**6th IEEE Global Conference on Signal and Information Processing**
Nov. 2018 - Anaheim, CA
**MHI L.2.3**

# Persistent Hyperspectral Observations of the Urban Lightscape

J. Baur, G. Dobler, F. Bianco, S. Koonin, M. Sharma, A. Karpf
**Urban Observatory**

NYU | Center for Urban Science + Progress

# **CUSP** Urban Observatory

Better cities through imaging

https://cuspuo.org

@CUSPUO

## Main Focus

- **Energy**
  - electrical energy consumption patterns
  - stresses on the power grid
- **Environment**
  - measuring the impact of cities on air quality
  - detecting plumes
- **Public Health & Policy**
  - light pollution
  - circadian rhythm

## Our Team

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UO Director

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Senior Research Scientist

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CUSP Director

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**Andreas Karpf**
Project Manager

**Julien Baur**
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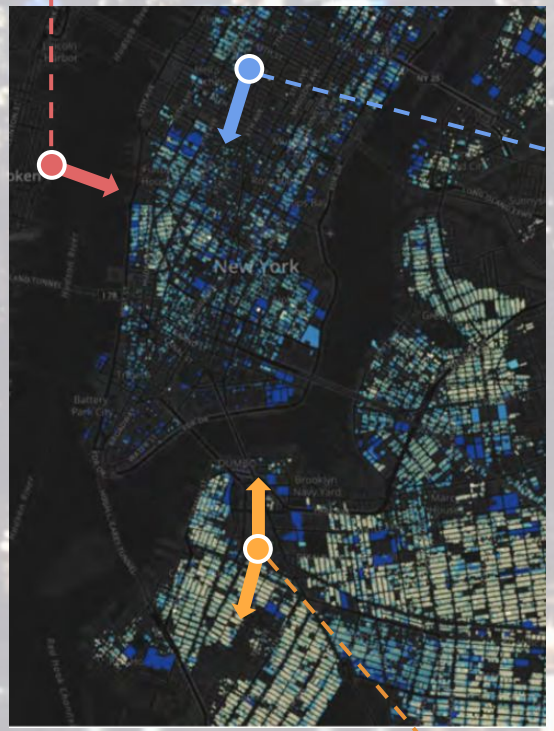
Advanced Research Projects Agency • ENERGY

**IDEAS** grant AR0000886-F0217:
Grid Dynamics and Energy Consumption Patterns through remote observations of city lights

# Imaging the NYC Lightscape

Remote, Persistent, Synoptic




view from Hoboken, NJ



view from Downtown Brooklyn

# Hyperspectral Imaging

## Instrumentation

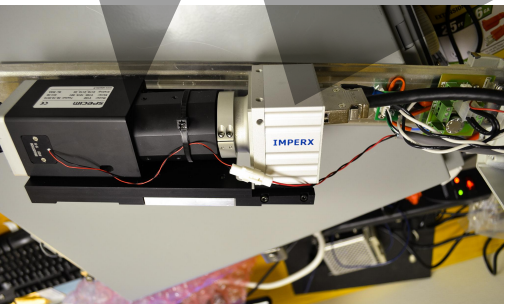
*Middleton Spectral Vision*

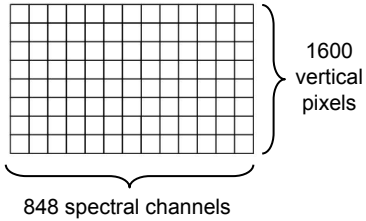
**Specim V10E**
vertical slit (30$\mu$m) aperture spectrograph

| | |
|---|---|
| range: | 0.4 - 1.1 $\mu$m |
| resolution: | 0.72 x $10^{-3}$ $\mu$m (fwhm) |


**Imperx B1621 camera (mono)**
KAI-02050 CCD image sensor

| | |
|---|---|
| pixel size: | 5.5 $\mu$m |
| sensor format: | 8.98 mm x 6.78 mm |
| resolution: | 1600 x 1200 pixels |
| frame rate: | 42 fps |

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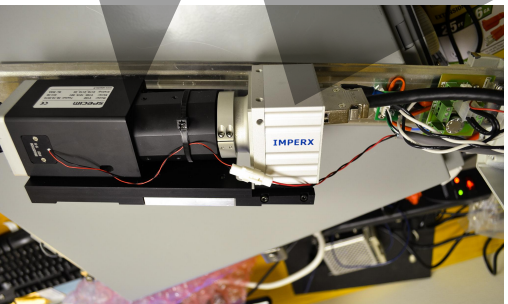


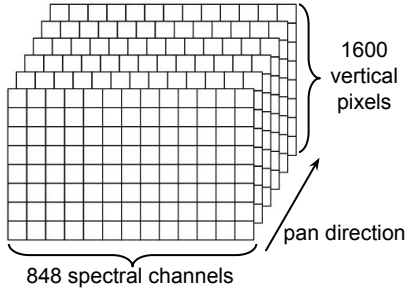


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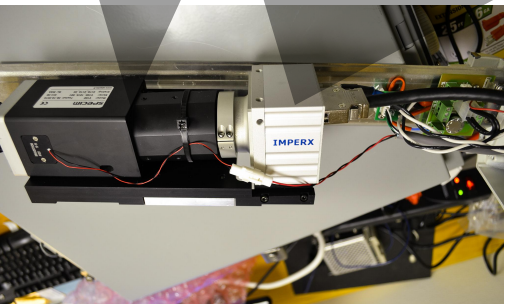


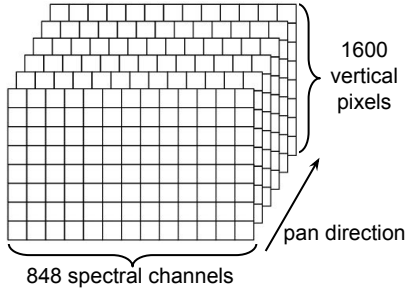



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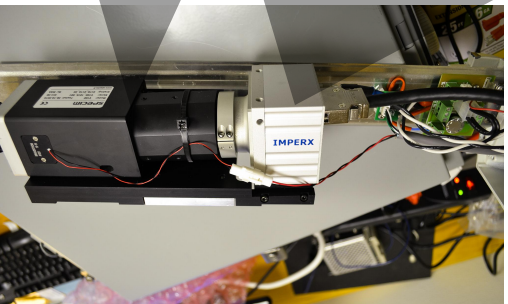


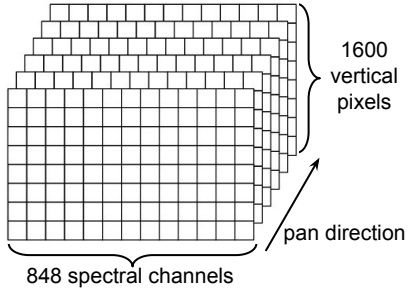


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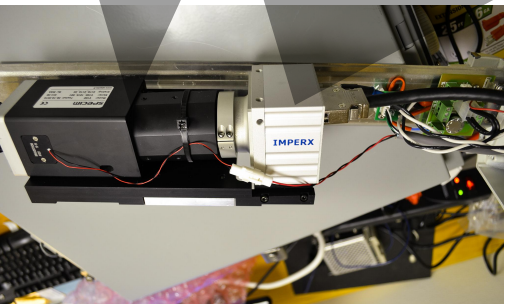
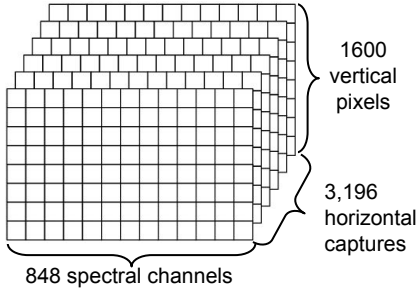
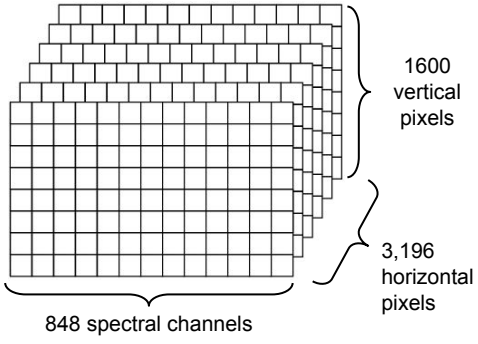


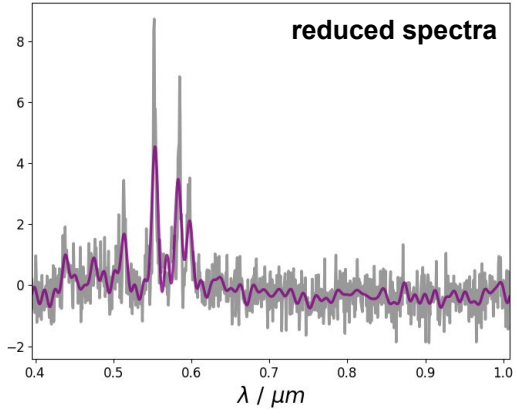





# Hyperspectral Imaging

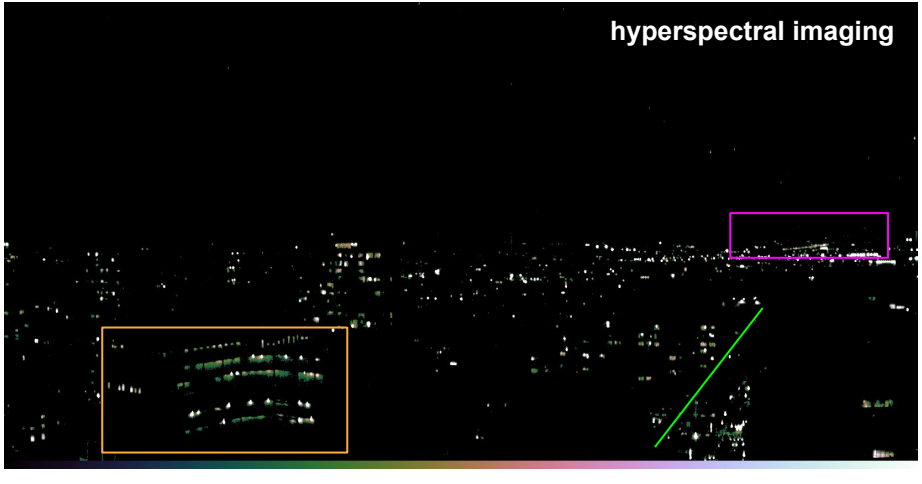
## Cleaned Data

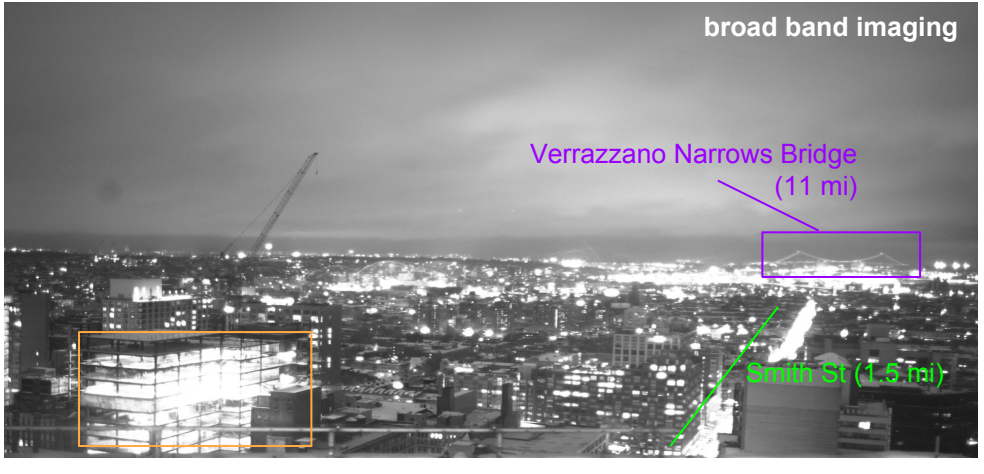



**Hyper Spectral Observations:**

- 25 consecutive nights
- one scan every 6 min
- from 21h to 05h
- 2,000 scans



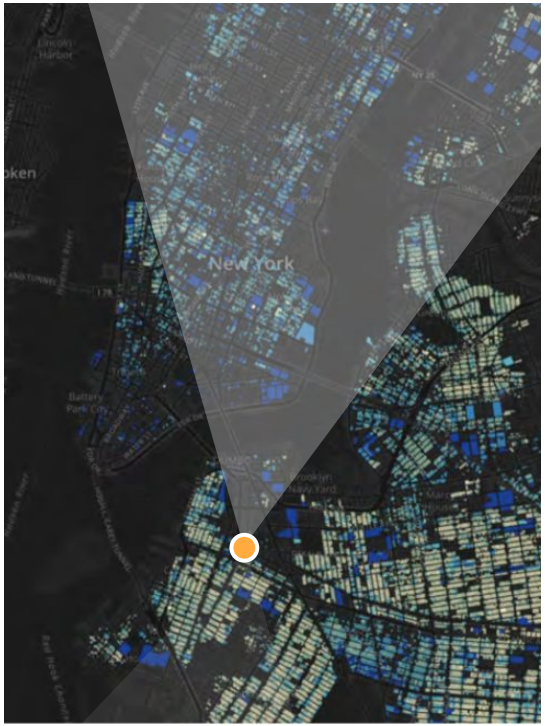



# Hyperspectral Survey

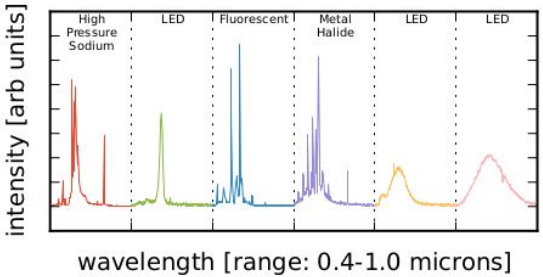
Manhattan, 2013

"A Hyperspectral Survey of New York City Lighting Technology"
Dobler, Ghandehari, Koonin & Sharma
***Sensors*, vol.16 no12, 2016** DOI:10.3390/s16122047

**Manhattan view (north facing)**



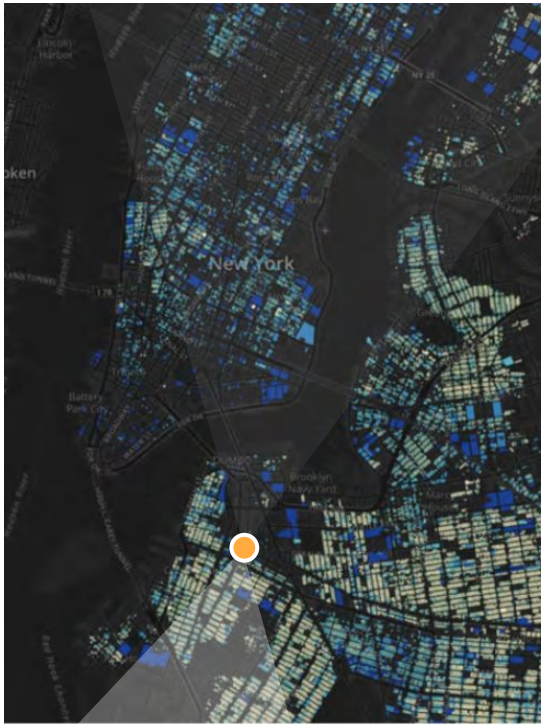

New York City Lighting Technologies




# Hyperspectral Survey

Brooklyn, 2017

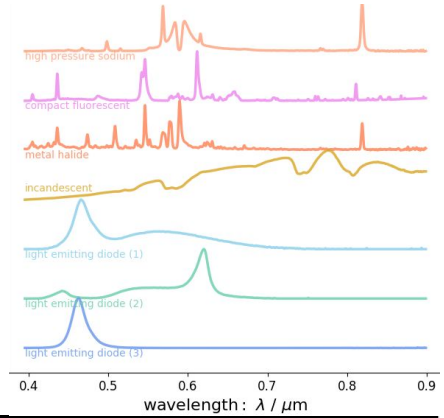
**Brooklyn view (south facing)**

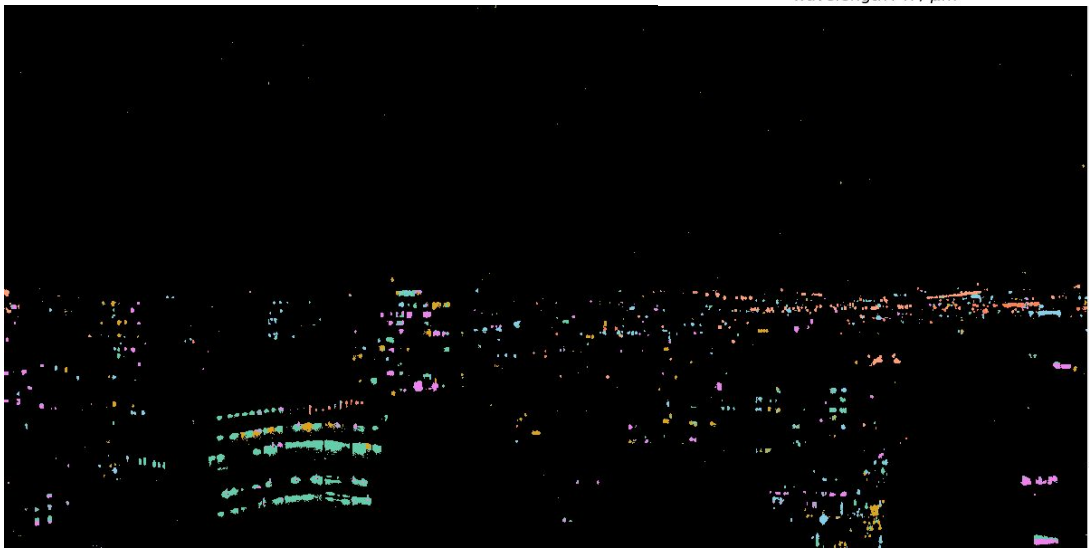



**L**amp **S**pectral **P**ower **D**istribution Database

courtesy of **Johanne Roby** (CEGEP Sherbrook, QC)
*www.lspdd.com*

- lab-measured spectral distributions of 254 light types
- **BLACK-Comet** spectrometer (*StellarNet*)



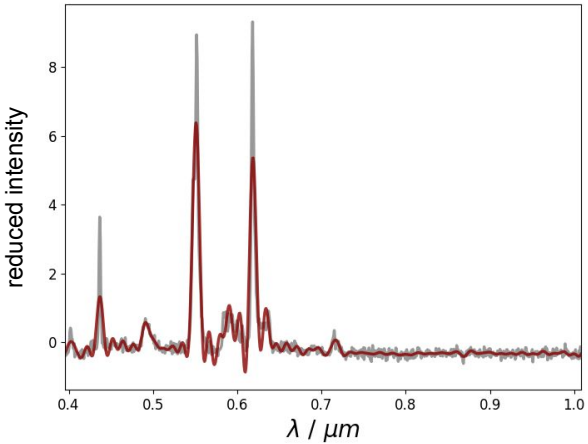
# Identifying Sources

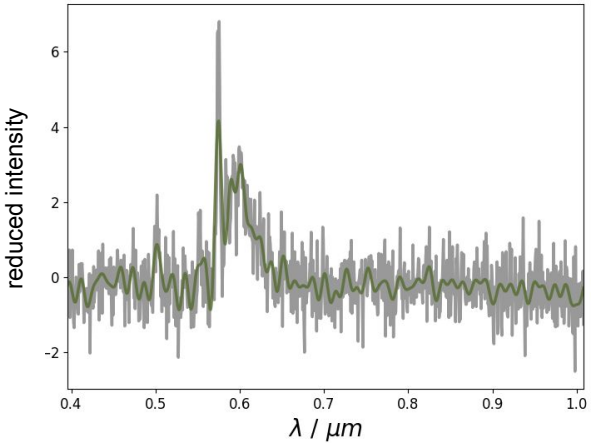
## Detecting Dim Lights

reduced intensity $\bar{s}(\lambda) = \dfrac{s - \langle s \rangle_\lambda}{\sigma_\lambda}$

integrated intensity $I(\lambda) = \int d\lambda \; \bar{s}(\lambda)$


integrated intensity [ log scaled ]

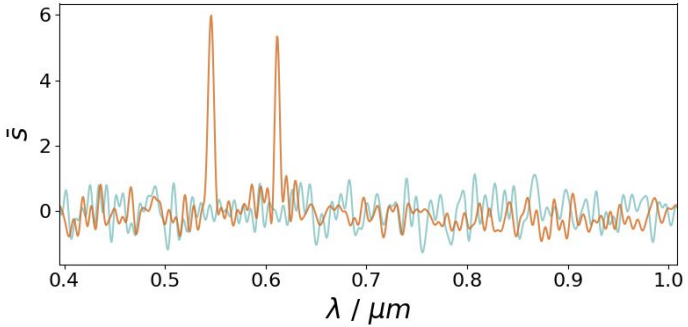


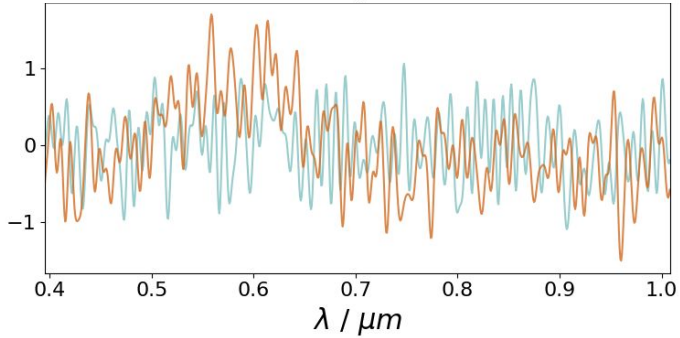



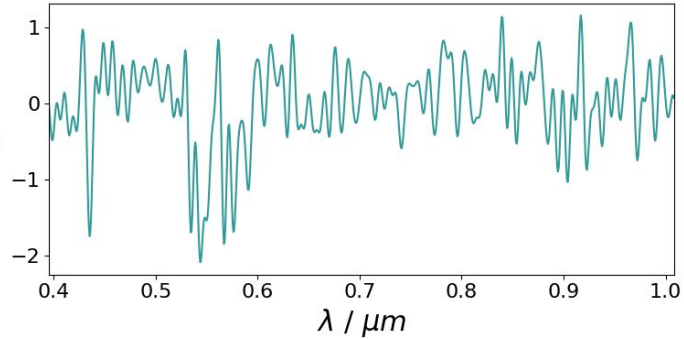
# Source Detection

## Selection

***training sample: 500 source, 500 noise***

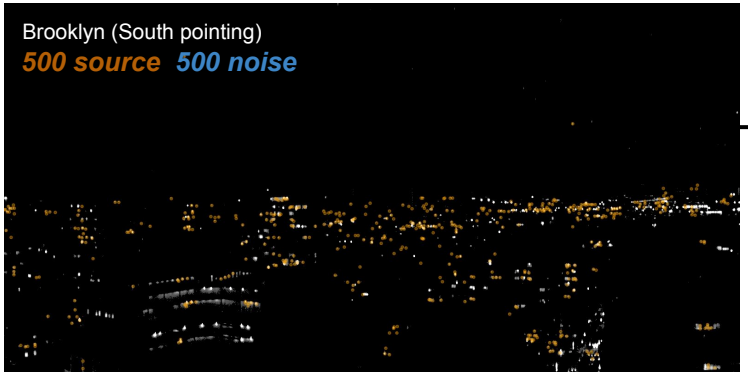


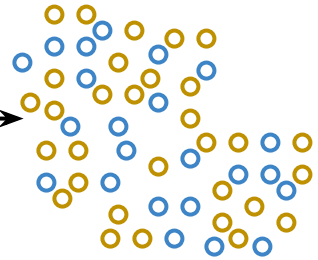



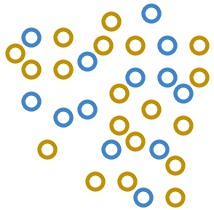
# Supervised Classifier

## Sample Split




667 training set

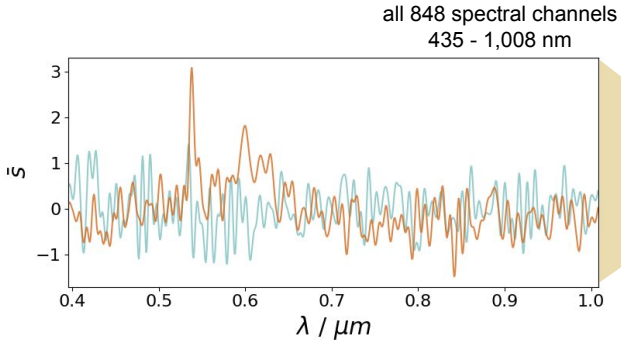


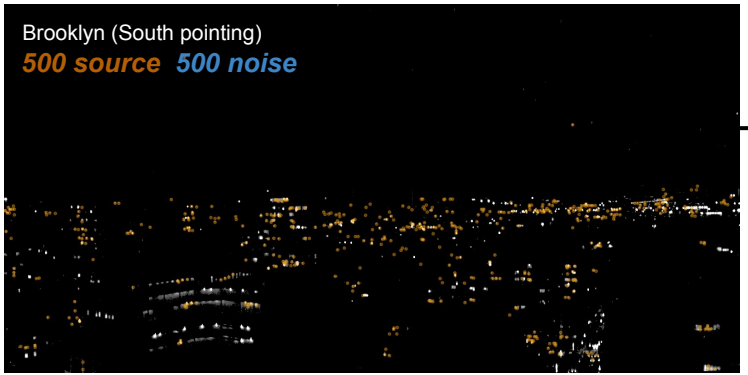


333 testing set

# Supervised Classifier

## Training




667 training set

333 testing set

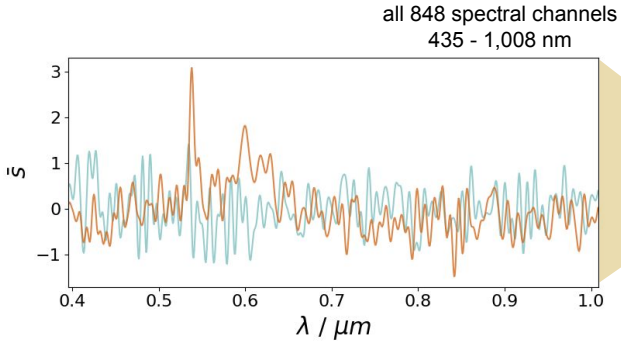
training (learning features)

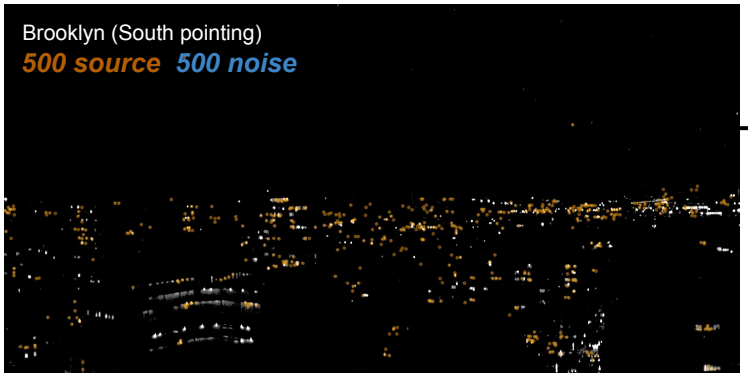
**S**upport **V**ector **M**achines
(S.V.M.)

**Cortes & Vapnik** (1995) "Support-vector networks"
*Machine Learning.* ***20*** *(3): 273–297*
doi:10.1007/BF00994018.

# Supervised Classifier

## Classification

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classification test

# Supervised Classifier

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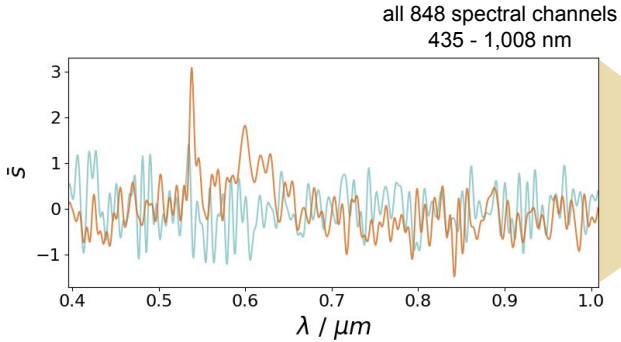


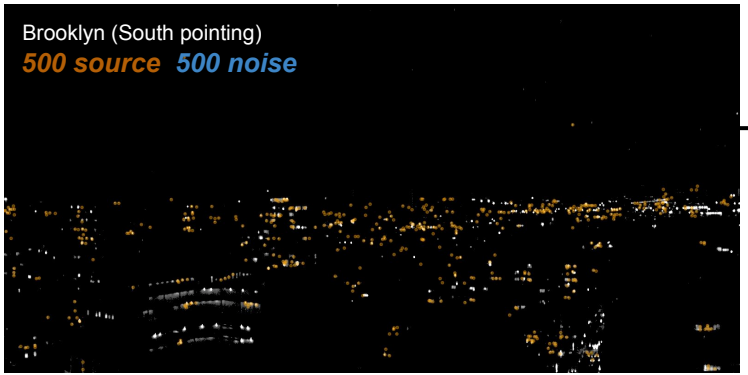


667 training set

333 testing set

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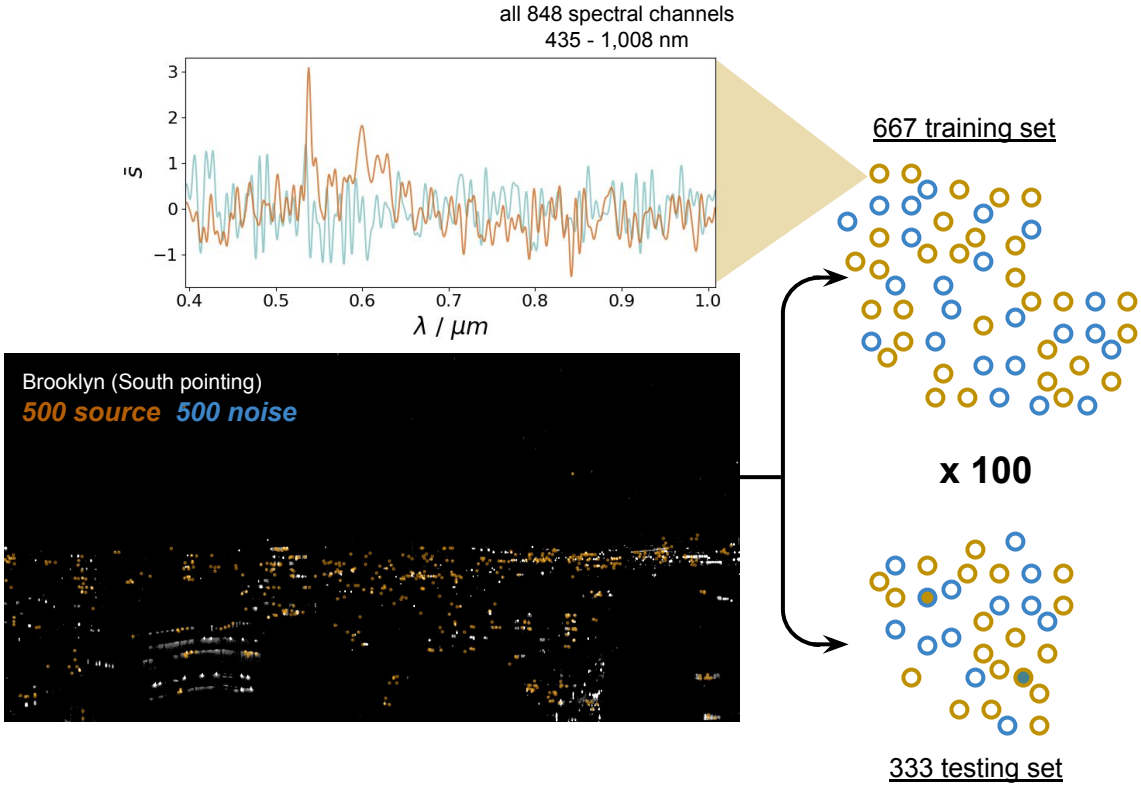
classification test

# Supervised Classifier

## Performance




**1** **Test on samples** *100 tests, shuffle*

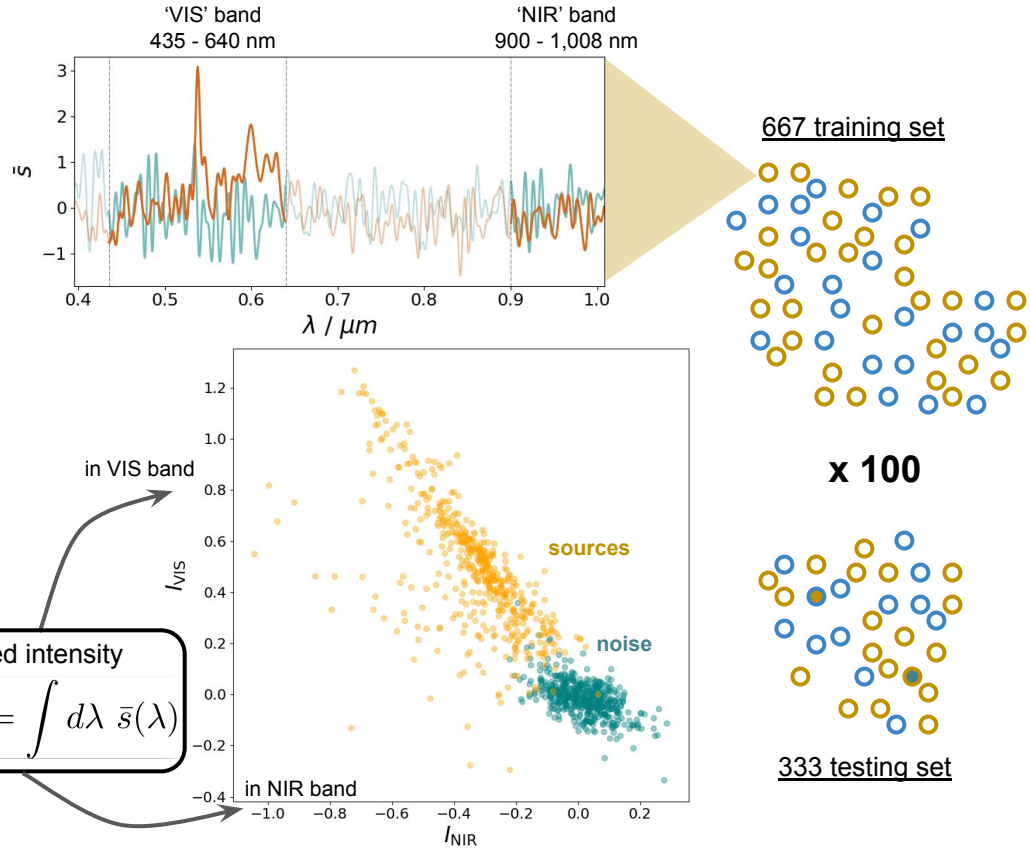
| | 848 features (all $\lambda$) | 2 features (VIS - NIR) |
|---|---|---|
| accuracy score | 97.4 % (± 0.7) | 96.2 % (± 0.9) |
| false ⊕ | 0.5 % (± 0.4) | 0.7 % (± 0.4) |
| false ⊖ | 2.1 % (± 0.7) | 3.1 % (± 0.9) |

**2** **Labelling full cube** *5.1 x$10^6$* pixels

| | | |
|---|---|---|
| cpu time (1 core) | ∿ 960 sec | ∿ 60 sec |

# Supervised Classifier

## Performance

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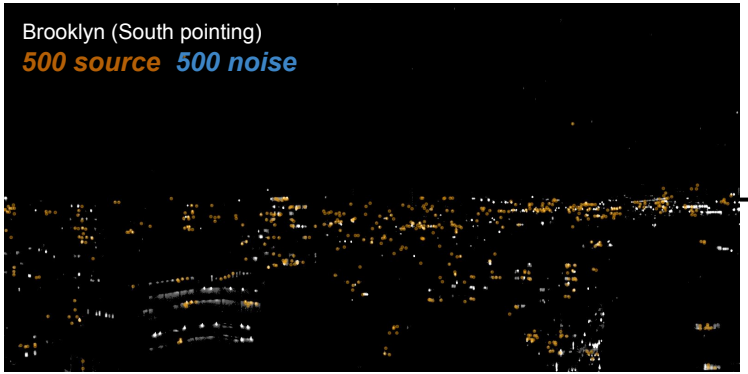
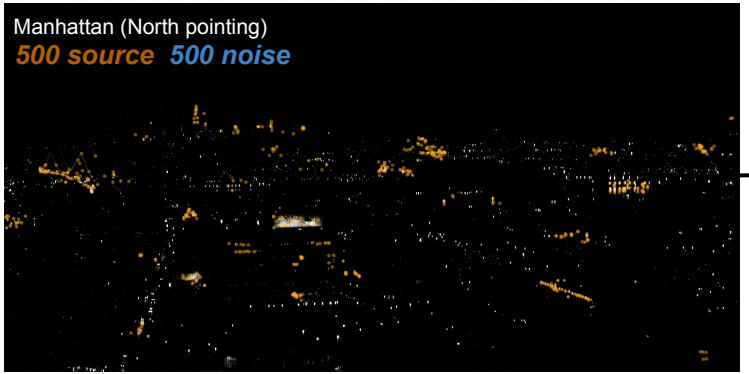
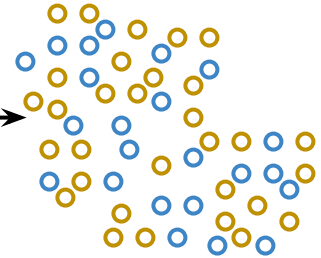
# Transferability

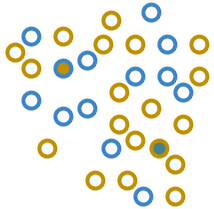



667 training set



x 100



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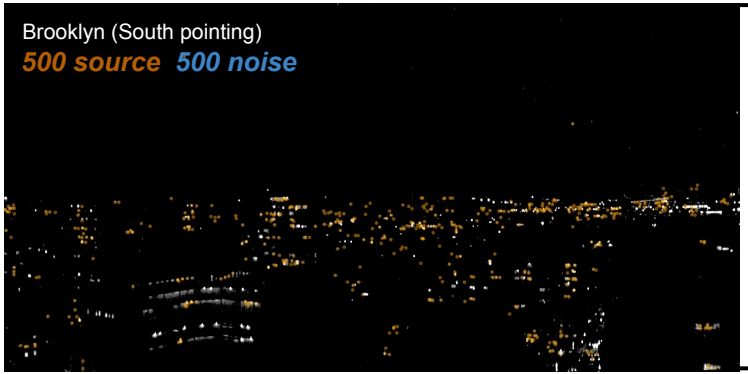
|---|---|---|
| accuracy score | 97.4 % (± 0.7)<br>96.2 % (± 0.4) | 96.2 % (± 0.9)<br>93.8 % (± 0.9) |
| false ⊕ | 0.5 % (± 0.4)<br>0.4 % (± 0.2) | 0.7 % (± 0.4)<br>0.2 % (± 0.1) |
| false ⊖ | 2.1 % (± 0.7)<br>3.3 % (± 0.5) | 3.1 % (± 0.9)<br>6.0 % (± 0.6) |

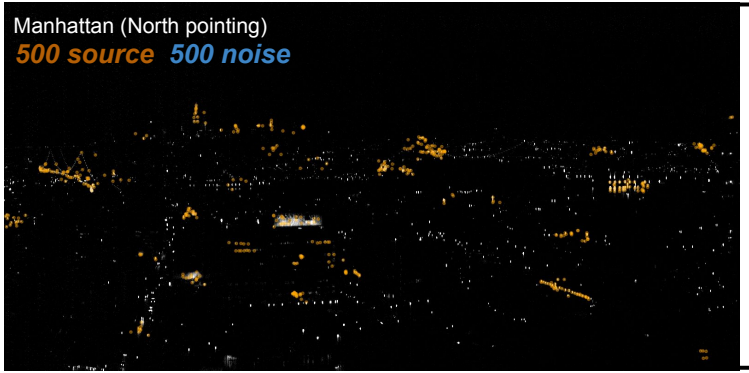
**2** **Labelling full cube** *2.5 x$10^6$ pixels*

| | | |
|---|---|---|
| cpu time (1 core) | ∿ 960 sec<br>∿ 460 sec | ∿ 60 sec<br>∿ 29 sec |

# Transferability




848 wavelengths
0.395 - 1.008 microns
stack of 10 scans
external deployment
summer night




872 wavelengths
0.400 - 1.030 microns
singular 30-s scan
internal deployment
late fall night

**1** **Test on samples** *100 tests, shuffle*

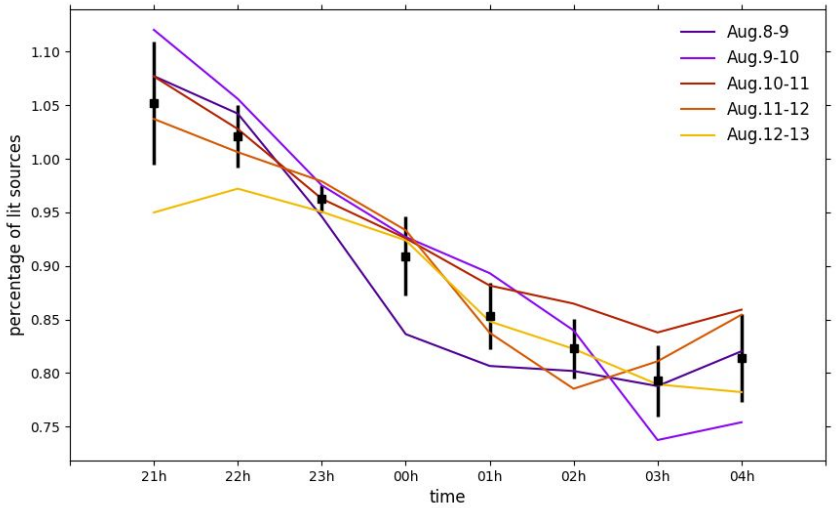
| | **848 features (all $\lambda$)** | **2 features (VIS - NIR)** |
|---|---|---|
| **accuracy score** | 97.4 % (± 0.7)<br>96.2 % (± 0.4) | 96.2 % (± 0.9)<br>93.8 % (± 0.9) |
| **false ⊕** | 0.5 % (± 0.4)<br>0.4 % (± 0.2) | 0.7 % (± 0.4)<br>0.2 % (± 0.1) |
| **false ⊖** | 2.1 % (± 0.7)<br>3.3 % (± 0.5) | 3.1 % (± 0.9)<br>6.0 % (± 0.6) |

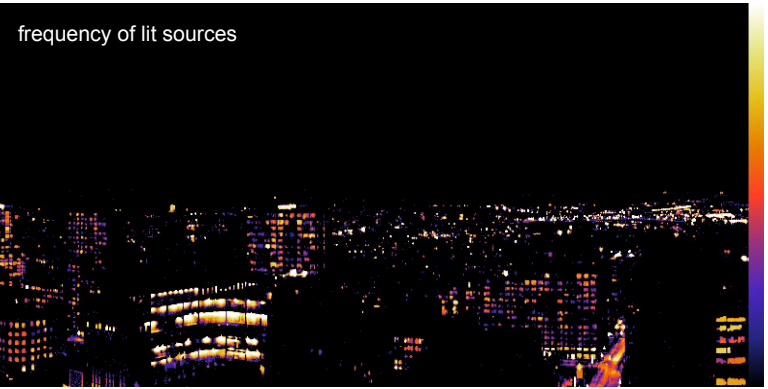
**2** **Labelling full cube** *2.5 x$10^6$* pixels

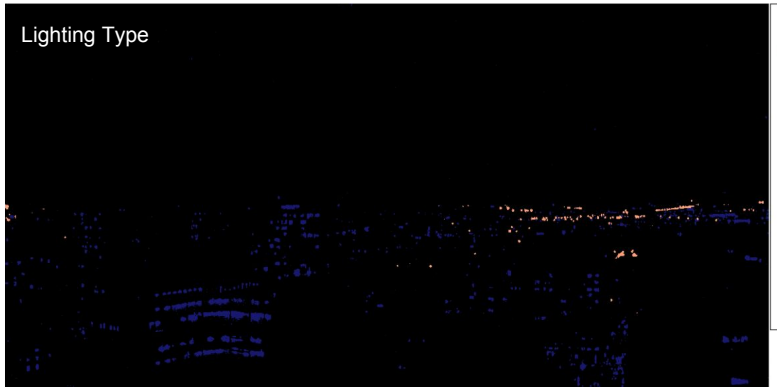
| | | |
|---|---|---|
| **cpu time (1 core)** | ∿ 960 sec<br>∿ 460 sec | ∿ 60 sec<br>∿ 29 sec |

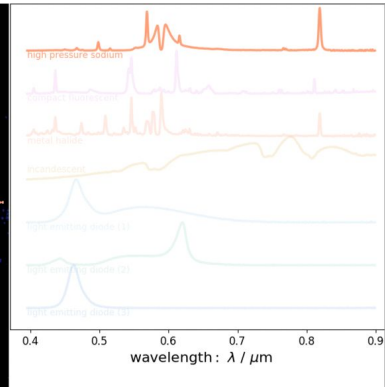
# Next Step

## Technology Penetration & Time Series

# Thank You

for your attention


email **julien.baur@nyu.edu**

UO website **https://cuspuo.org**

Twitter **@CUSPUO**

CUSP website **http://cusp.nyu.edu/**