Jet Propulsion Laboratory
California Institute of Technology

Real-time detection of methane plumes by AVIRISng

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Agenda

- Why real-time?
- Prior studies
- Our approach
  - Comparison of methods
  - Operational application
- Future directions

Why real-time remote sensing?

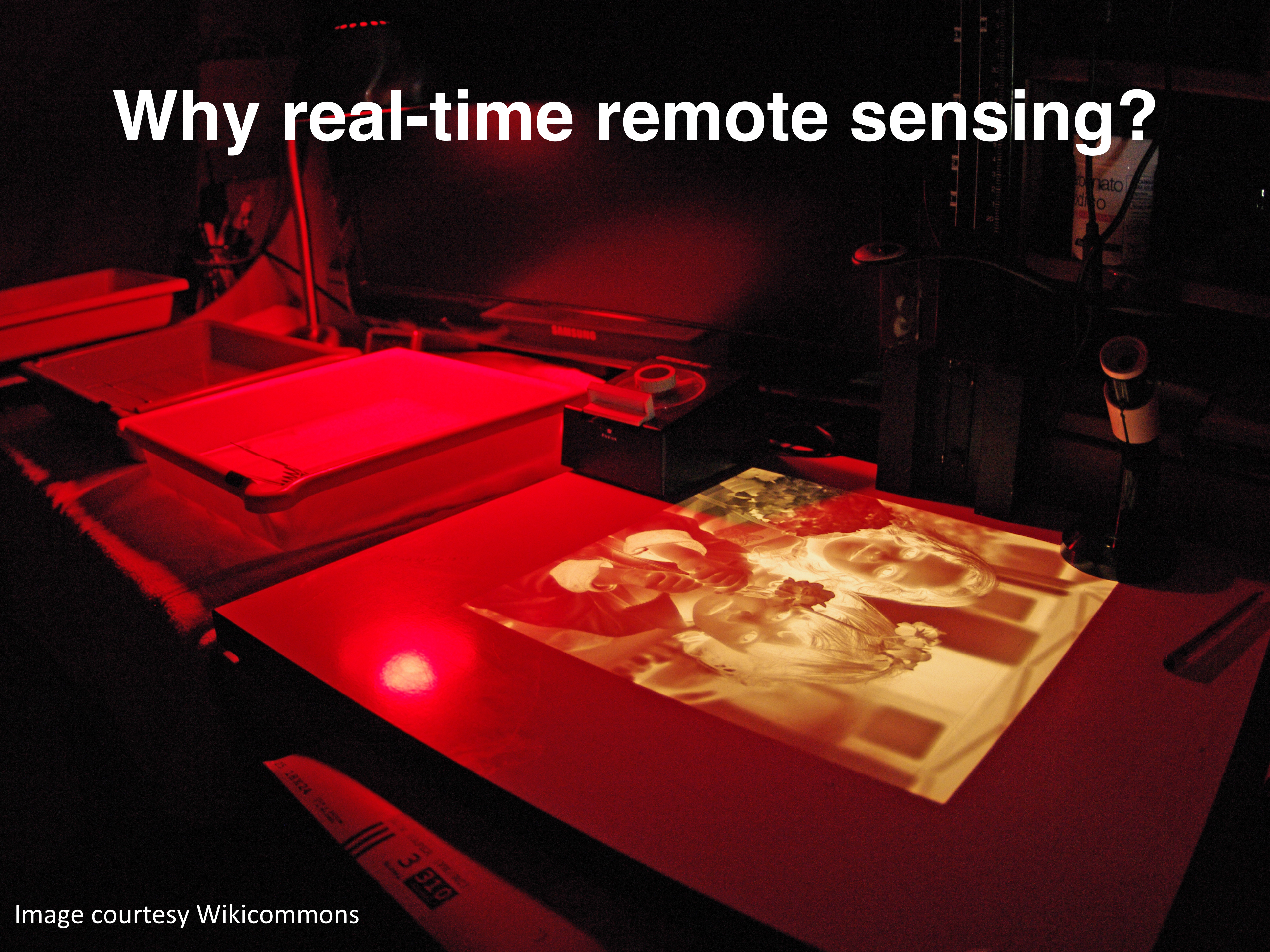


Image courtesy Wikicommons

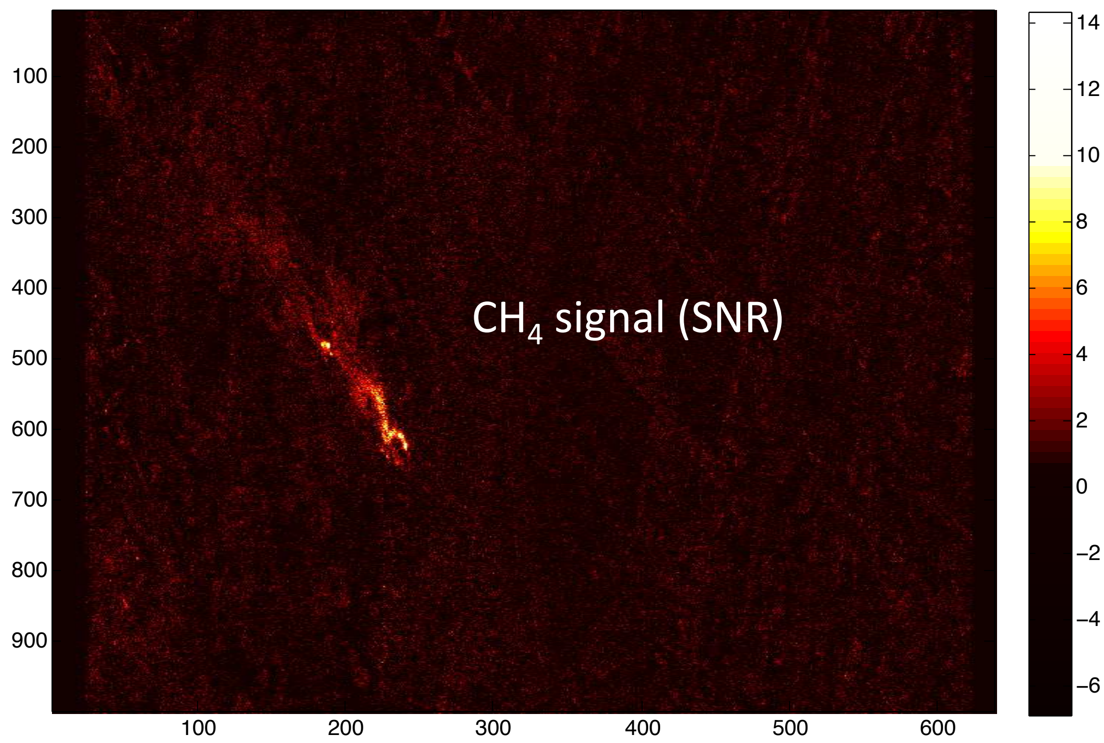
Why real-time remote sensing?

In flight: Provide tactical feedback to pilots

Post-flight trace gas detection

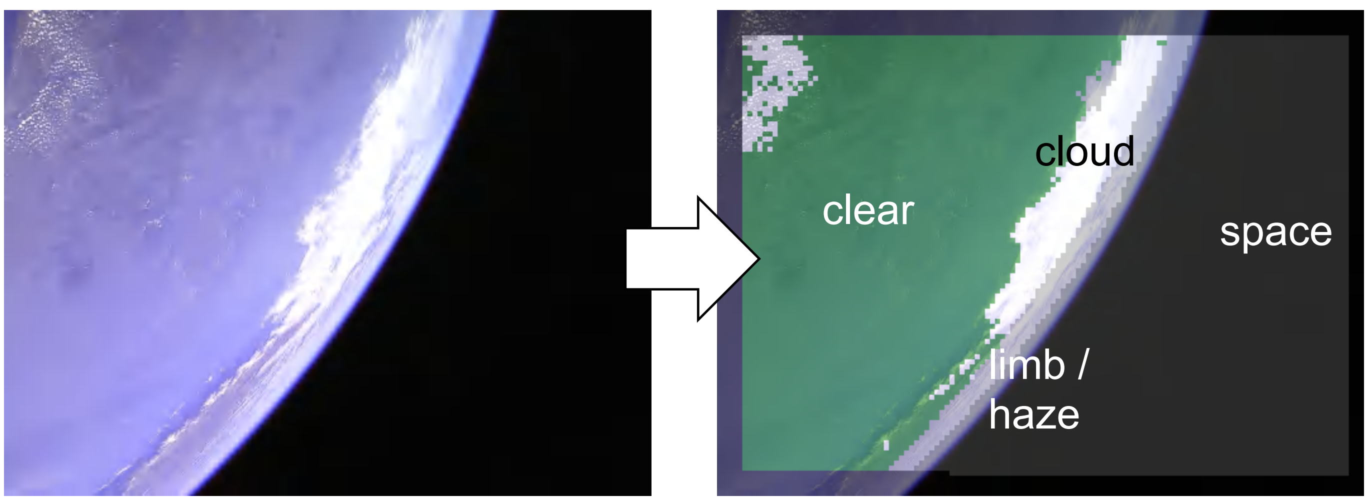
Unambiguous source attribution

Reveal plume structure



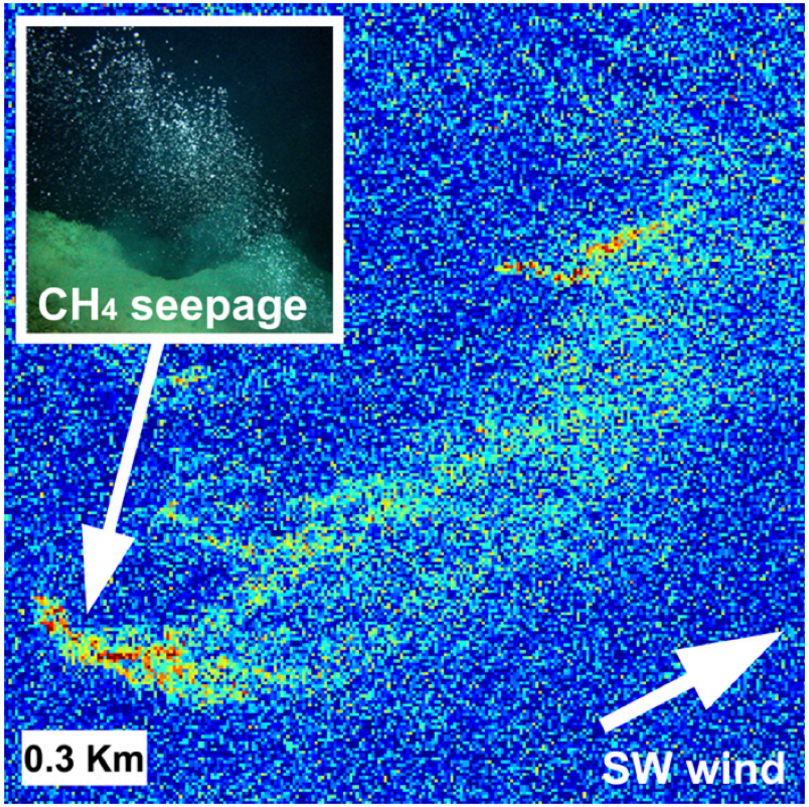
Some prior work in real-time remote sensing

- **Cloud detection [Thompson et al., *TGRS 2014,* Altinok et al. (in review)]**
- **Endmember detection [Thompson et al., *TGRS 2013*]**
- **Spectral band ratios by EO-1 [Chien et al., 2005]**



Some prior work in trace gas detection

- **Trace gas detection in marine seeps [Thorpe et al., *RSE* 2013, Roberts et al., *RSE* 2010]**
- **CO_2 [Dennison et al., *RSE* 2013]**
- **Band Ratios [Bradley et al., *GRL* 2011]**
- **… and many others**



Thorpe et al., SPIE 2012

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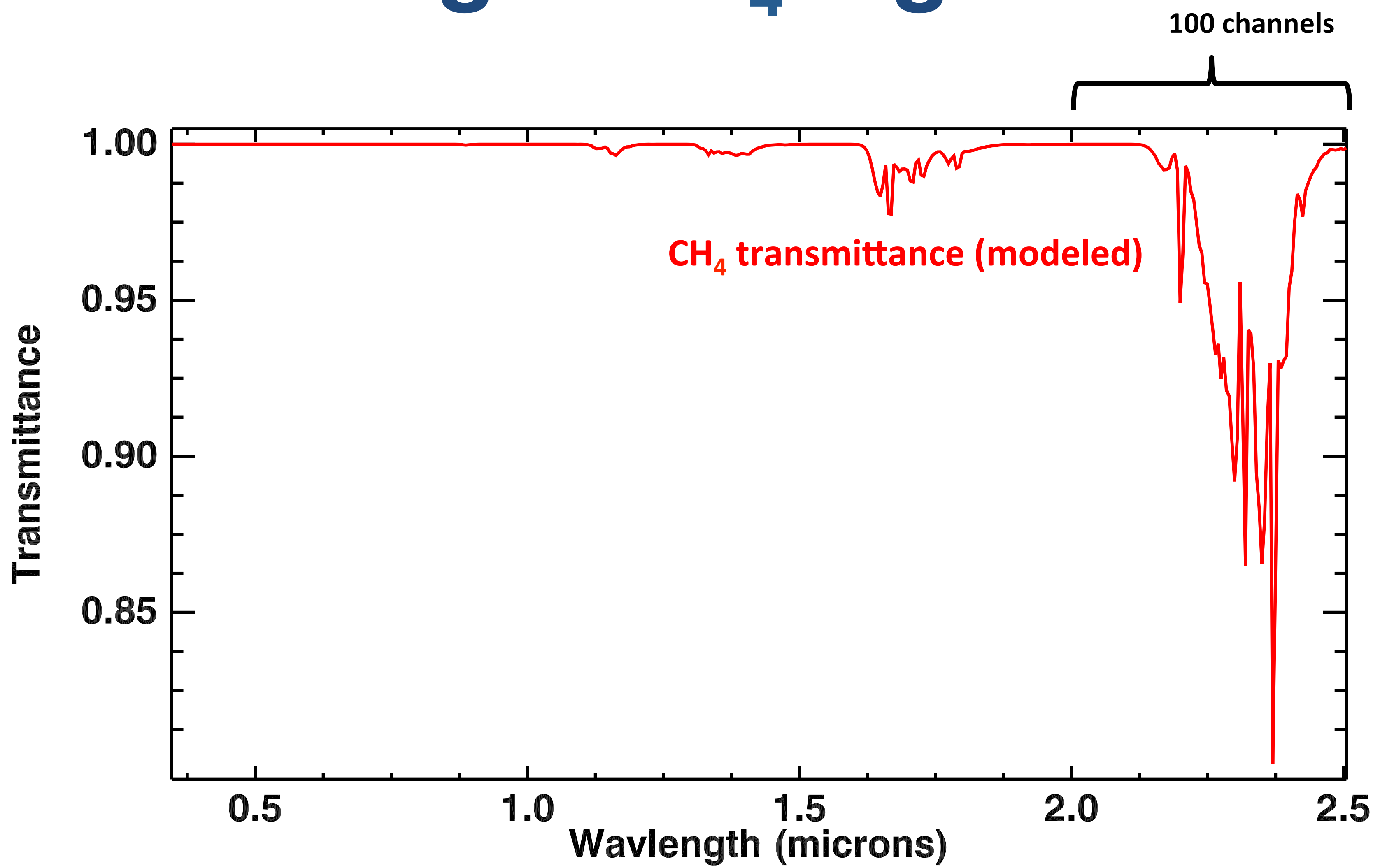
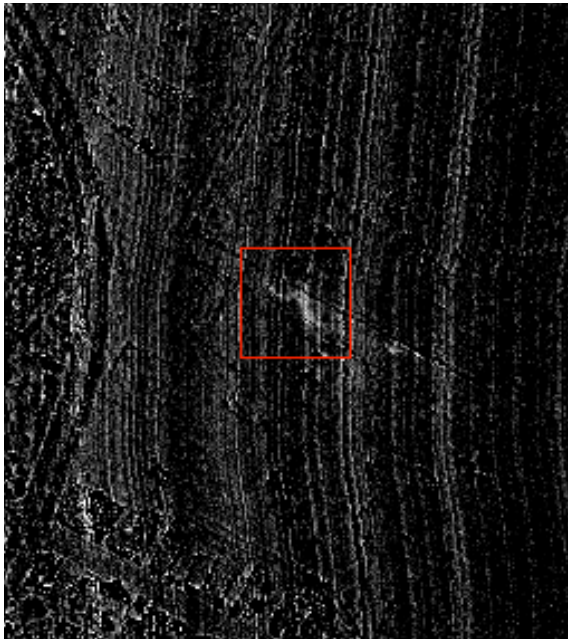
Target CH_4 signal



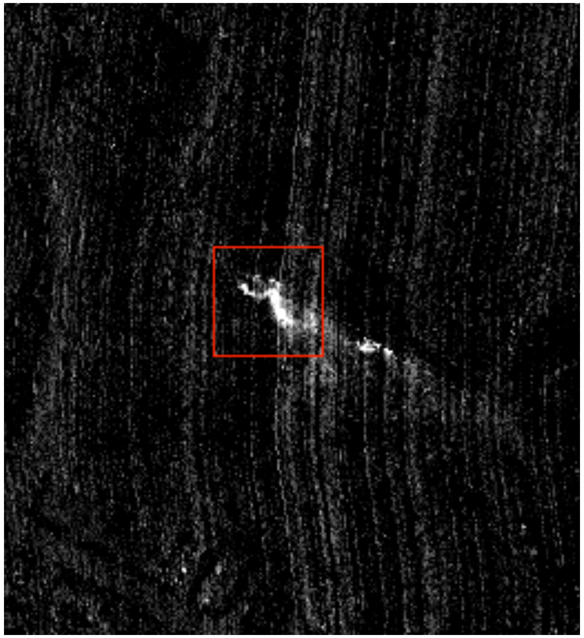
Kern River Oil Field, Bakersfield

Three detection methods

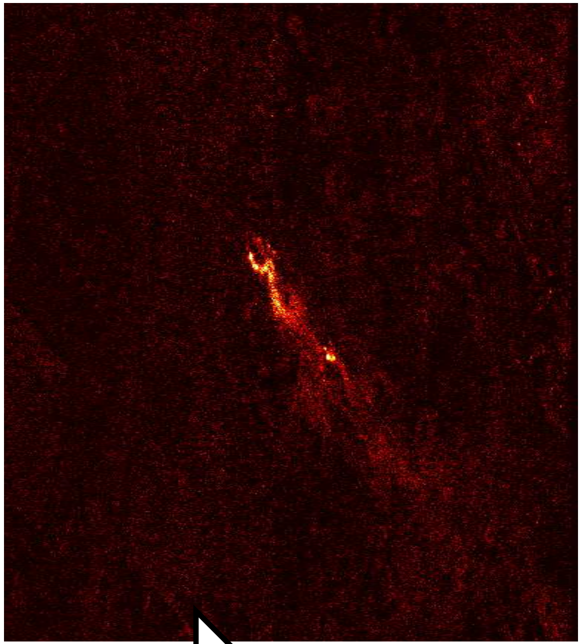
Continuum-Interpolated Band Ratio



Matched filter

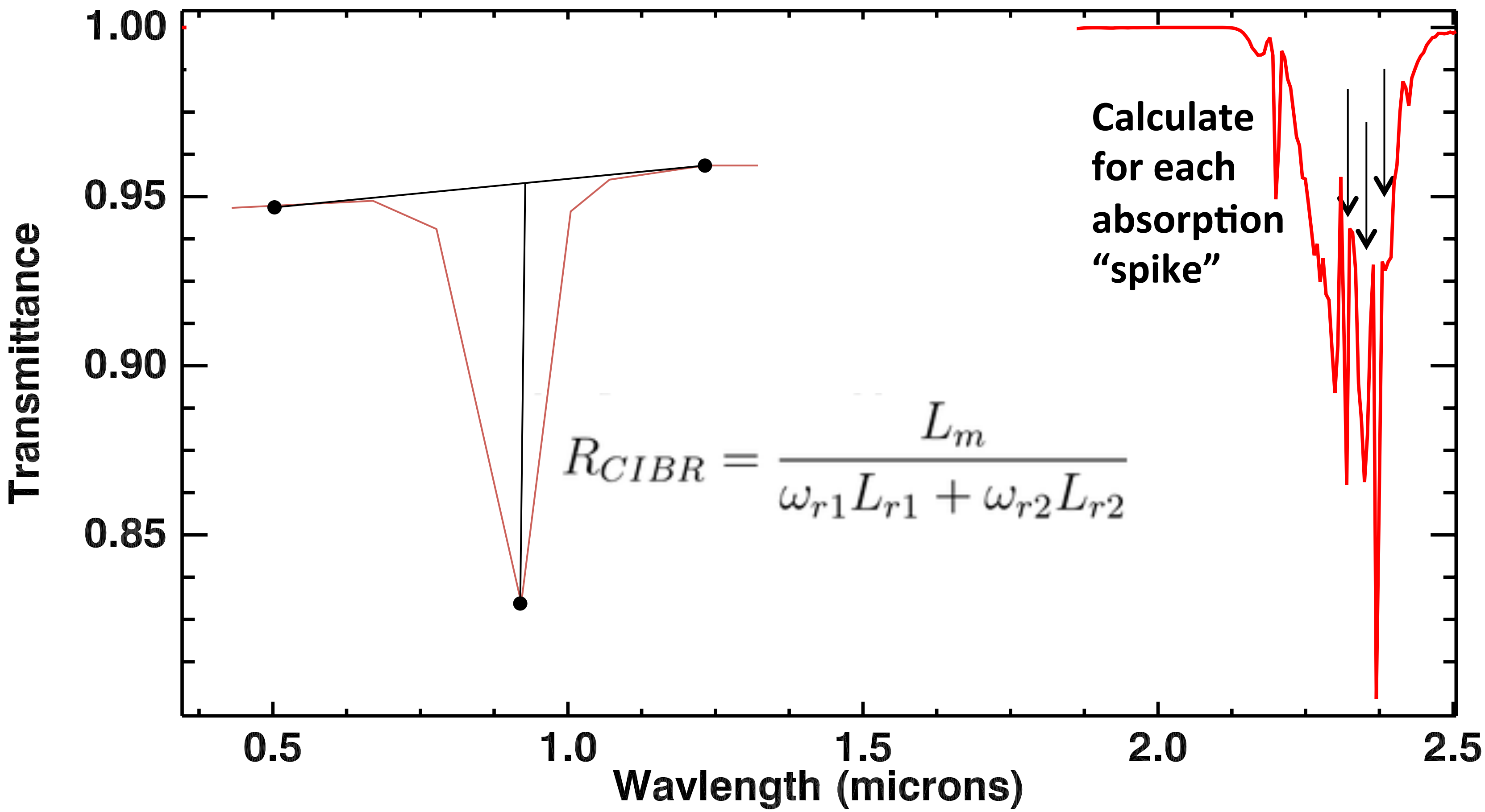


Columnwise matched filter



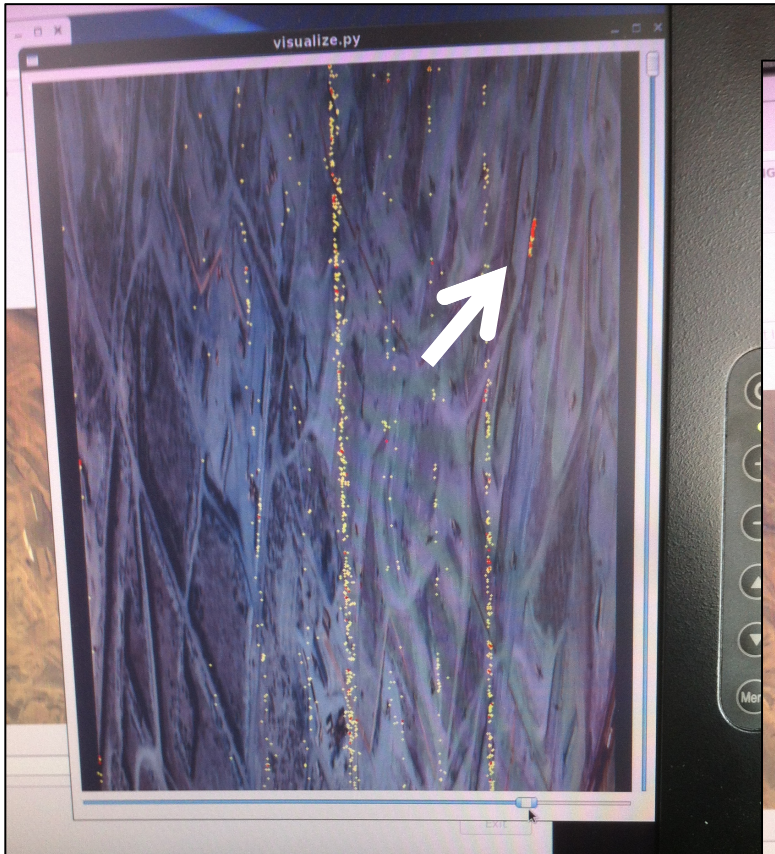
Increasing computational complexity

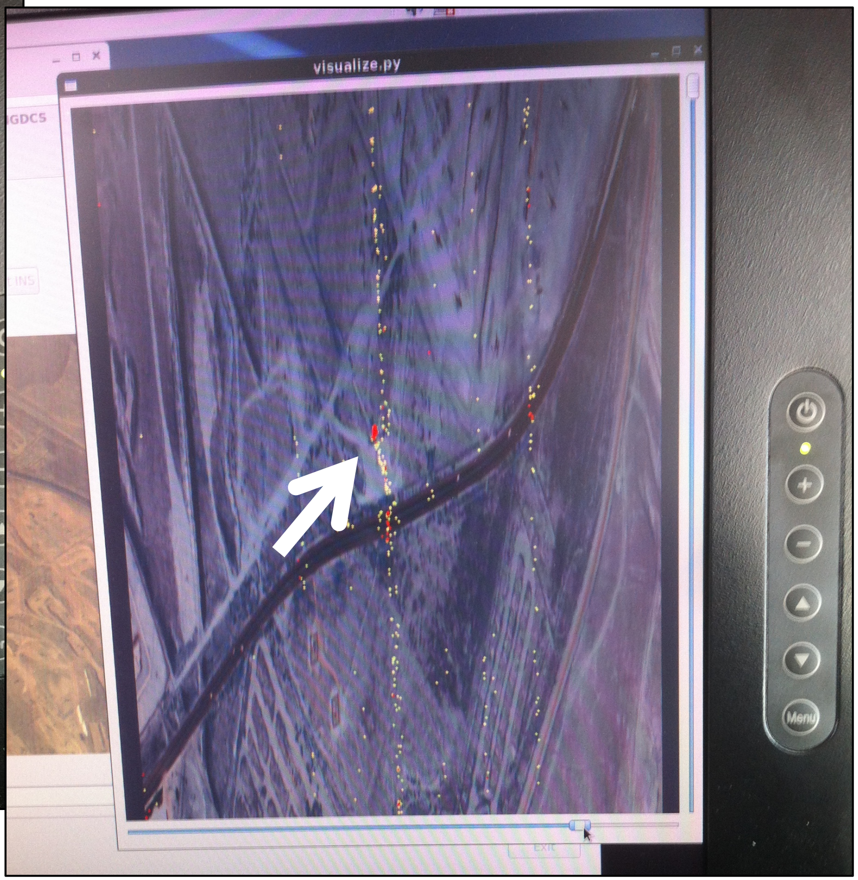
Continuum Interpolated Band Ratio (CIBR)



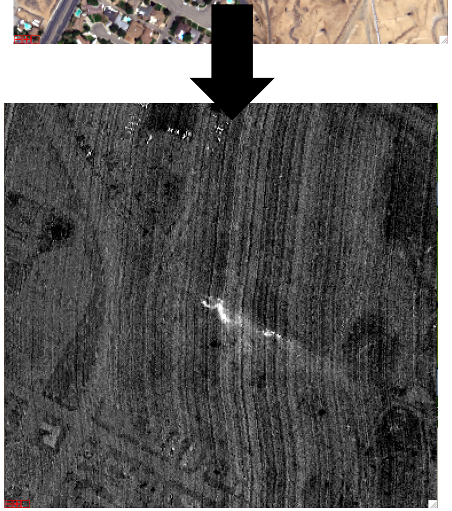
$$R_{CIBR} = \frac{L_m}{\omega_{r1}L_{r1} + \omega_{r2}L_{r2}}$$

In-flight detections (examples)

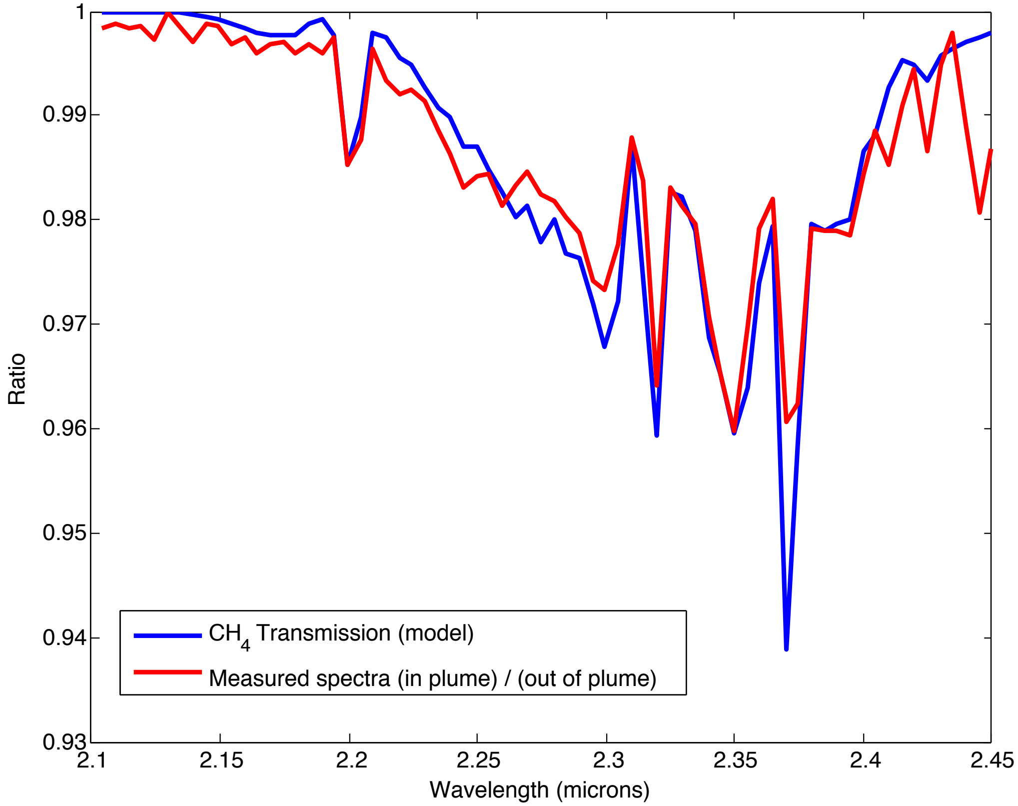




Validation methods



(in plume) / (out of plume) ratio
vs. modeled transmittance



Can we do better? Matched filter detection

- **Decide between hypotheses:**

Target absent $H_0 : \mathbf{x} \sim N(\mu, \Sigma)$

Target present $H_1 : \mathbf{x} \sim N(\mu + \alpha\mathbf{t}, \Sigma)$

Target signature

- **Optimal decision rule:**

$$\alpha(\mathbf{x}) = \frac{(\mathbf{t} - \hat{\mu})^T \hat{\mathbf{\Sigma}}^{-1} (\mathbf{x} - \hat{\mu})}{\sqrt{(\mathbf{t} - \hat{\mu})^T \hat{\mathbf{\Sigma}}^{-1} (\mathbf{t} - \hat{\mu})}}$$

A columnwise matched filter

Buffer blocks of 2000 lines,
Apply one matched filter per column

Advantages

- **Completely removes striping**

Challenges

- **Just 2000 samples to estimate the 100x100 covariance matrix**
- **We must invert the matrix once per column**

Dominant mode suppression

[Manolakis et al., 2009]

1. **Decompose covariance matrix (SVD)**

$$\boldsymbol{\Sigma} = \sum_{i=1}^{p} \lambda_i \boldsymbol{q}_i \boldsymbol{q}_i^T$$

eigenvectors

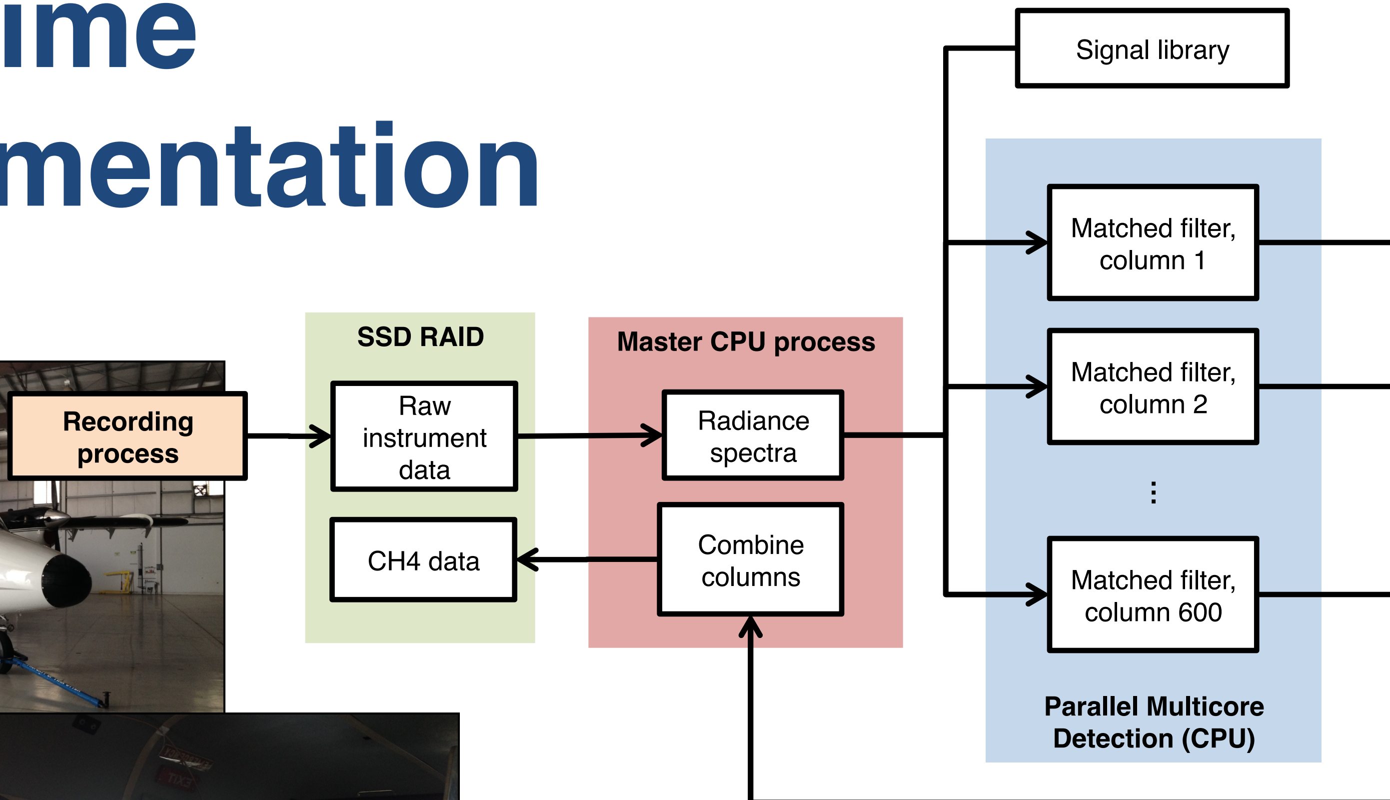
2. **Approximate the inverse using just the top *d eigenvalues***

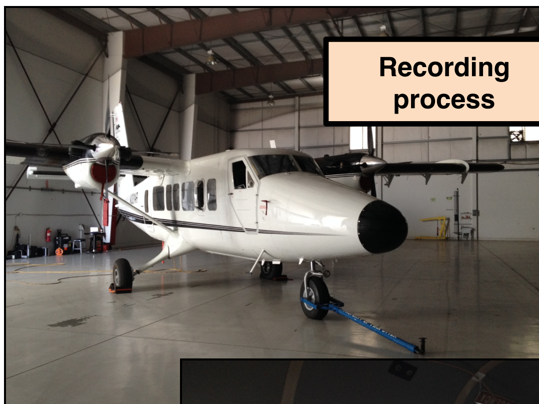
$$\tilde{\boldsymbol{\Sigma}}^{-1} = \frac{1}{\alpha}\left[\boldsymbol{I} - \sum_{i=1}^{d}\left(\frac{\lambda_i - \alpha}{\lambda_i}\right)\boldsymbol{q}_i\boldsymbol{q}_i^T\right] \qquad \alpha = \frac{1}{p-d}\left(\mathrm{tr}\boldsymbol{\Sigma} - \sum_{i=1}^{d}\lambda_i\right)$$

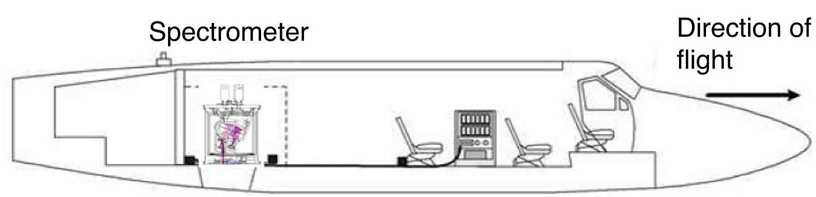
Advantages: few parameters, stable, fast.

Regularized versions use diagonal loading

Real time implementation

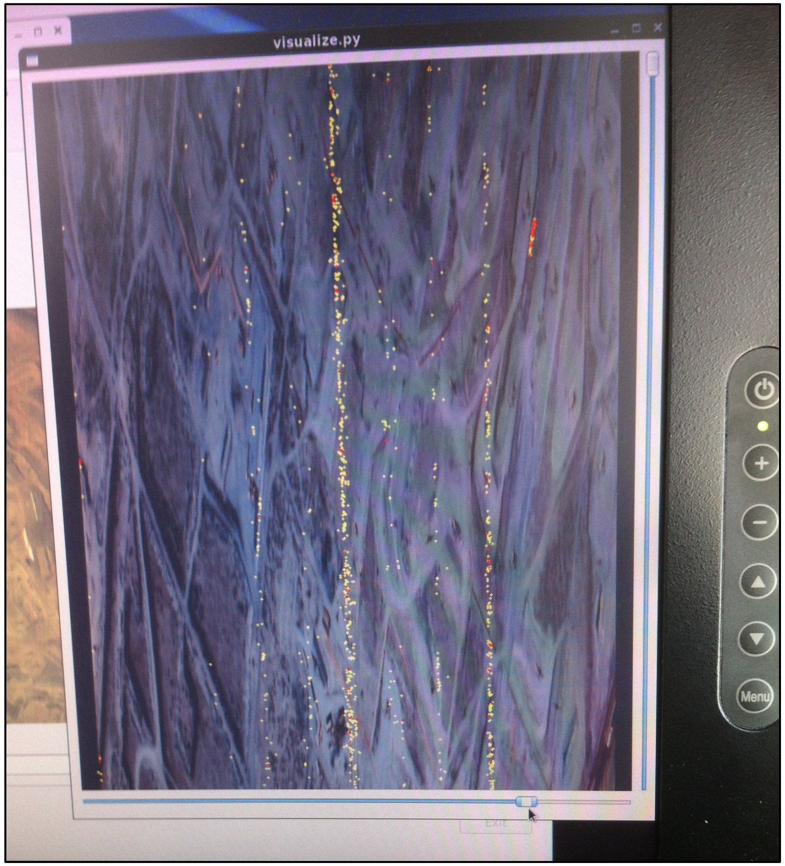






Example

Before



After

Conclusions

- We demonstrated detection of methane plumes in real time
- A columnwise matched filter performs real time CH_4 detection at 500MB/s
- Next steps:
  - Refine target signature (use Jacobians?)
  - Automatic geolocalization
  - Quantify sensitivity?

Thanks!

Christian Frankenberg, Andrew Thorpe, Andrew Aubrey, Dar Roberts. Didier Keymeulen, Brian Bue, Sarah Lundeen, Mark Helmlinger, Scott Nolte and the AVIRIS-NG team…

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