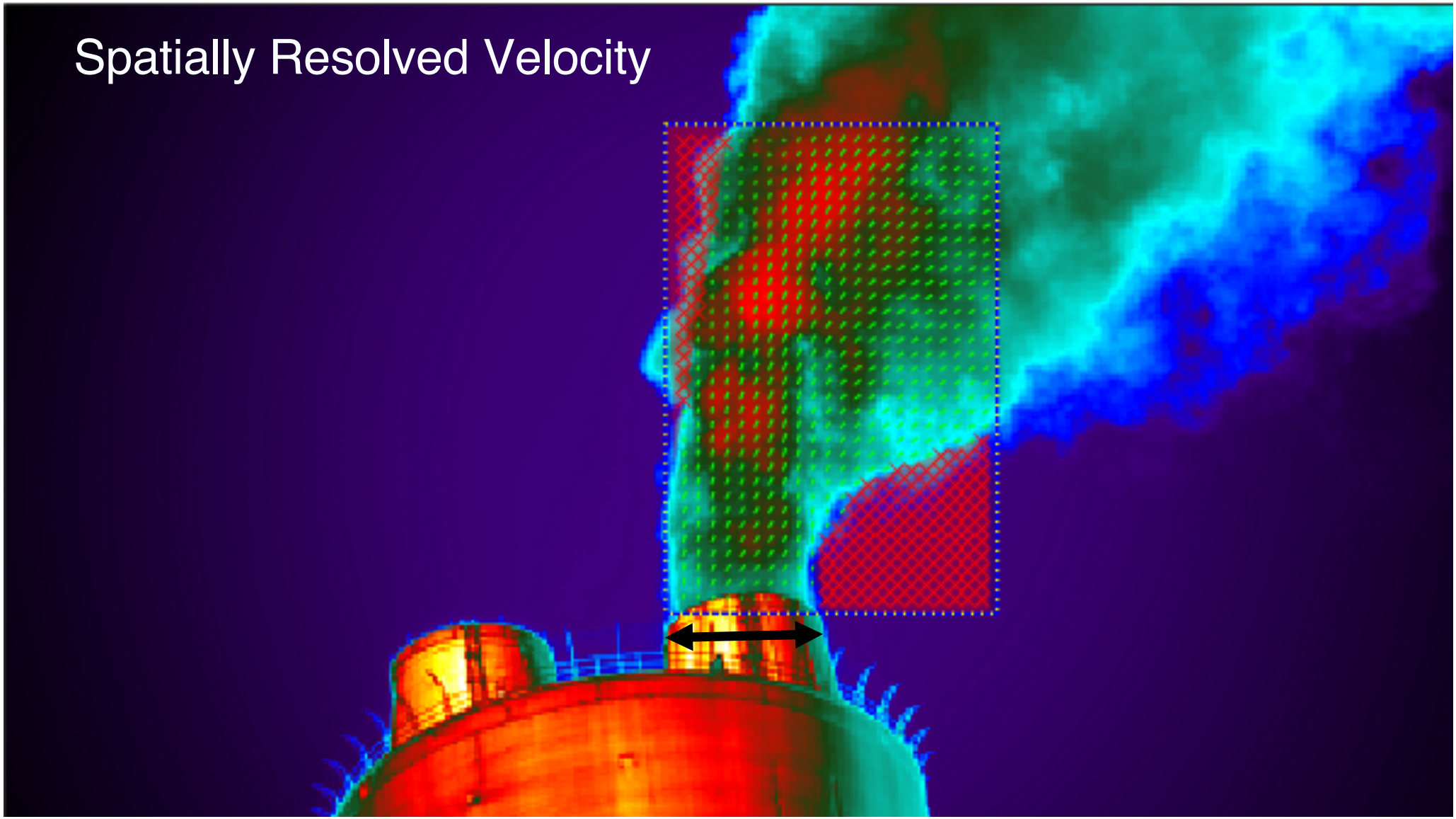
0	0	0	0	1	1	1	0	0	0
0	0	0	0	1	1	1	0	0	0
0	0	1	1	1	1	1	1	1	0
0	0	1	1	1	1	1	1	1	0
0	0	1	1	1	1	1	1	1	0
0	0	1	1	1	1	1	1	1	0
0	0	0	0	1	1	1	0	0	0
0	0	0	0	1	1	1	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Minimize:

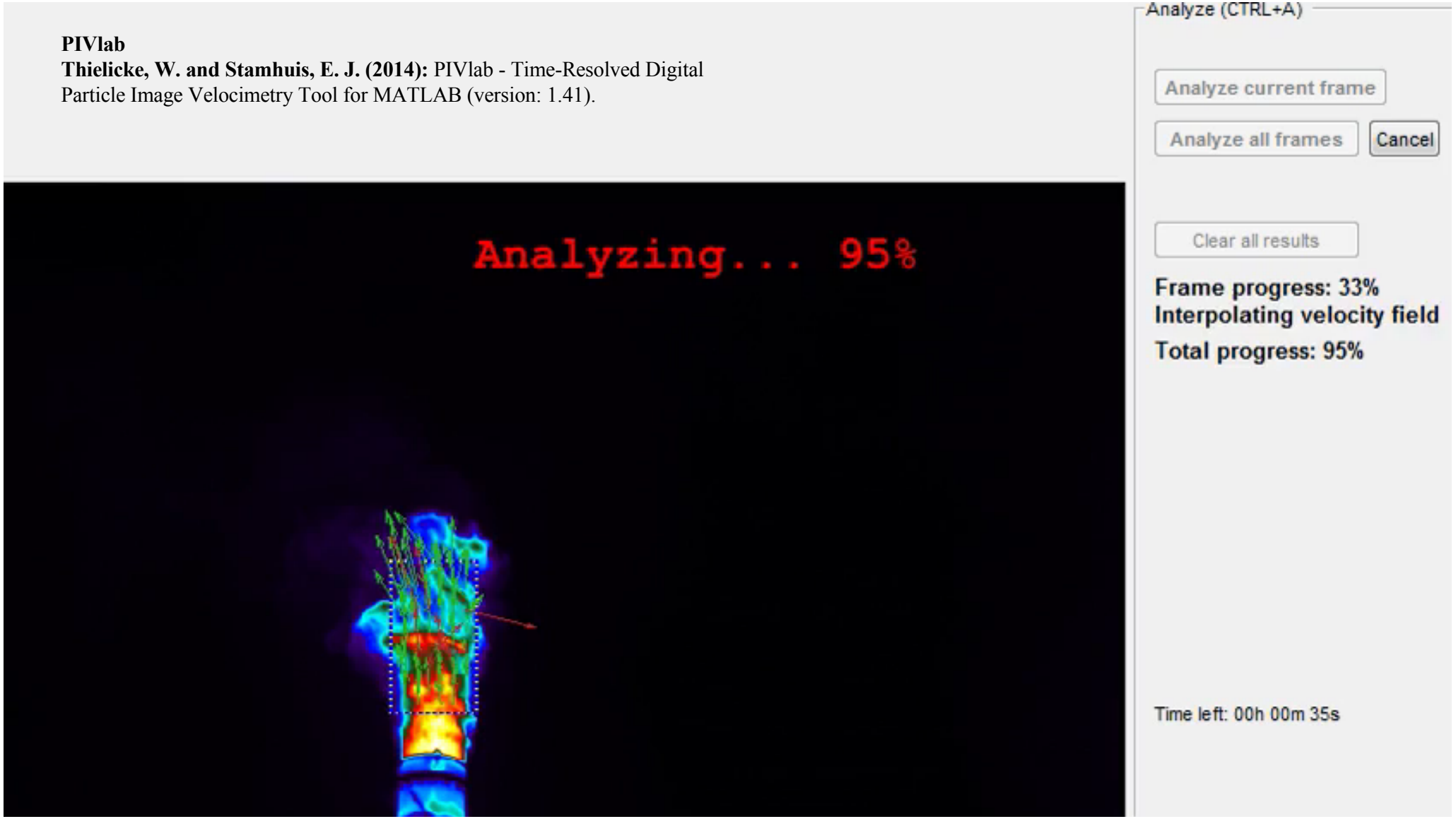
$$\frac{\sum_x \sum_y [f(x+i, y+j) - \bar{f}][g(x,y) - \bar{g}]}{\sqrt{\sum_x \sum_y [f(x,y) - \bar{f}]^2 \sum_x \sum_y [g(x,y) - \bar{g}]^2}}$$

$g()$ = pixel intensity in image 1
$f()$ = is pixel intensity in image 2
$\bar{g}, \bar{f}$ = mean intensity of subset

Solve for i and j


Spatially Resolved Velocity

PIVlab
Thielicke, W. and Stamhuis, E. J. (2014): PIVlab - Time-Resolved Digital Particle Image Velocimetry Tool for MATLAB (version: 1.41).

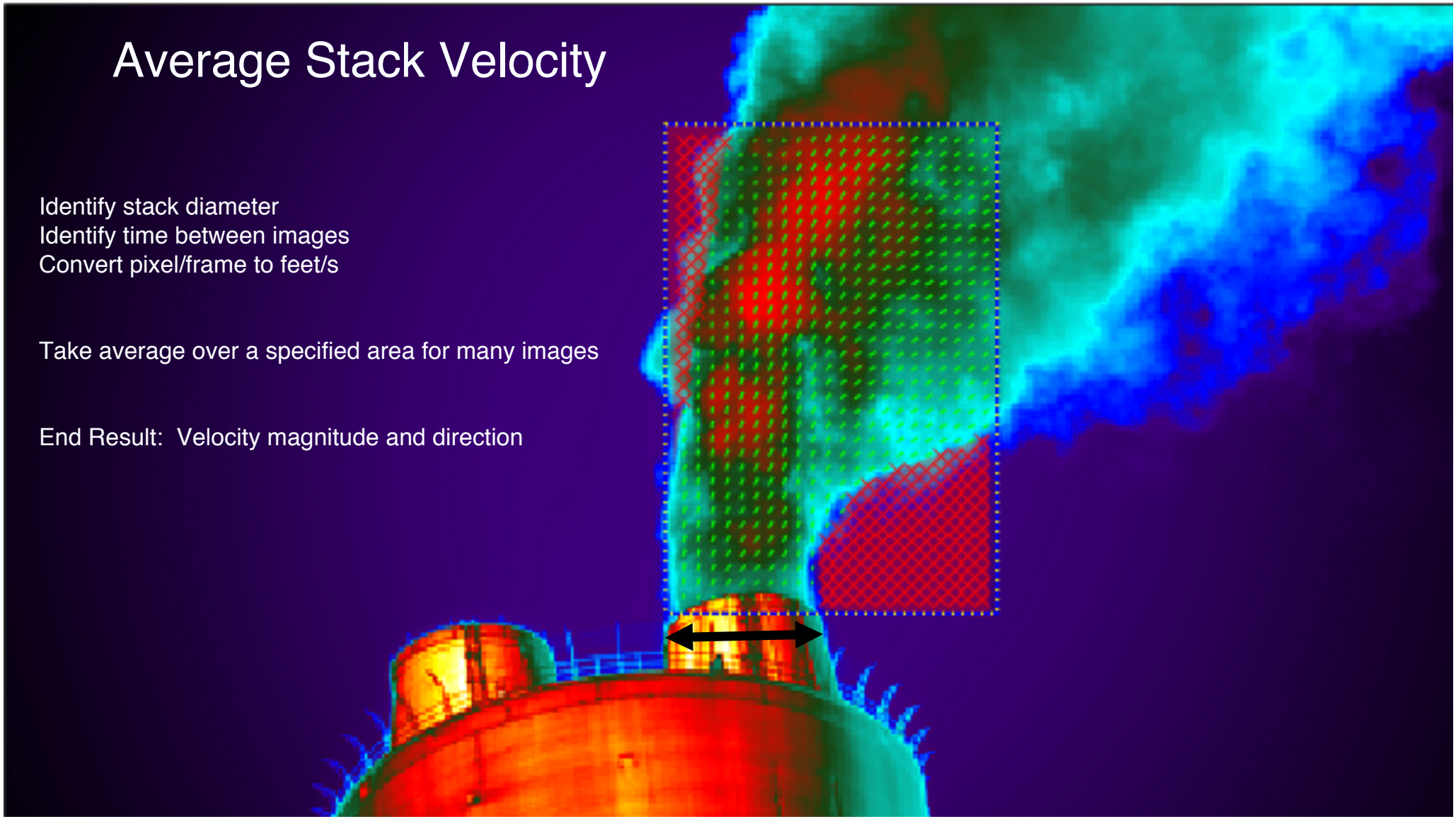


Average Stack Velocity

Identify stack diameter
Identify time between images
Convert pixel/frame to feet/s

Take average over a specified area for many images

End Result: Velocity magnitude and direction



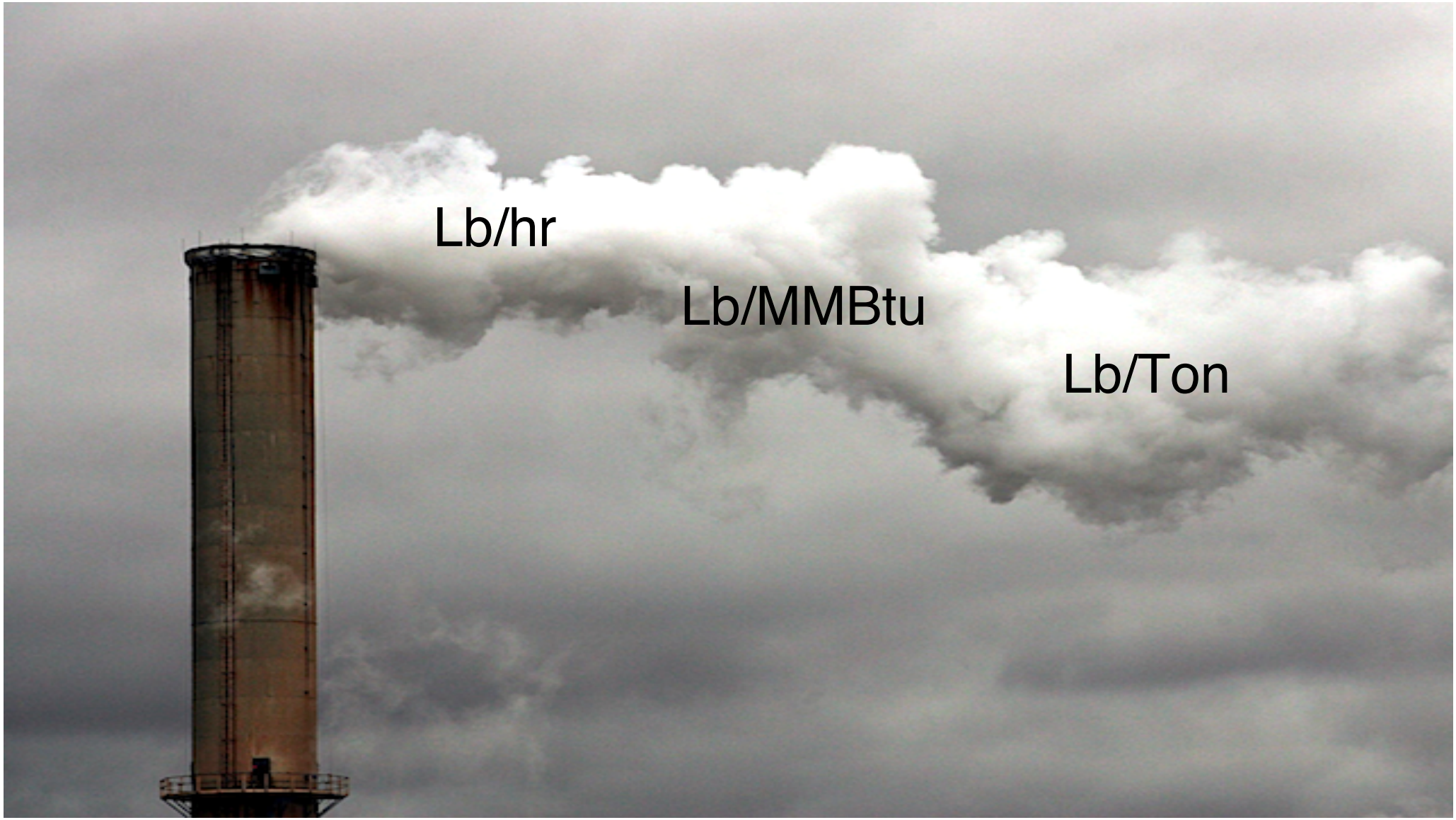
Field Trials

1344 x 784 pixels at 120 frames/s

Field Trial	Camera (ft/s)	Reference (ft/s)
1	29.9 ± 4.0	[a]28.9 ± 0.3
2	74.8 ± 12.8	[b]75.4 ± 5.5

> 16 segments of 1000 images obtained over 8 s
Segments obtained over 2 hours

[a]Method 2, [b]Method 2F


Lb/hr
Lb/MMBtu
Lb/Ton

UAS Advantages

Increase in safety

- UAS vs. standalone scaffolding

Decreasing costs

- Reduced equipment needs and time on site

Quality Data

- Flexible mounting solutions and real time control

UAS Specs

22 Minute average flight time

UAS runs at 66v

3D Printed gimbal mount

3D Printed mirror plate

Custom built mirror clusters

18 mph wind speed max

9 mph wind speed while retaining quality data

Six motors for redundancy

Three GPSs for redundancy

Six batteries for redundancy

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