CENTER FOR URBAN
SCIENCE+PROGRESS

Bottom-up techniques for Urban Sensing

Nicholas E. Johnson - Feb 27, 2017

Overview

- Part I - Sensor Foundations
  - sensor concepts and foundations, calibration methods, tools and techniques for measuring
- Part II - Low-cost remote sensing
  - Balloon photography of waterways and landfills, satellites and landfills, the radio spectrum with software defined radios (no landfills)
- Part III - Hands on!
  - Spectrometer workshop, air quality sensor

Bottom-up Techniques

- It’s not just about **low-cost** technologies but also includes:
    - the increase in connected devices via the internet; the proliferation of **open source** communities and initiatives; citizen science and public participation; technological advancements and increased access to new technologies
- As data scientists, the bottom-up approach can fill certain gaps in situations with limited data access, low resolution data and a general lack of data.
- Prevents the “trusting data scientist” and asks the critical questions:

Where does data come from?

"Sensors are the way that we read the physical world using computers."

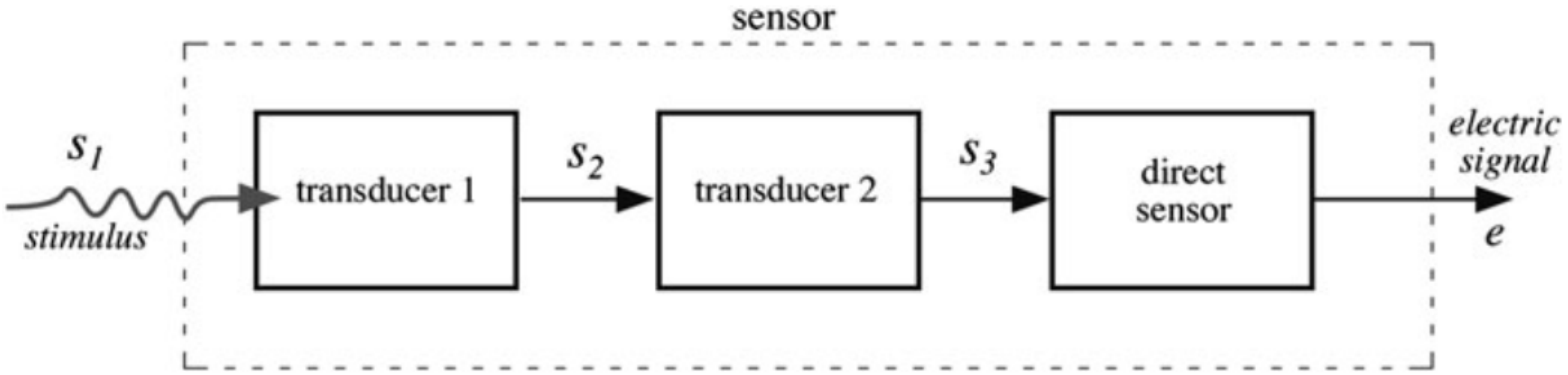
–Tom Igoe

SENSORS

- A **sensor** is a device which detects some characteristic of its environment and provides a corresponding **electrical output**.
- A sensor's output signal maybe in the form of **voltage, current** or **charge**
- These can further be described in terms of: **amplitude, polarity, frequency, phase**

SENSOR SYSTEMS

- A sensor does not function by itself; it is always a part of a larger system
- Sensors are often **transducers:**
  - a transducer is more than a sensor. It consists of a sensor along with some signal conditioning
- Sensors convert physical forms of energy into electrical signals which can then be read and interpreted by **microcontrollers**



MEASURING VS INFORMATION

- **What does the sensor measure?** Light, motion, temperature, magnetic fields, gravity, humidity, moisture, vibration, pressure, electrical fields, sound, and other physical aspects of the **external environment.**

How do you interpret those measurements?

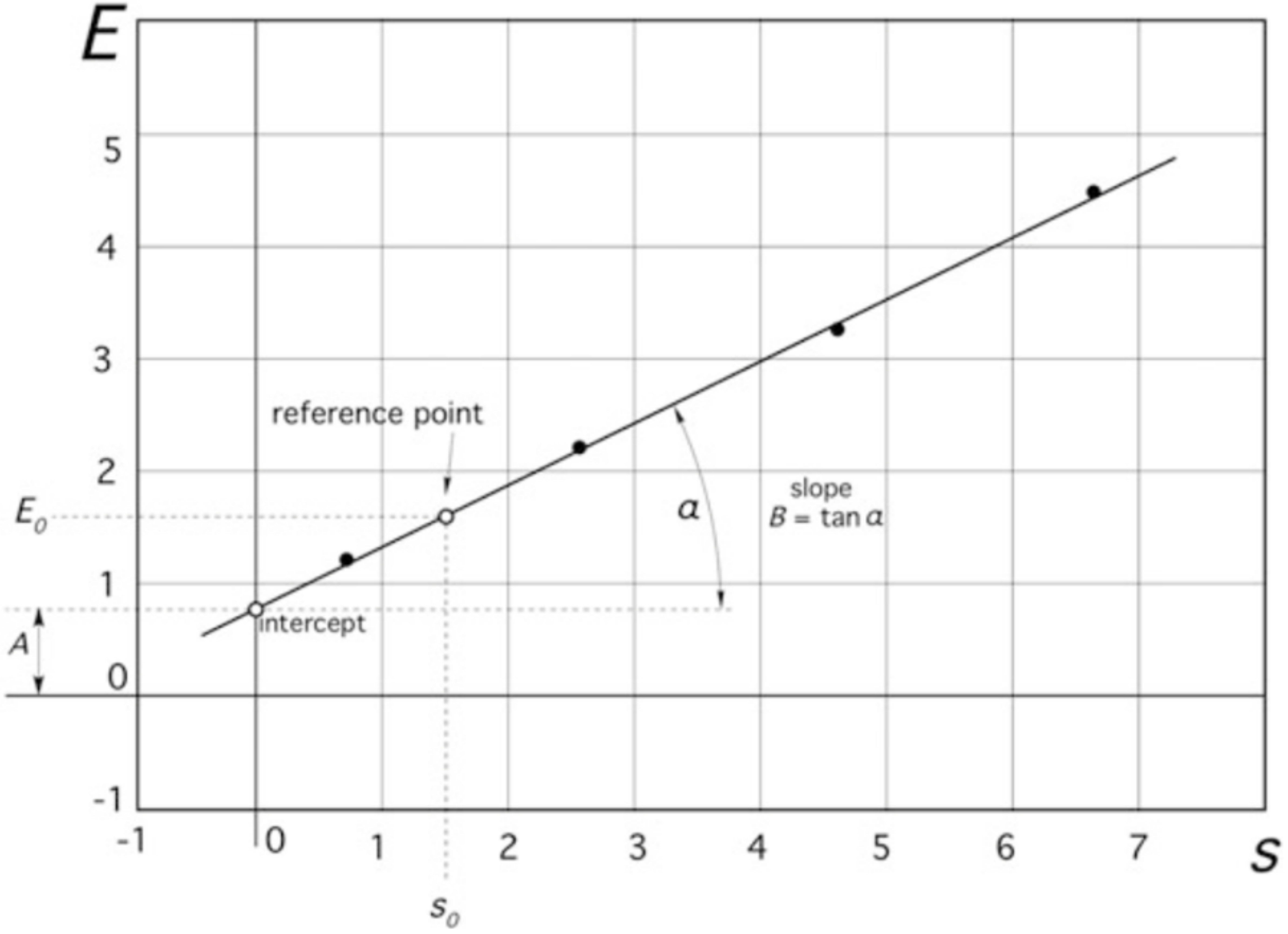
SENSOR CHARACTERISTICS

- Each sensor has a ‘characteristic curve’ or **transfer function** (E) that describes the ideal input-output (stimulus-response) relationship.

- The simplest transfer function is linear:

$$E = A + Bs$$

- ***E*** is the sensor output which becomes ‘known’ during measurement and represents the stimulus (***s***). ***A*** is the sensor’s offset value and ***B*** is it’s sensitivity (slope)



SENSOR CHARACTERISTICS

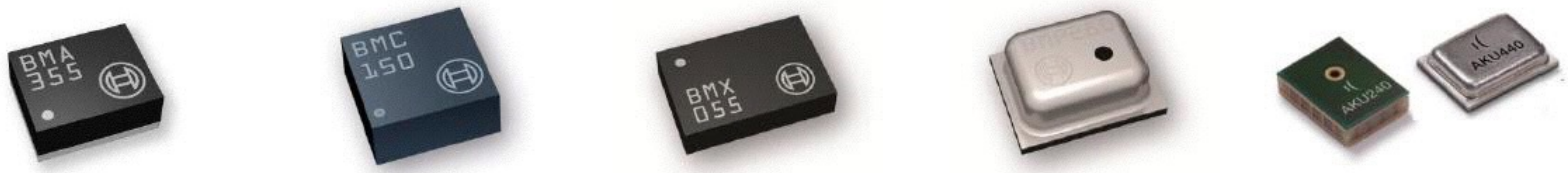
- **Sensitivity** means how much the output of a device changes with unit change in input. This is a changing value for nonlinear sensors!
- The **range** of a sensor is the maximum and minimum values that can be measured
- **Resolution** is the smallest change in input that the device can detect

SENSOR CHARACTERISTICS

- A sensor is considered **bias or offset** when the output signal is not zero when the property measured is zero.
- Sensor **drift** is when the output signal slowly changes independent of the measured property. Usually occurs with the aging of the sensor.
- How well the sensor measures the environment in an absolute sense is known as **accuracy**
- **Noise** is random variations in the signal over time

MICRO-ELECTRO-MECHANICAL SYSTEM (MEMS)

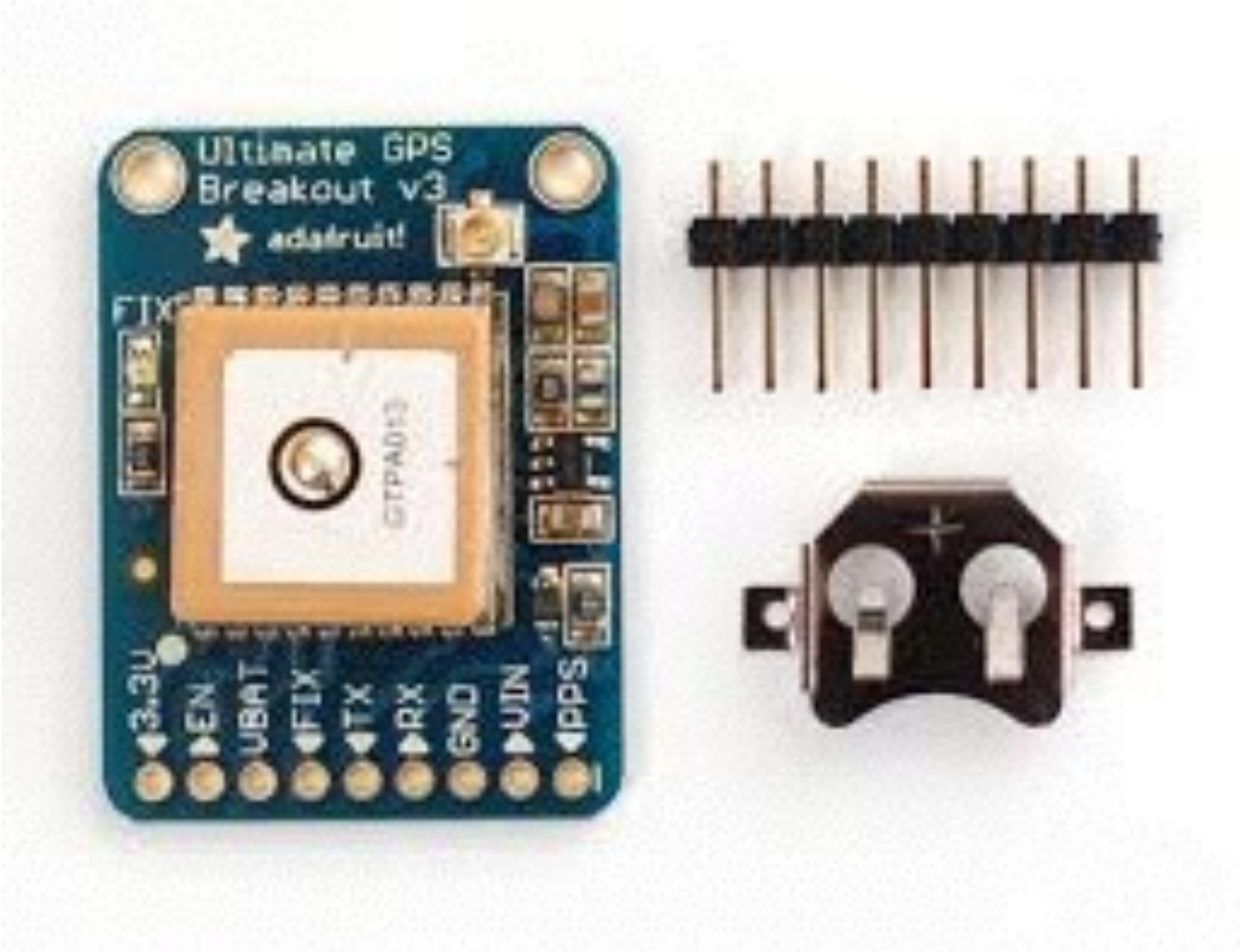
3-axis sensors	6-axis sensors	9-axis sensors	environmental	microphones
▪ Accelerometer ▪ Gyroscope ▪ Magnetometer	▪ eCompass ▪ IMU	▪ Absolute Orientation Sensor ▪ Application Specific Sensor Nodes (ASSNs, incl. µC)	▪ Barometric Pressure Sensor ▪ Integrated Environmental Unit	▪ Analog and digital MEMS microphones (Akustica) ▪ High quality voice input for mobile devices



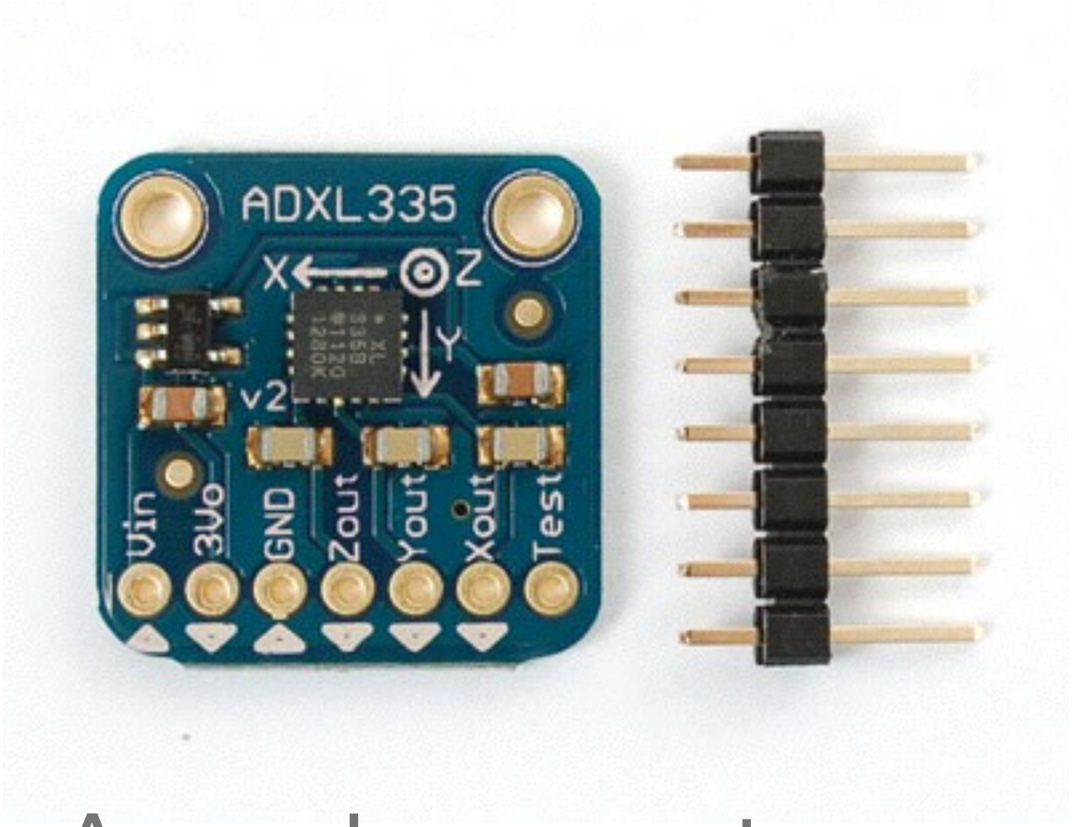
Tilt, Acceleration, Position, and Orientation

Gyrometer

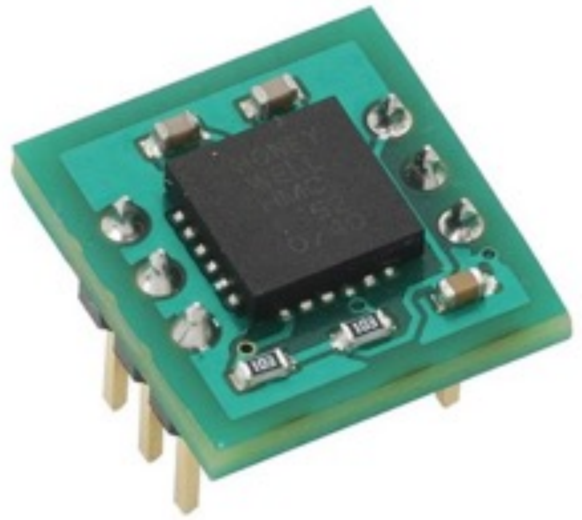
Tilt



GPS Location



Accelerometer

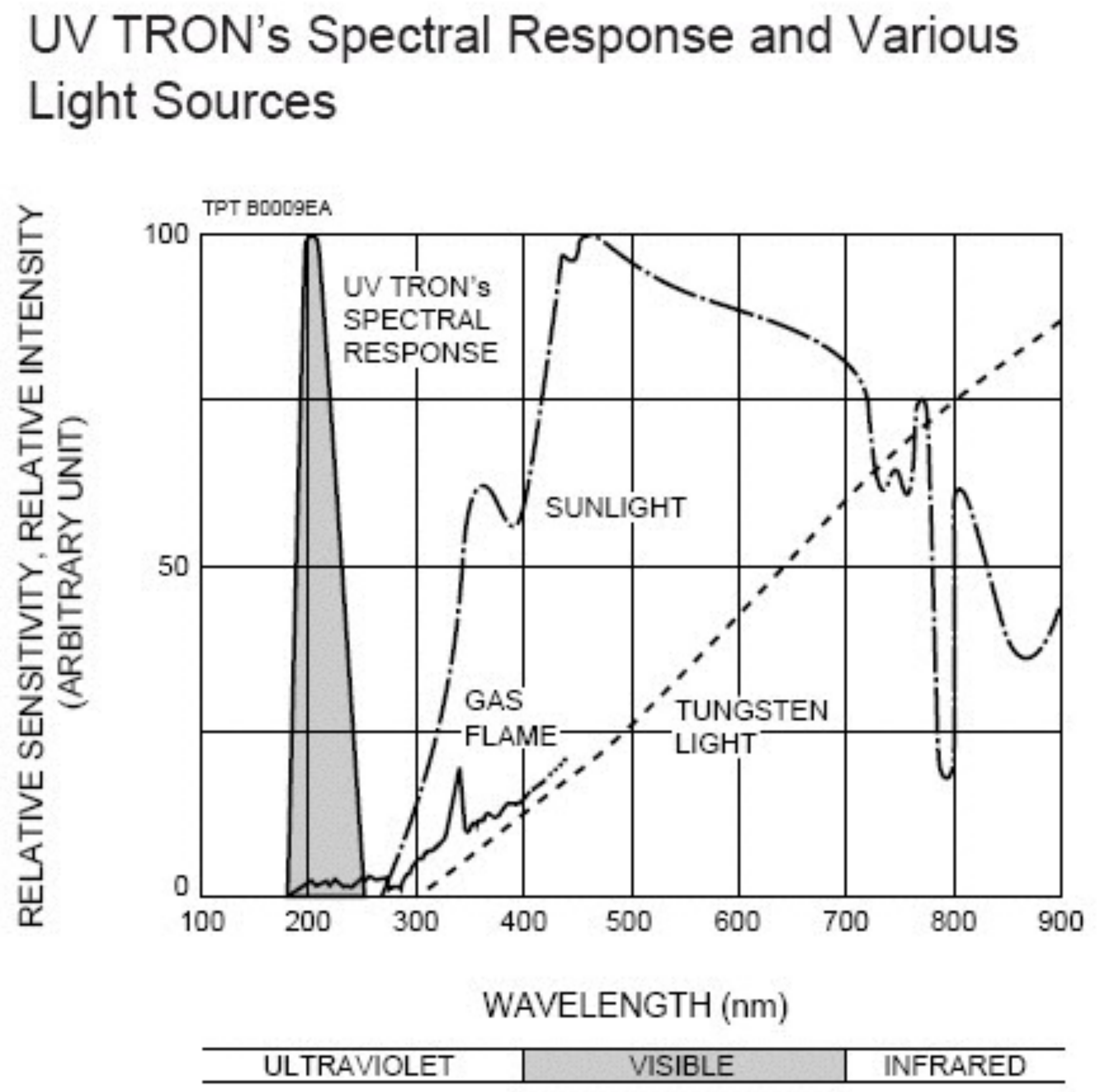


Magnetoresistive
(Compass)

ENVIRONMENTAL

Gas

Dust



Humidity

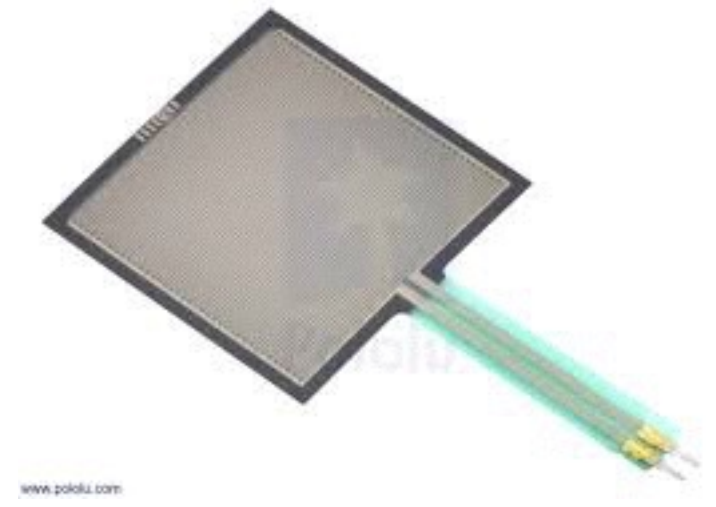
Temperature

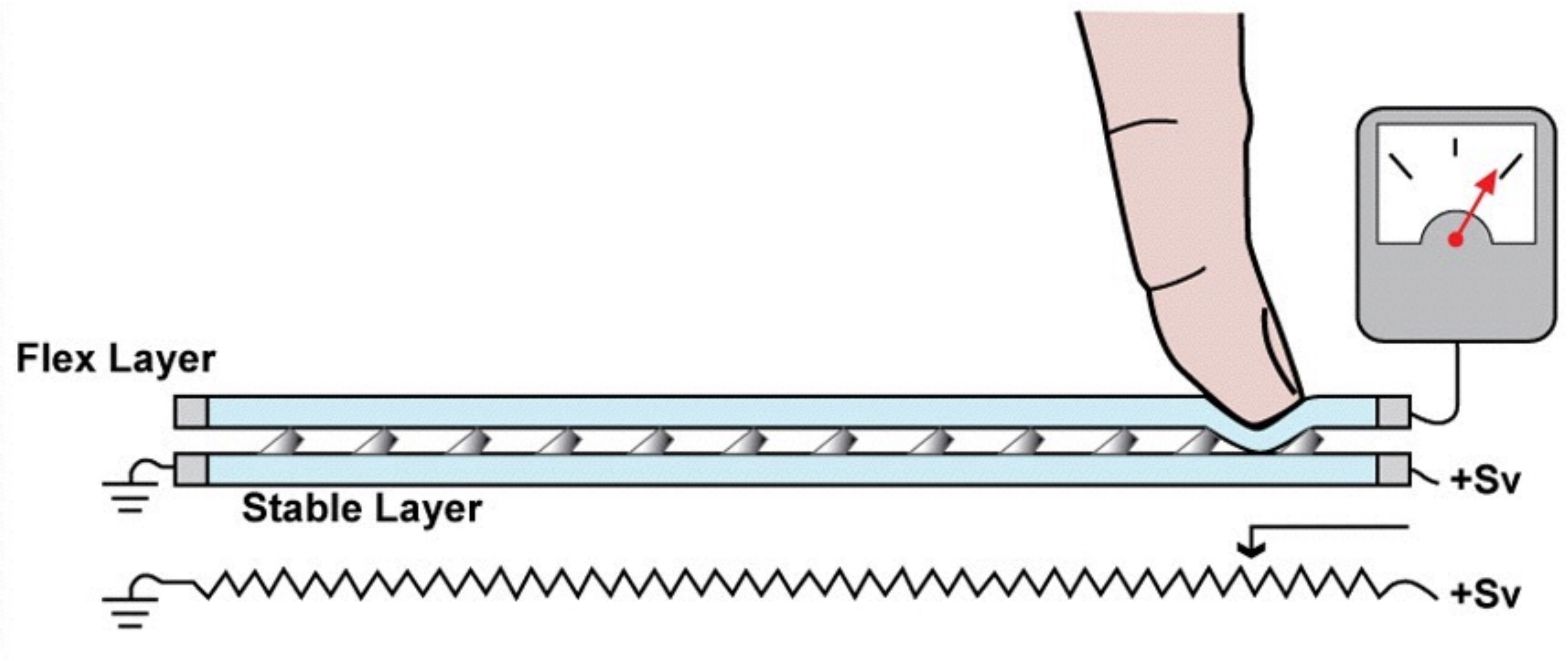
Anemometer

Flame

FORCE/STRETCH/BEND

- resistive sensors which are made of conductive carbon so the resistance changes as it is deformed. This change in resistance is measured

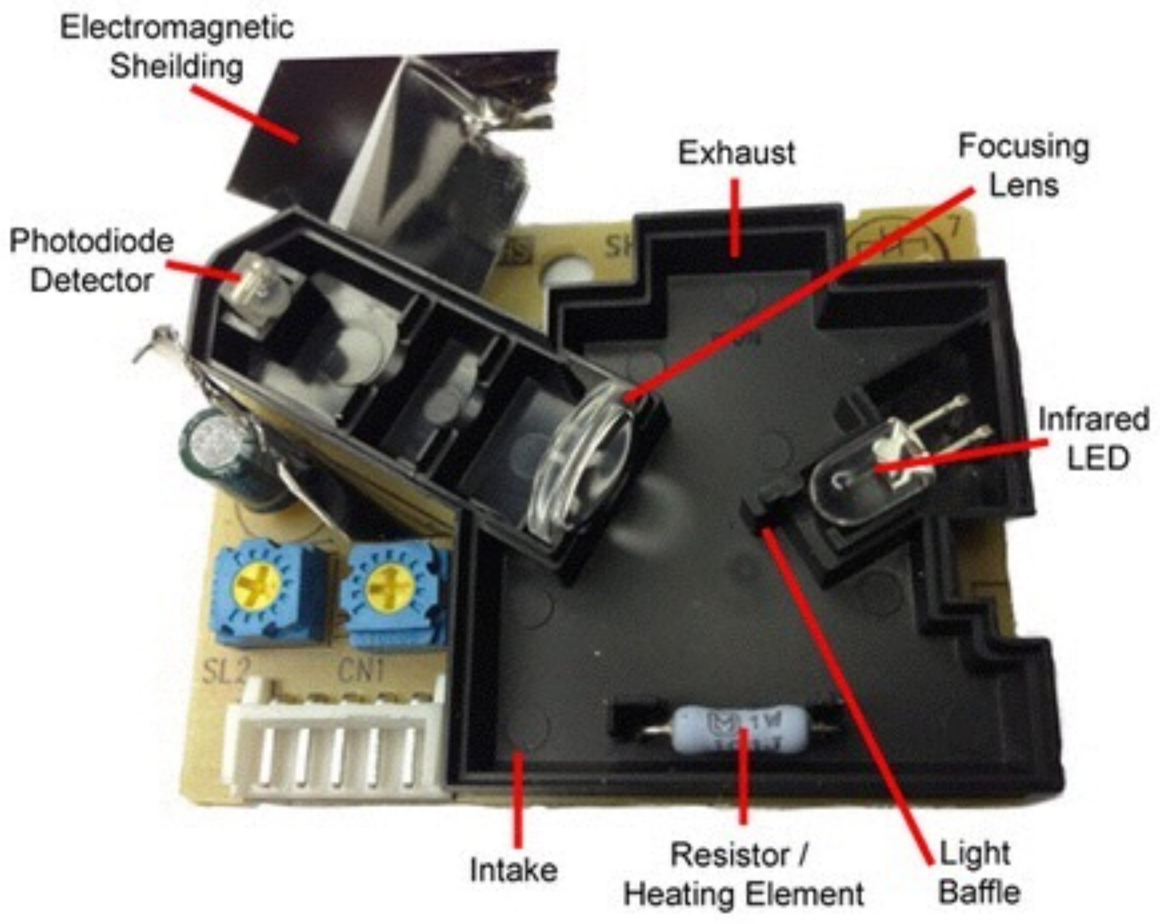




OPTICAL/LIGHT SENSORS

- convert light into electrical signals
- used for a variety of purposes including distance, pulse, air quality etc…

Luminosity



Dust Sensor

LidarLite

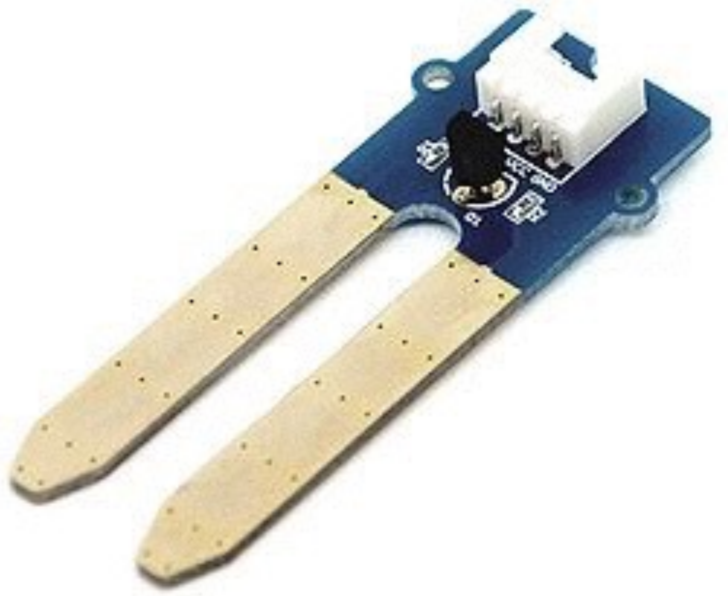
IR Distance

Pulse Sensor

CHEMICAL SENSING

- often used for measuring concentrations, compositions and absorption

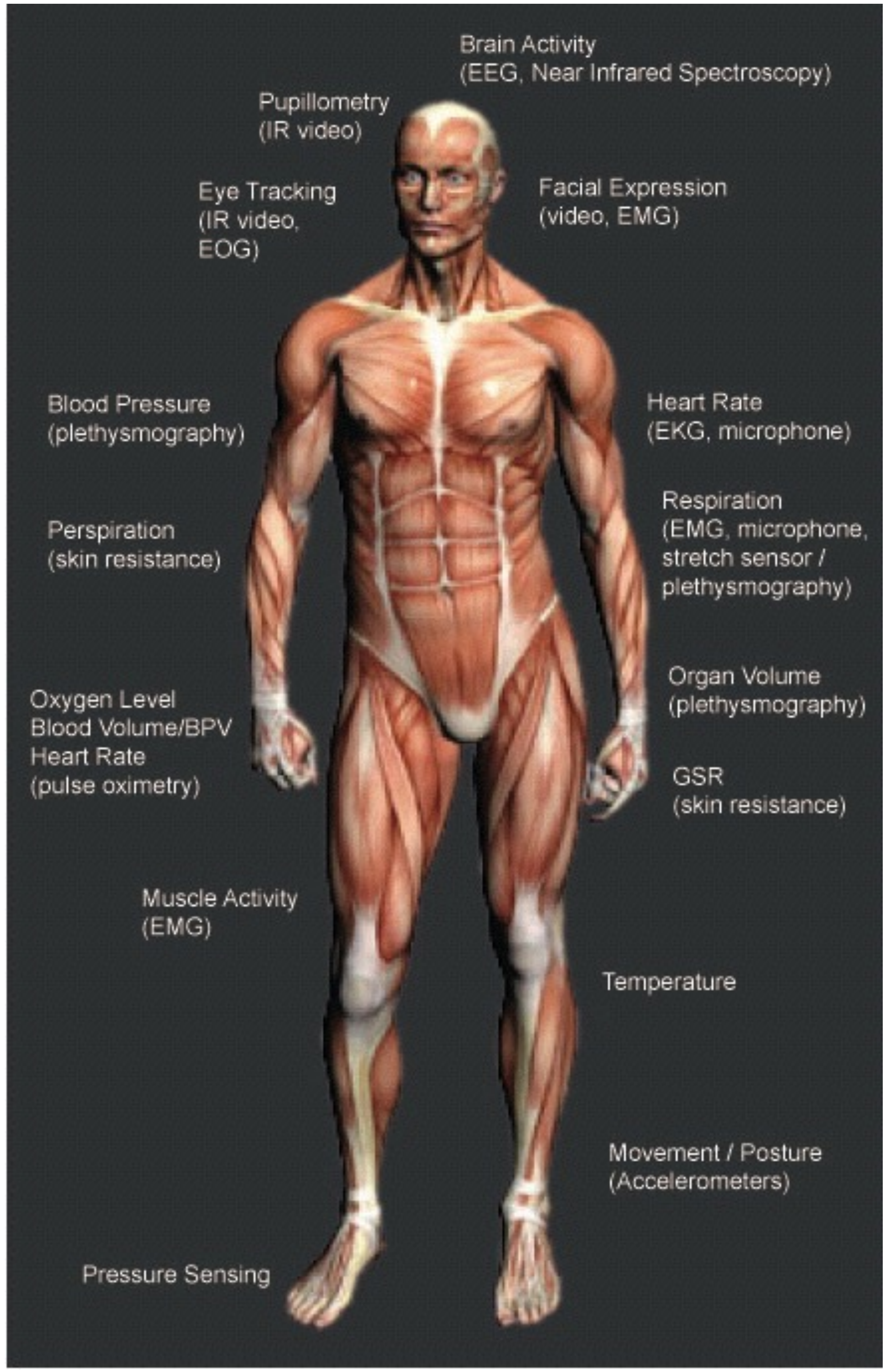
Conductivity



Moisture

Gas Sensors

BIOMETRIC



EEG

Stretch

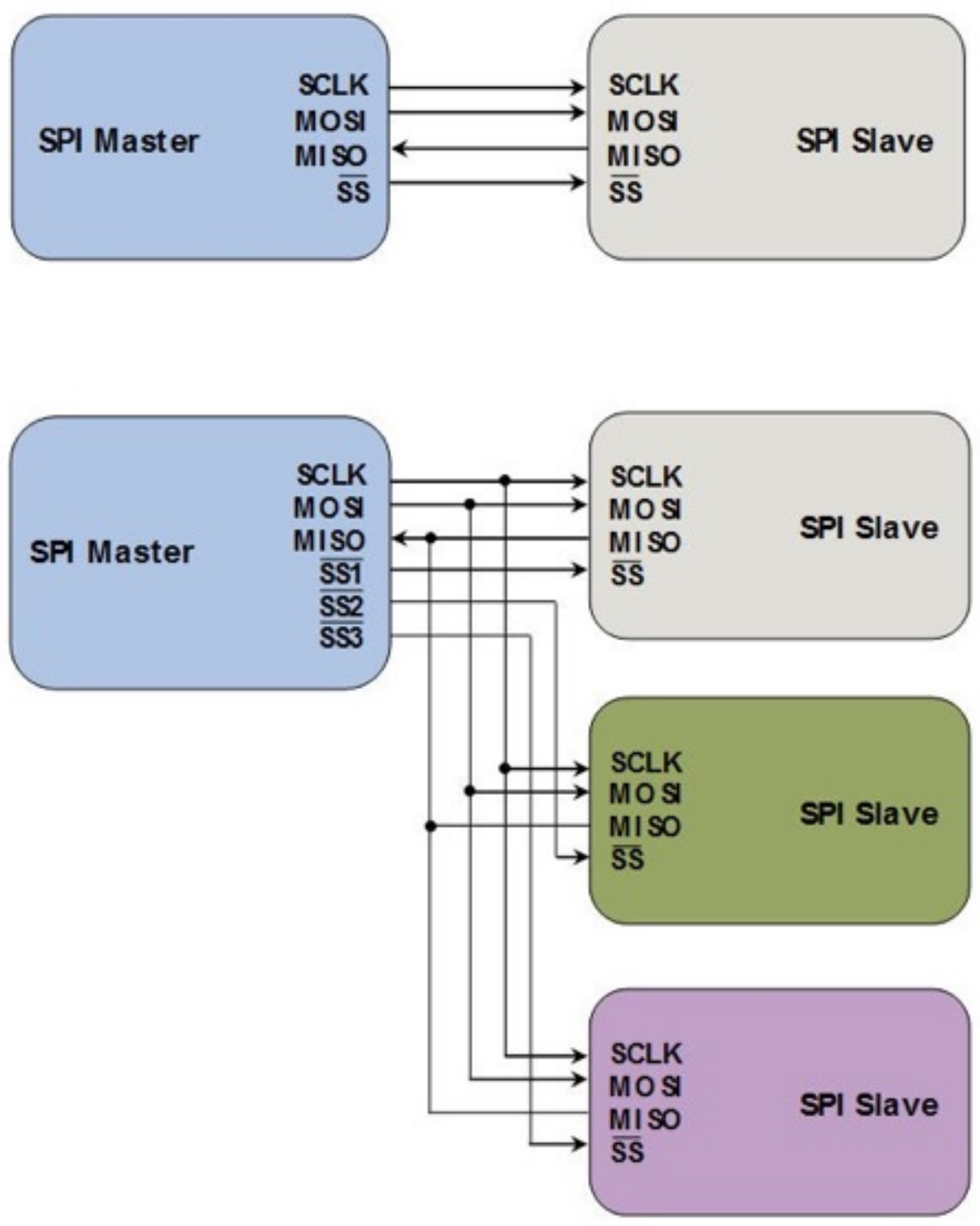
Pulse Sensor

Sean Montgomery

COMMUNICATION

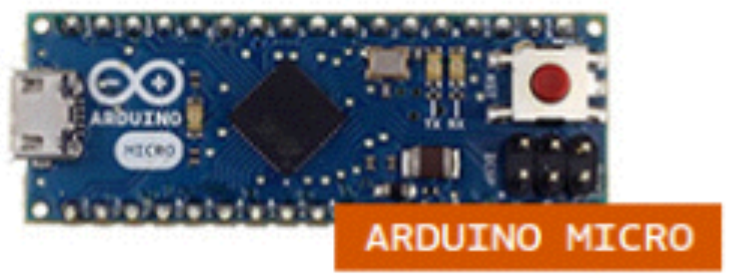
- **Analog:** often microcontrollers will have an A/D
- **Digital:** computers must have speed, electrical and logical agreement
  - Serial
    - synchronous (with clock) - SPI, I2C, UART
    - asynchronous (no clock) - slower data rates
  - Frequency Encoded
    - measuring pulse width or pulse frequency

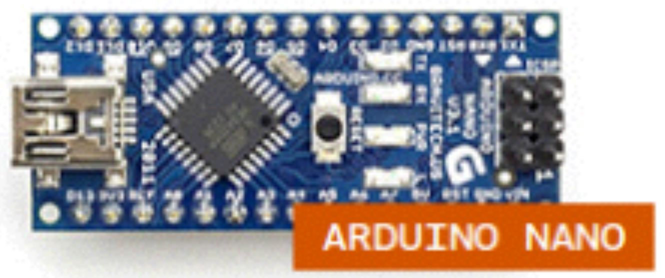
Figure 1 : Two SPI busses topologies. The upper figure shows a SPI master connected to a single slave (point-to-point topology). The lower figure shows a SPI master connected to multiple slaves.



ARDUINO

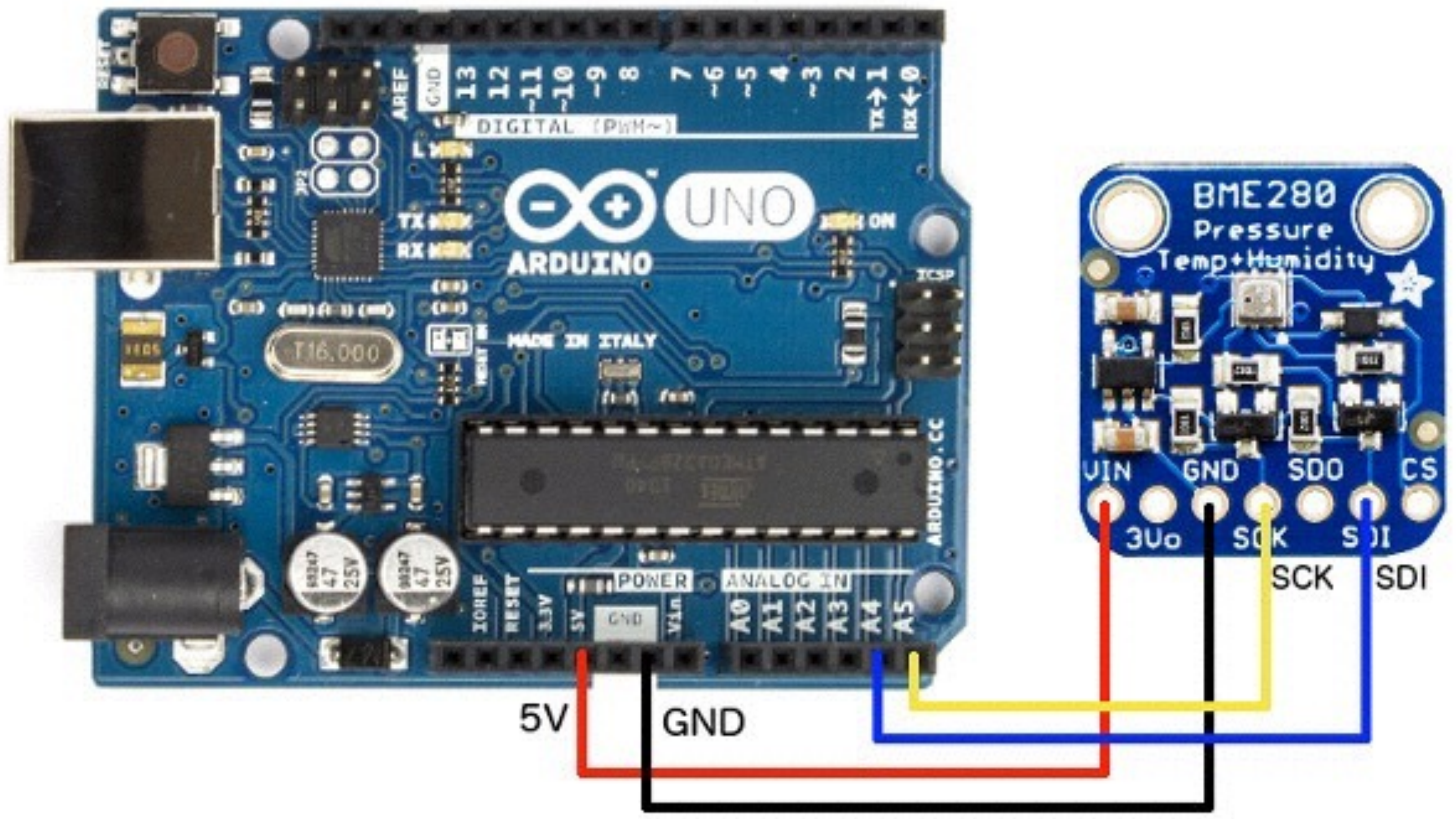
- Arduino is an **open-source** electronics platform based on easy-to-use hardware and software. It's intended for anyone making interactive projects.
- easy way for people to focus on sensors what they can do for you and how they work





EXAMPLE SETUP

- **I2C** digital communication
  - SCK- clock
  - SDA - data
- **5v** power

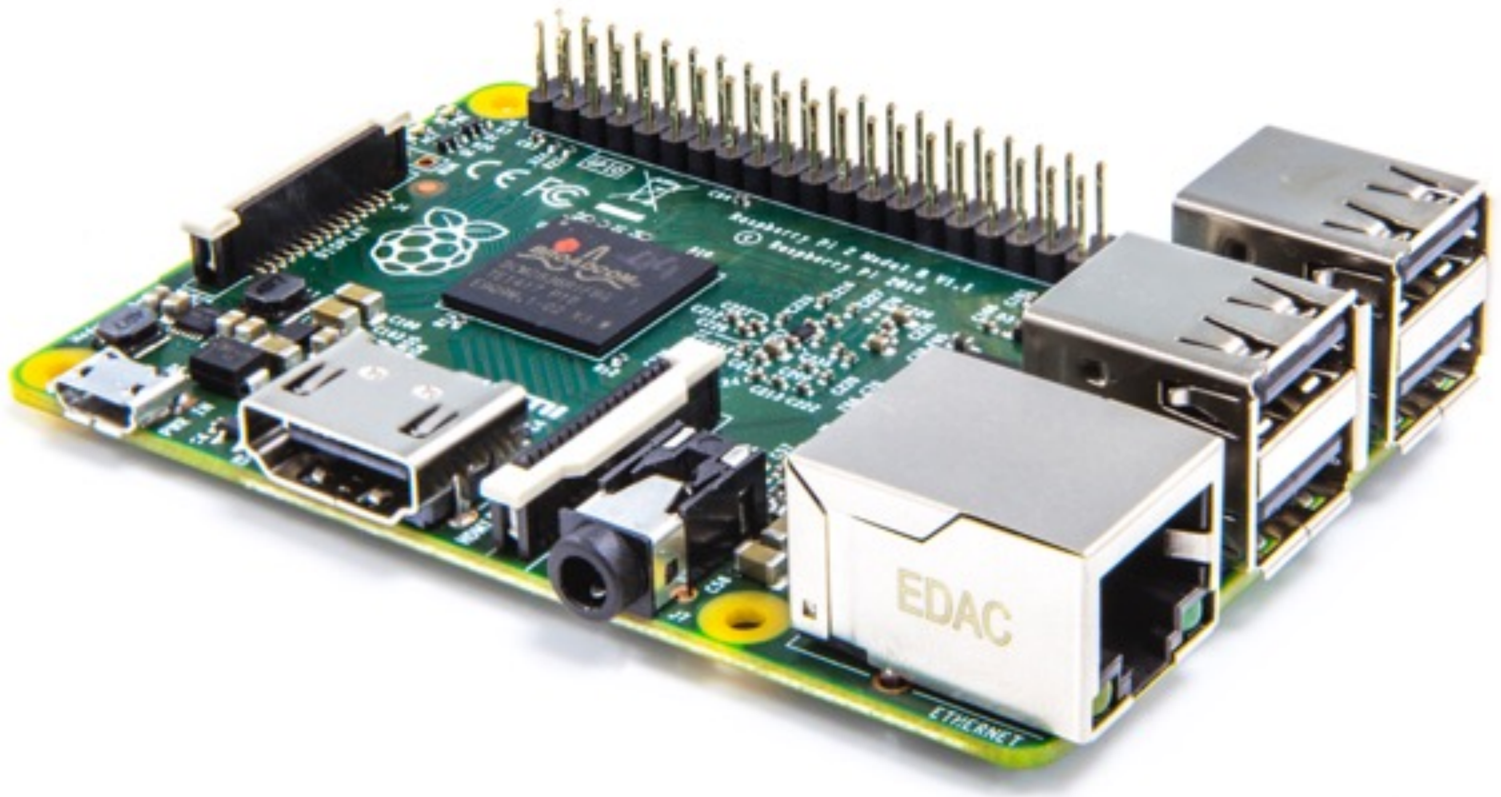


HARDWARE PLATFORMS

Arduino

VS

BeagleBone



Raspberry Pi

Sensor Calibration + Data Quality

What data quality do you need?

- What’s the question your trying to answer?
- Small data can sometimes be more important

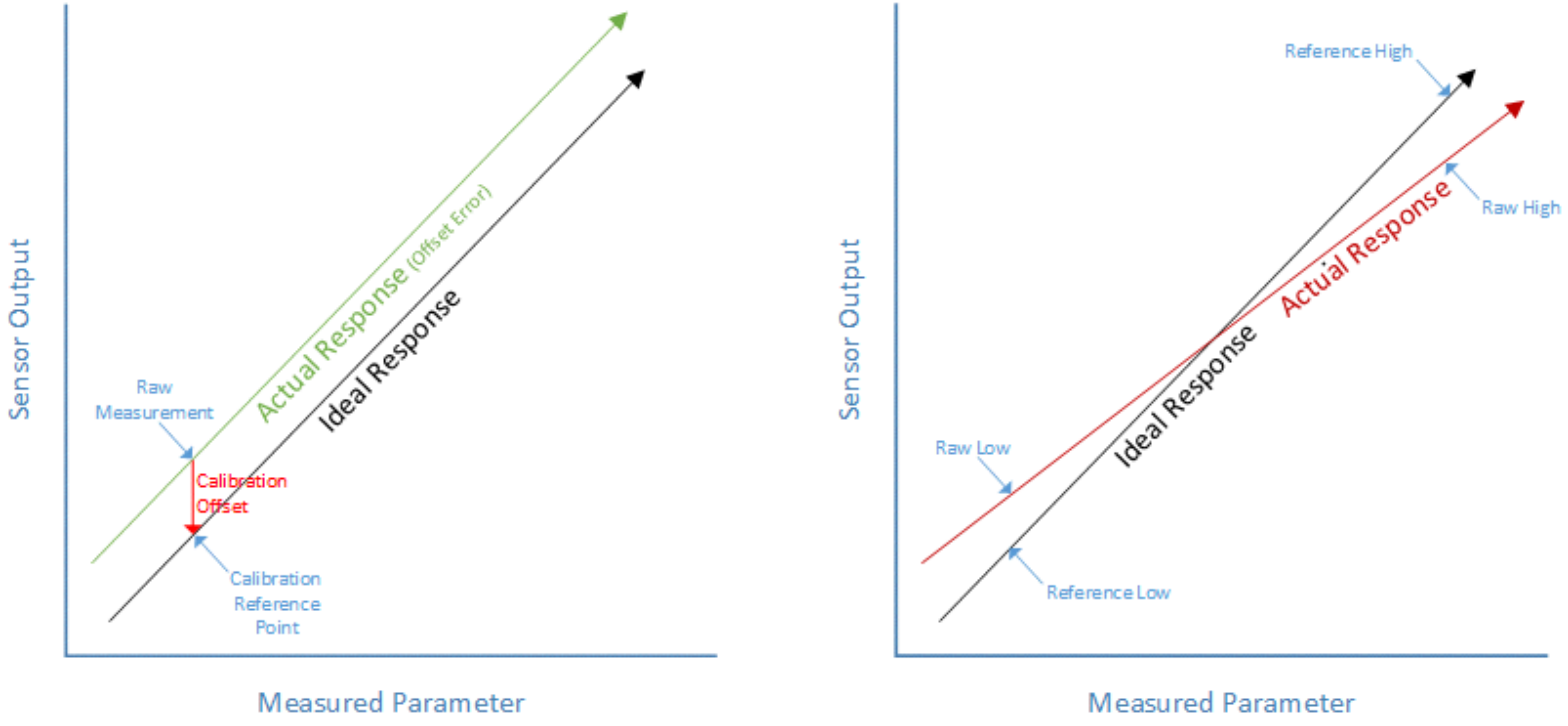
Calibration and why is it necessary?

- Calibration is the process of mapping the sensor’s output response to several precisely known stimuli to obtain the sensor

- Calibration is required whenever a higher accuracy is required from a less accurate sensor. And no sensor is perfect.

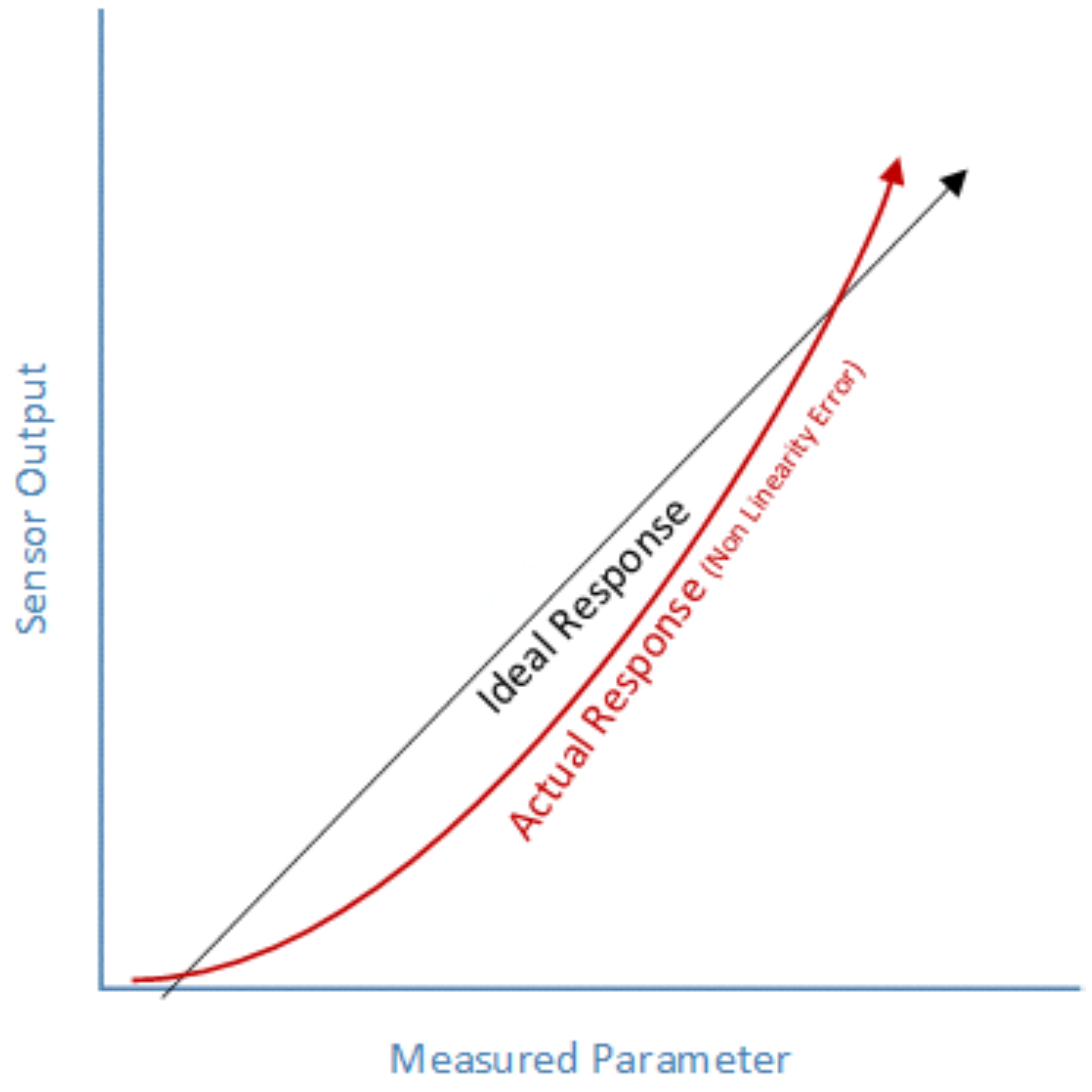
Calibration Methods

- Modify the transfer function to fit the experimental data (calibration points)
- If the sensor's response is linear across the measurement range:
    - **One point:** used to correct offset errors such as drift
    - **Two point**: can correct both slope and offset errors,



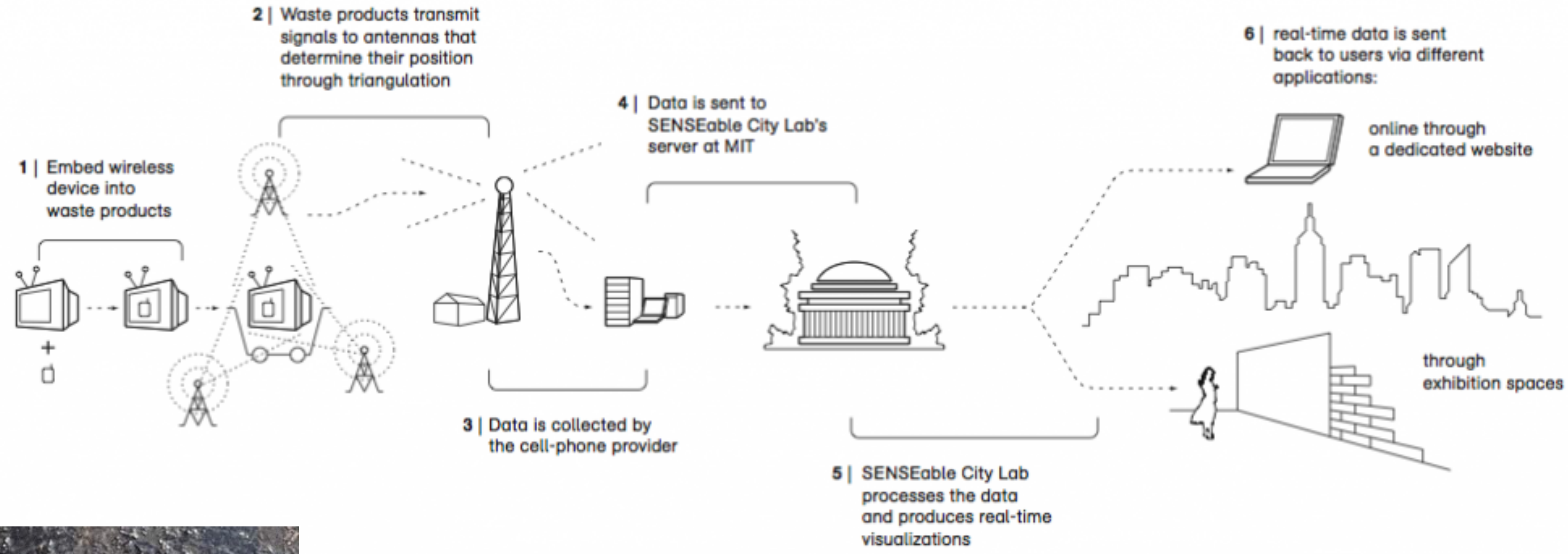
Calibration Methods

- if the response is non-linear:
    - multi-point: curve fitting



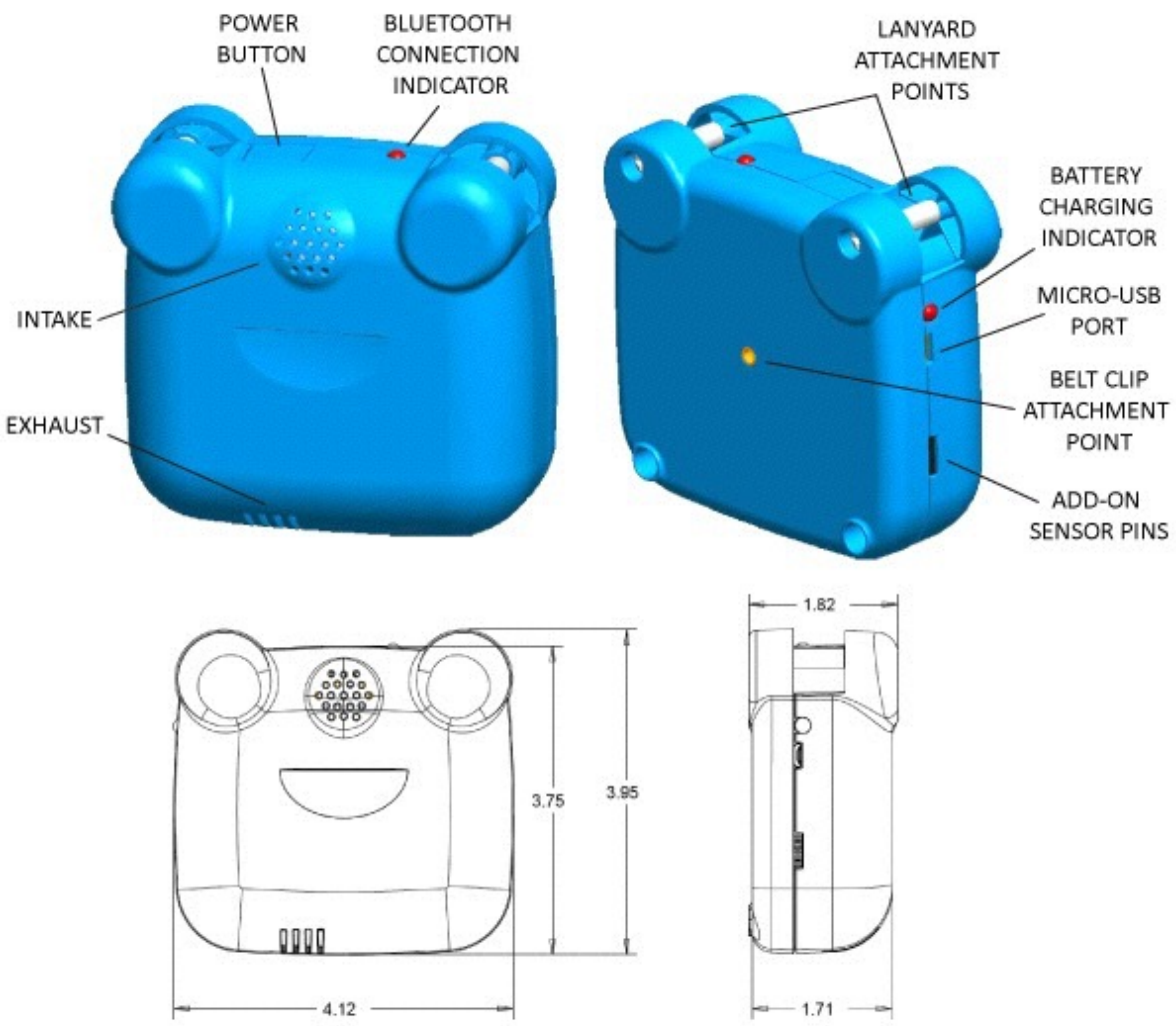
Urban Sensing Examples

MIT TRASH TRACK

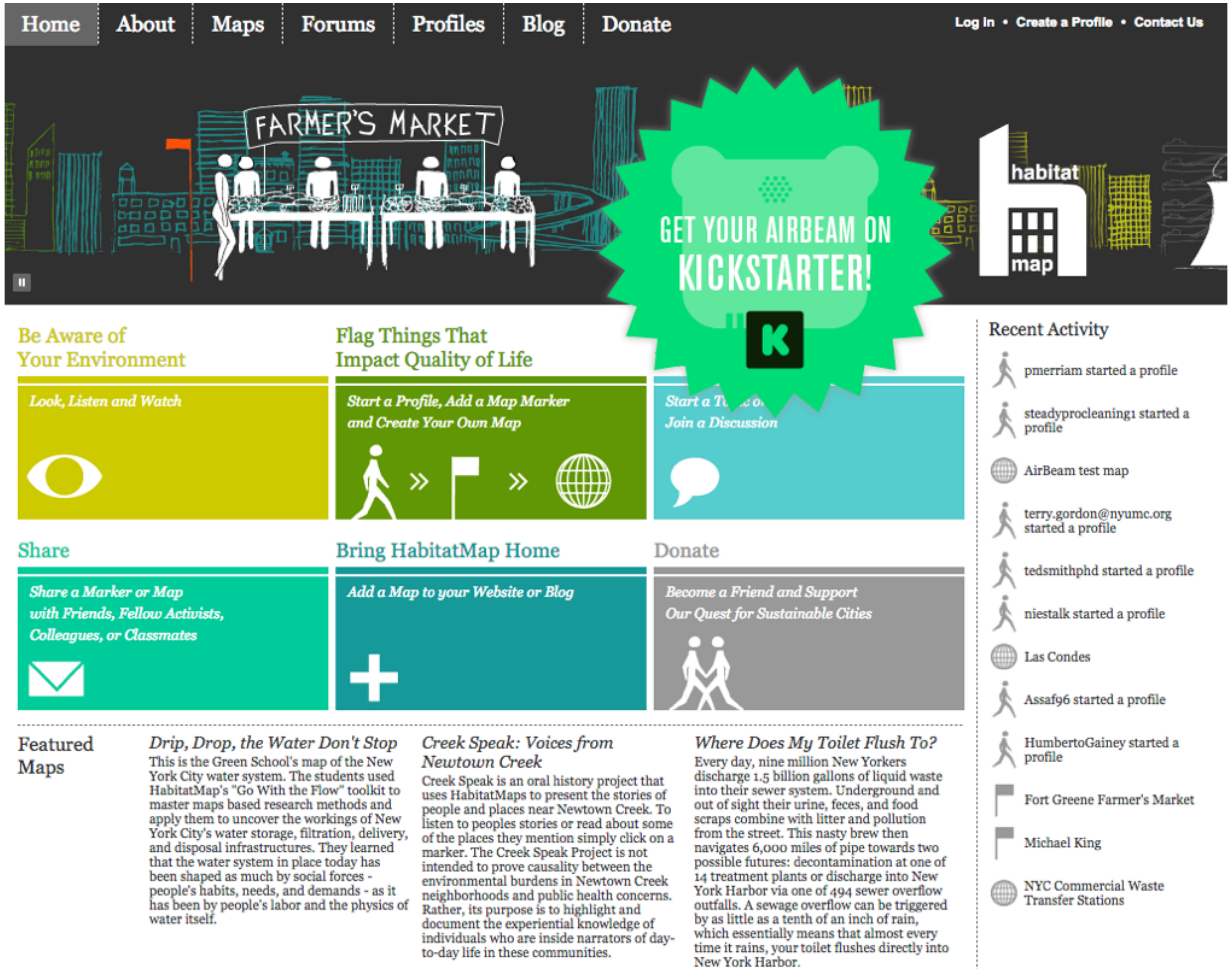


1148 traces
CITY
STATE
COUNTRY
BY TIME
BY SPEED
BY TYPE
BY STREAM
BY CITY
LINE
ARC
ANIM
PAPER
PLASTIC
RECYCLING
SPECIAL
TRANSIT
BELLEVUE
REDMOND
SEATTLE
SHORELINE
Milk carton
Coated cardboard container
Paper coffee cup
Cardboard burger box
Cranbrook MRF
Motorola cell phone
Printer cartridge
CFL
Batteries
Metal Conversion Technologies
Samsung cell phone
HP Officejet ink cartridge
Clover Technologies
Cellphone
cell phone
senseable city lab:.::

AIRBEAM



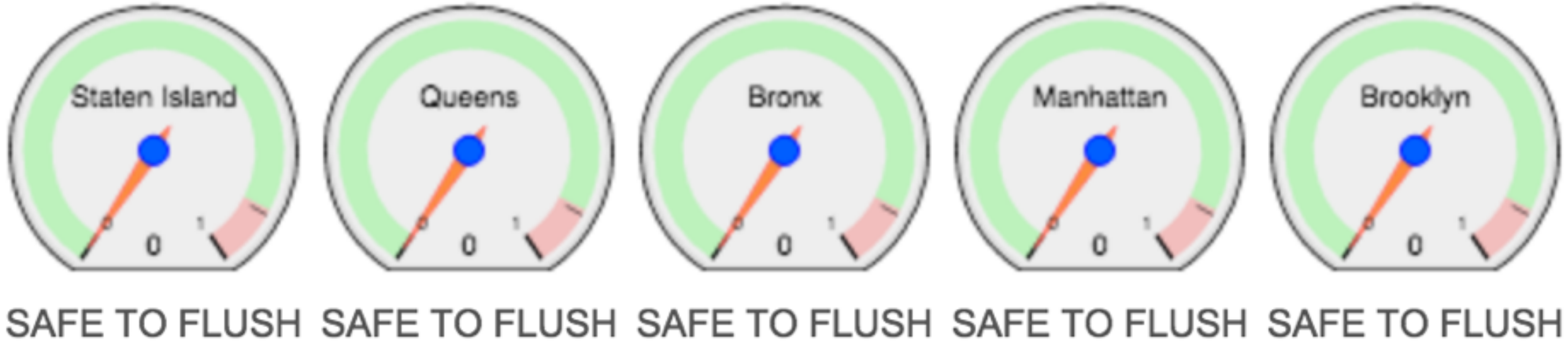
HABITAT MAP



Bridge Cam

Watch Video

dontflush.me



Leif Percifield

Open source technology for citizens' political participation in smarter cities

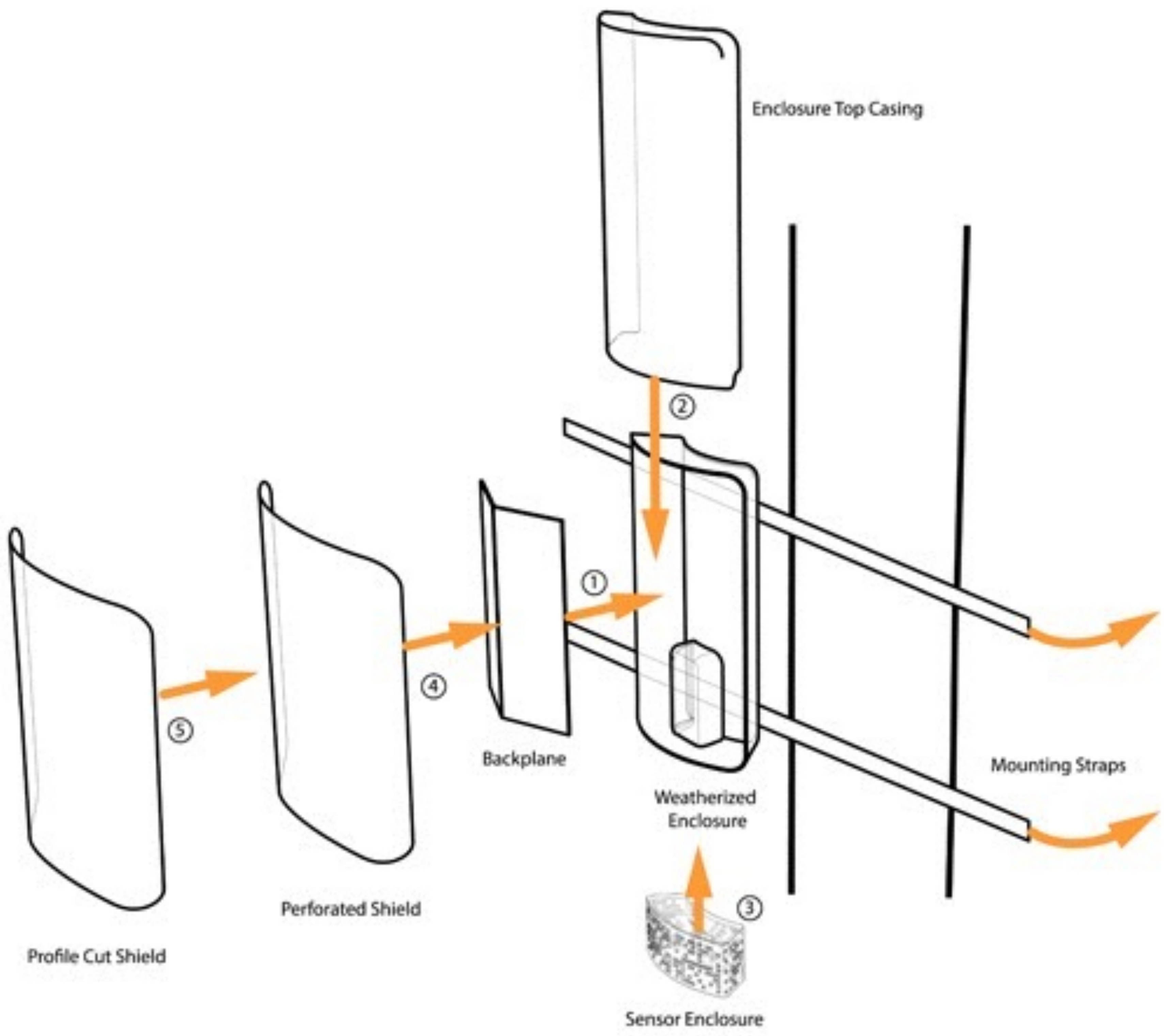
Based on geolocation, Internet of Things, Open Source hardware and software for data collection and sharing

SIGN IN

REGISTER

SMART CITIZEN

Array of Things: Chicago



https://arrayofthings.github.io/node.html

Air Quality Egg

community-led sensing network

Serial Number

ADD MY EGG

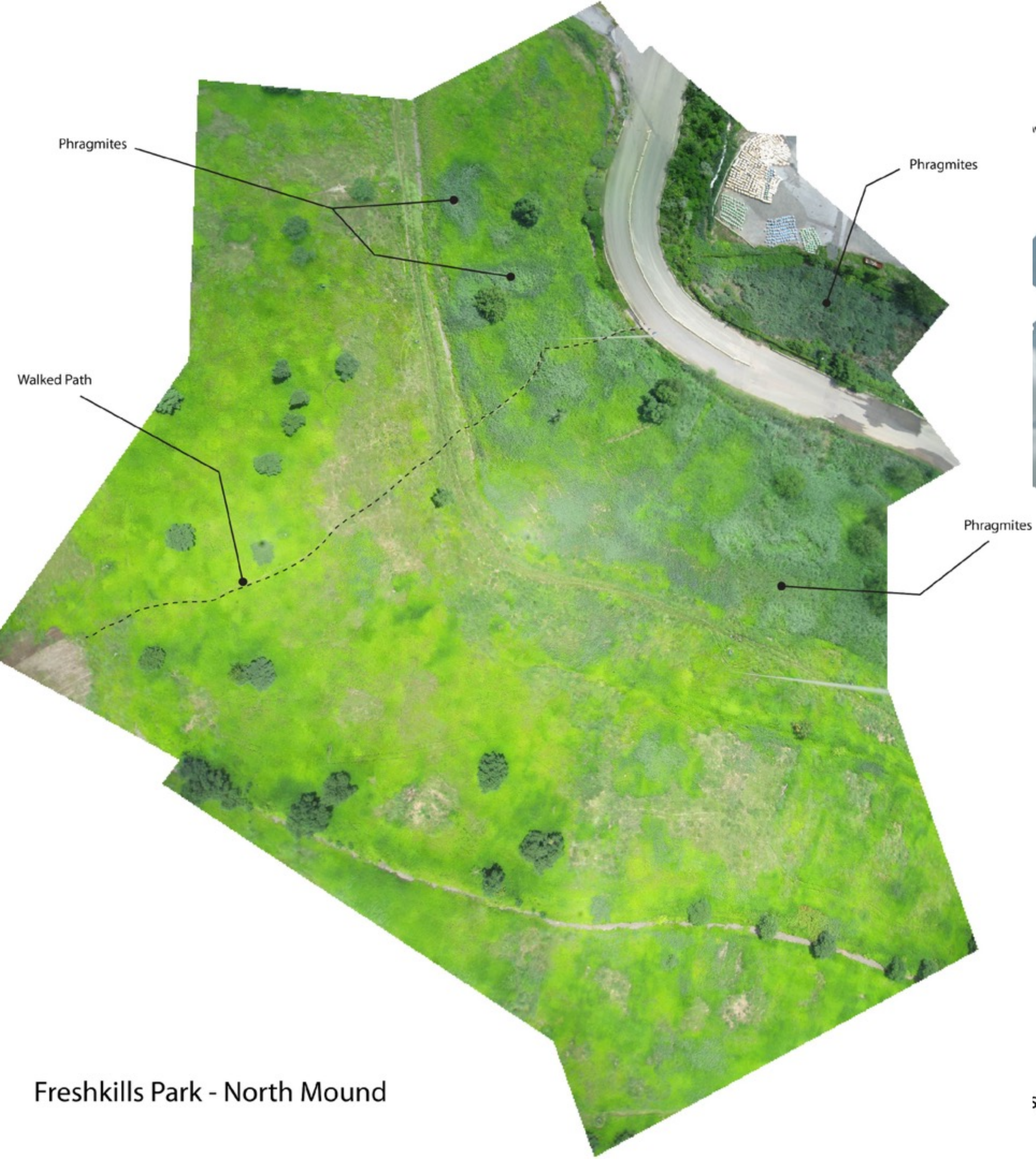
eCan

- detects the an object being thrown away in order to provide a financial incentive to pick up litter off the streets

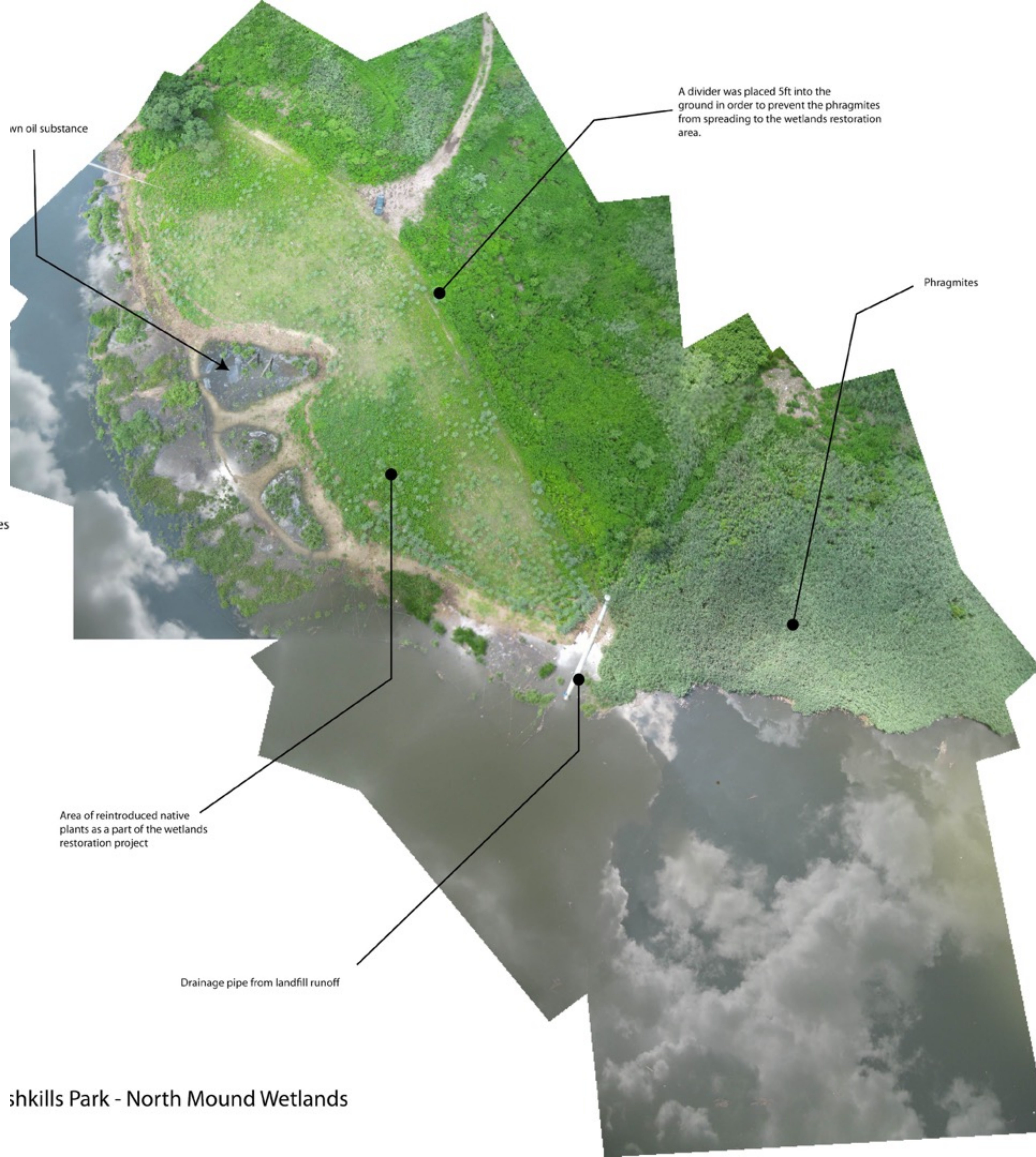
Part II - Low-cost Remote Sensing

Balloon Mapping

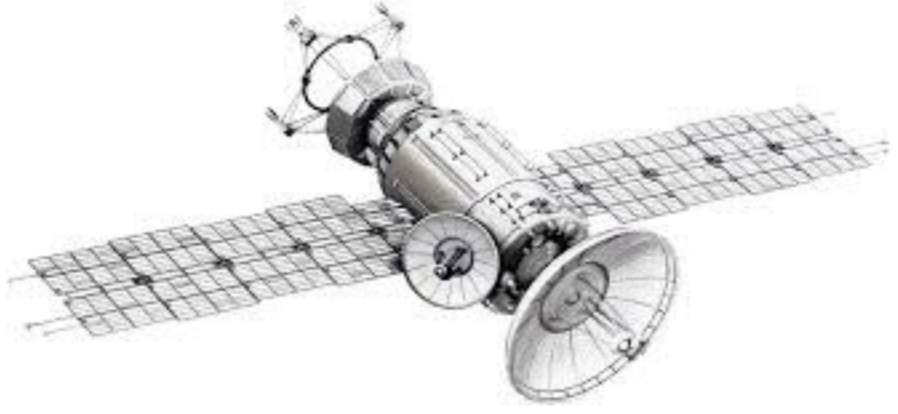
- Public Laboratory for Open Science (PLOTS or Public Lab)



Freshkills Park - North Mound



shkills Park - North Mound Wetlands



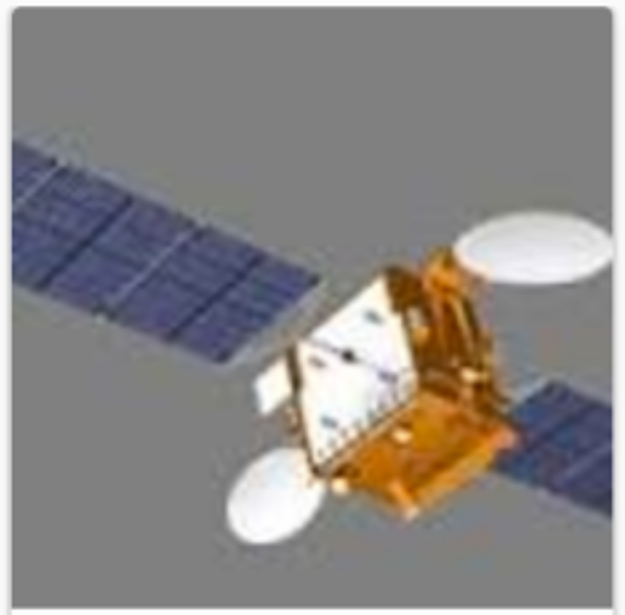
Landfills + Satellites

INFORMACIÓN DE LA CONFERENCIA

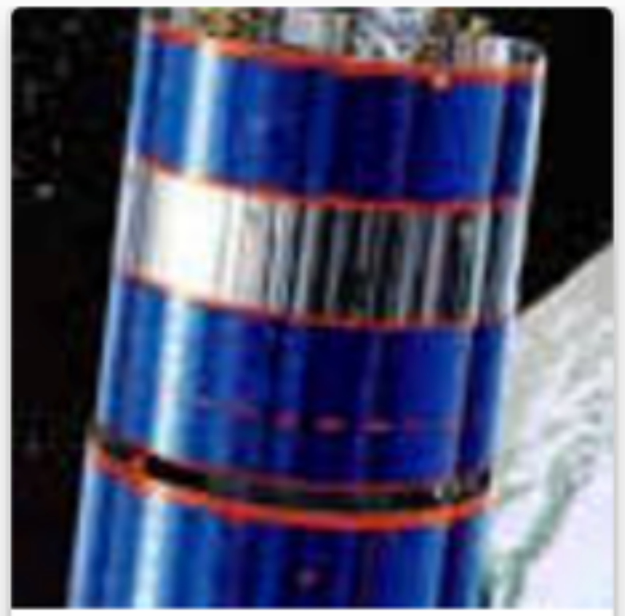
LA BASURA Y EL AGUA ESTANCADA

¿QUÉ SE PUEDE HACER PARA ELIMINAR LOS DESECHOS SIN RECOGER Y EL AGUA ESTANCADA DONDE SE REPRODUCEN LOS MOSQUITOS AEDES AEGYPTI?


Eutelsat 5 West A


Yamal 202


Eutelsat 33C


Eutelsat 31A

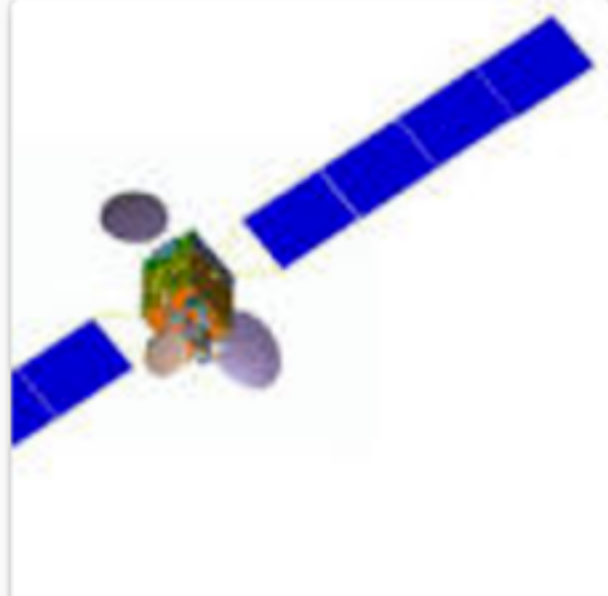

Cartosat-2


Intelsat 28


Venesat-1

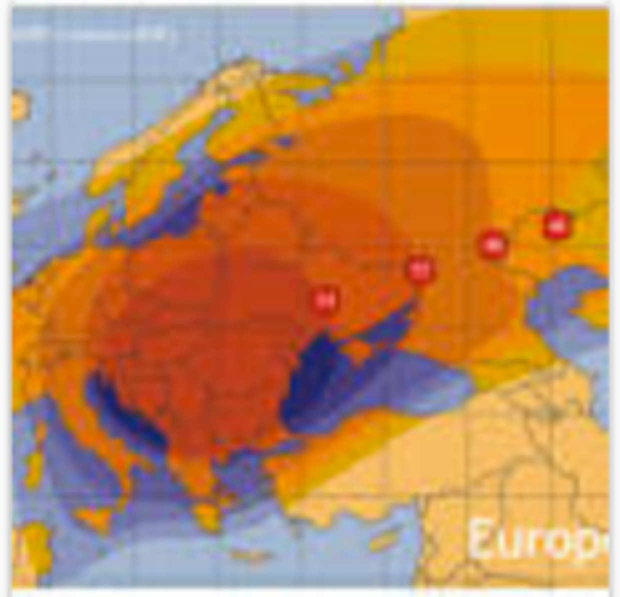

GSAT-15


GOES 14


NigComSat-1

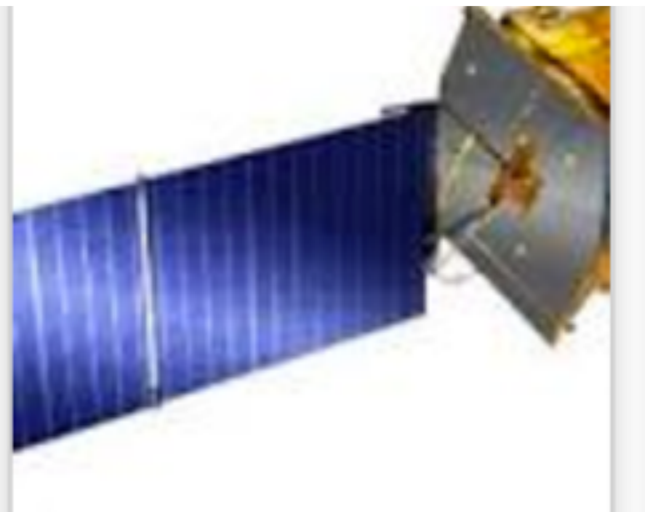

MEASAT-3


Intelsat 20


Amos-2


NSS-7


Intelsat 14


Chollian

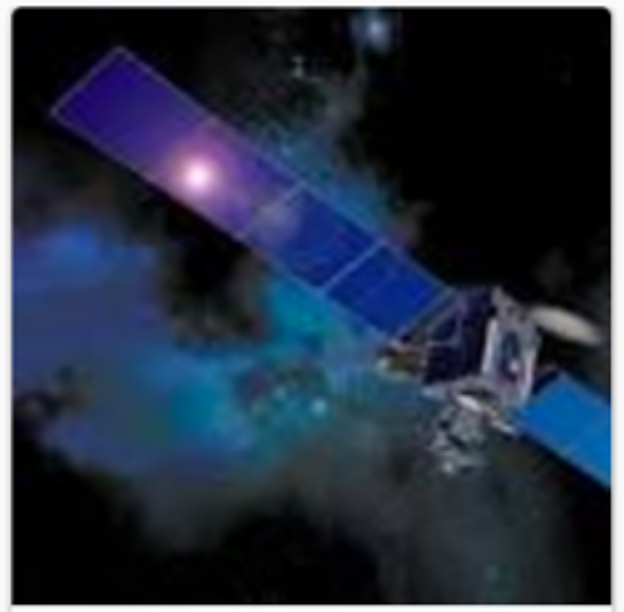

GSAT-3

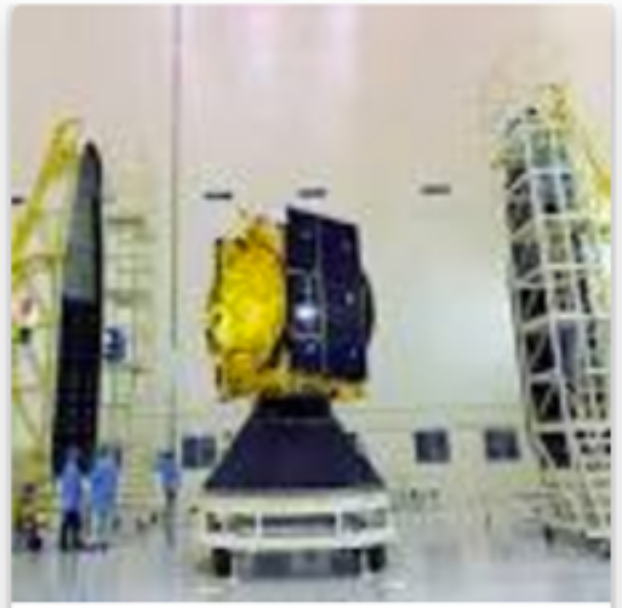

GSAT-10


Cartosat-1


Aqua

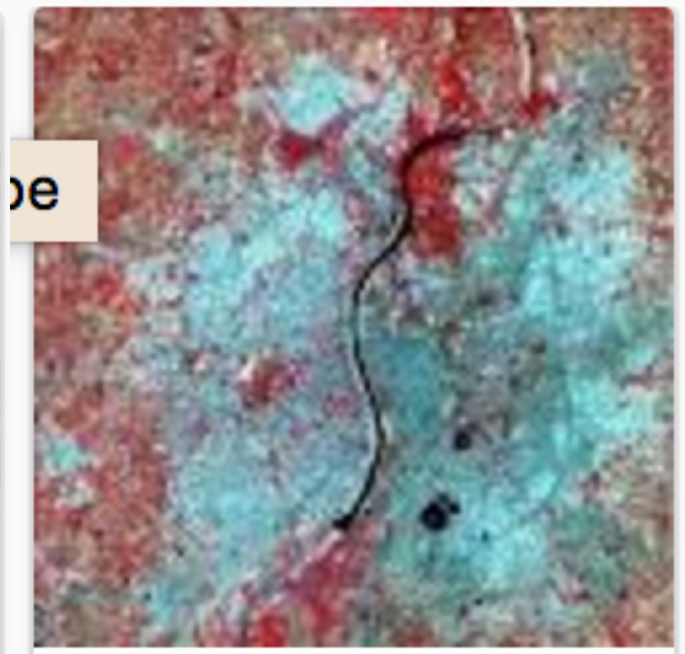

ACRIMSAT

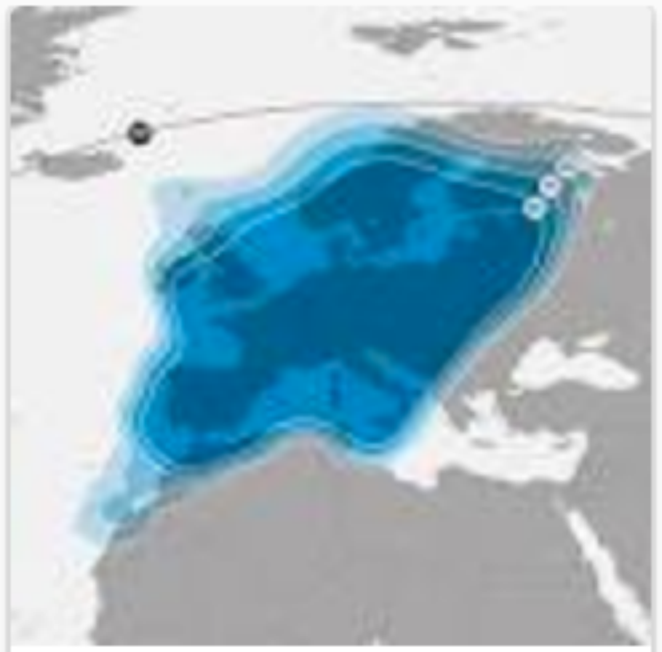

Telstar 12

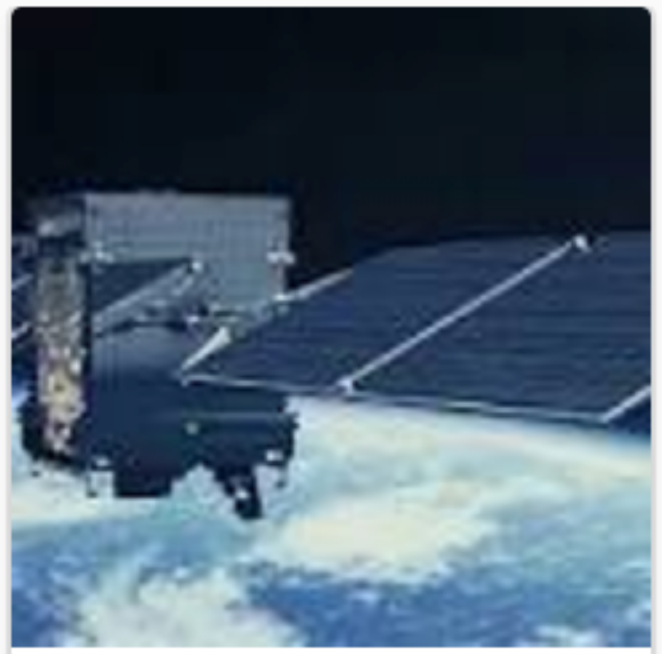

GSAT-14

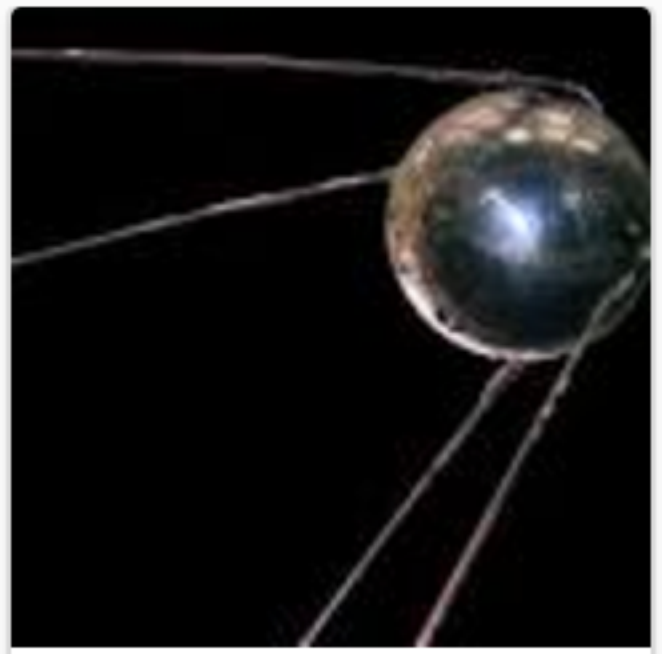

Intelsat 29e


GSAT-15


Resourcesat-1


Astra 2C


ARSAT-1

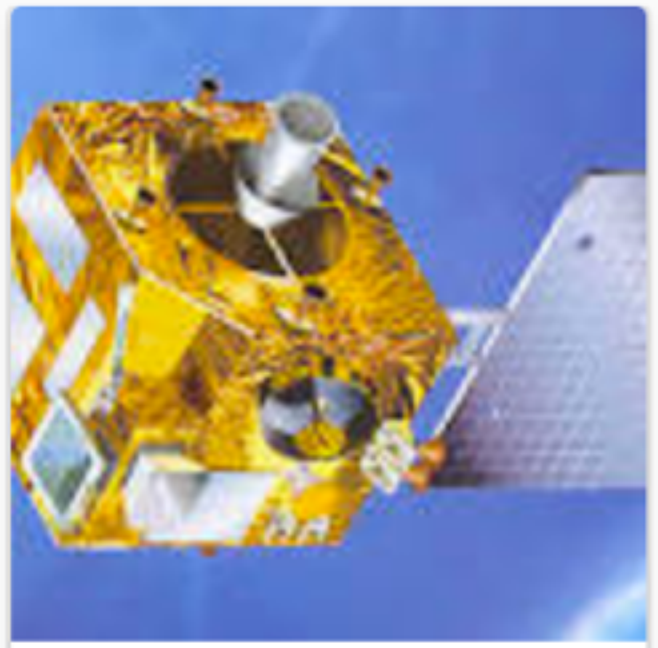

Sputnik 1

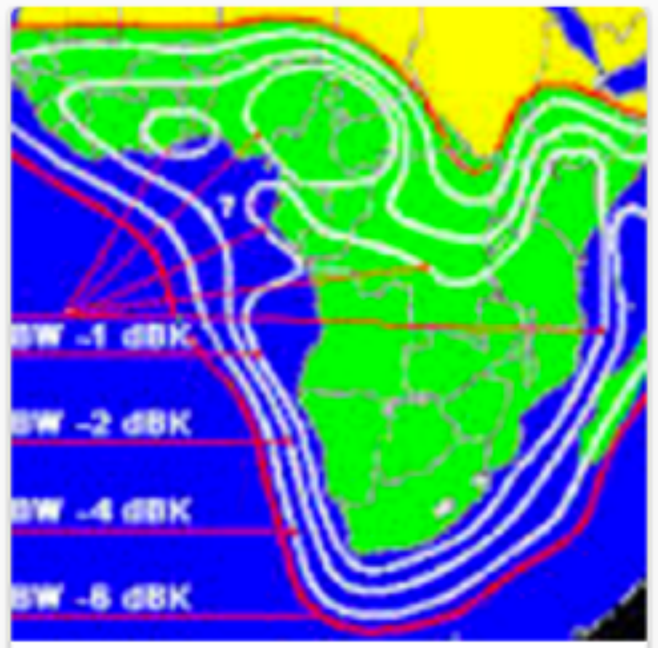

CloudSat


Hubble Space Telescope

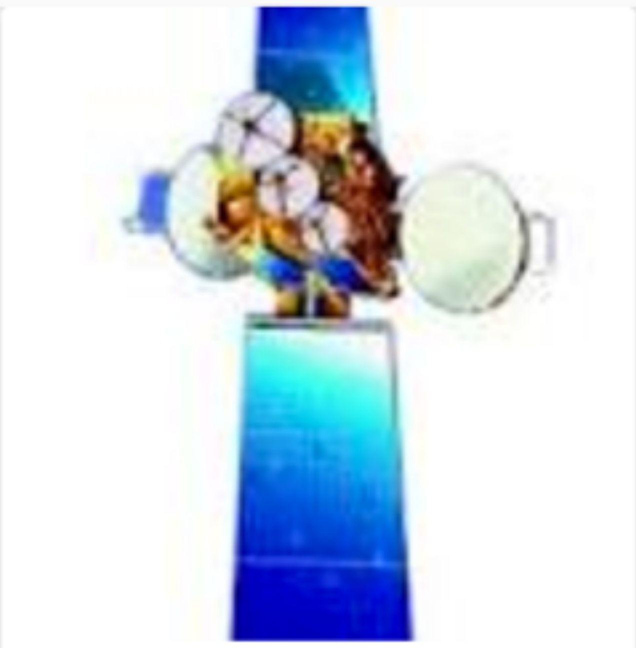

INSAT-4CR


Astra 4A


Kalpana-1



Eutelsat W3A


INSAT-3C


CALIPSO

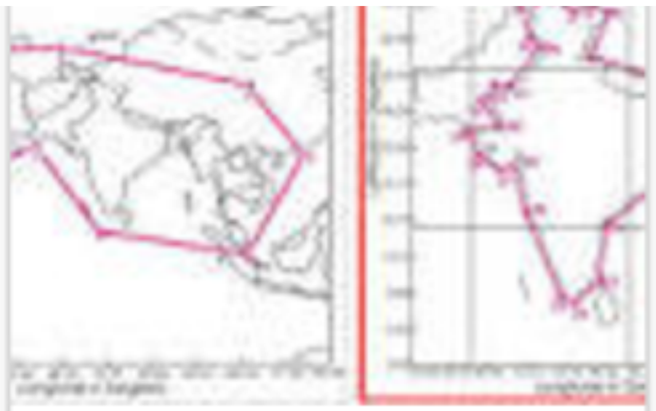

Eutelsat 8 West C


Astra 3B

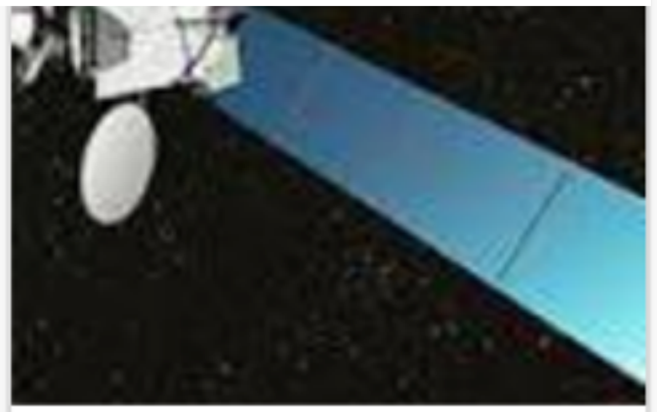

Paksat-1R


KazSat-1


Advanced Land Observation ...


INSAT-4A


GSAT-7

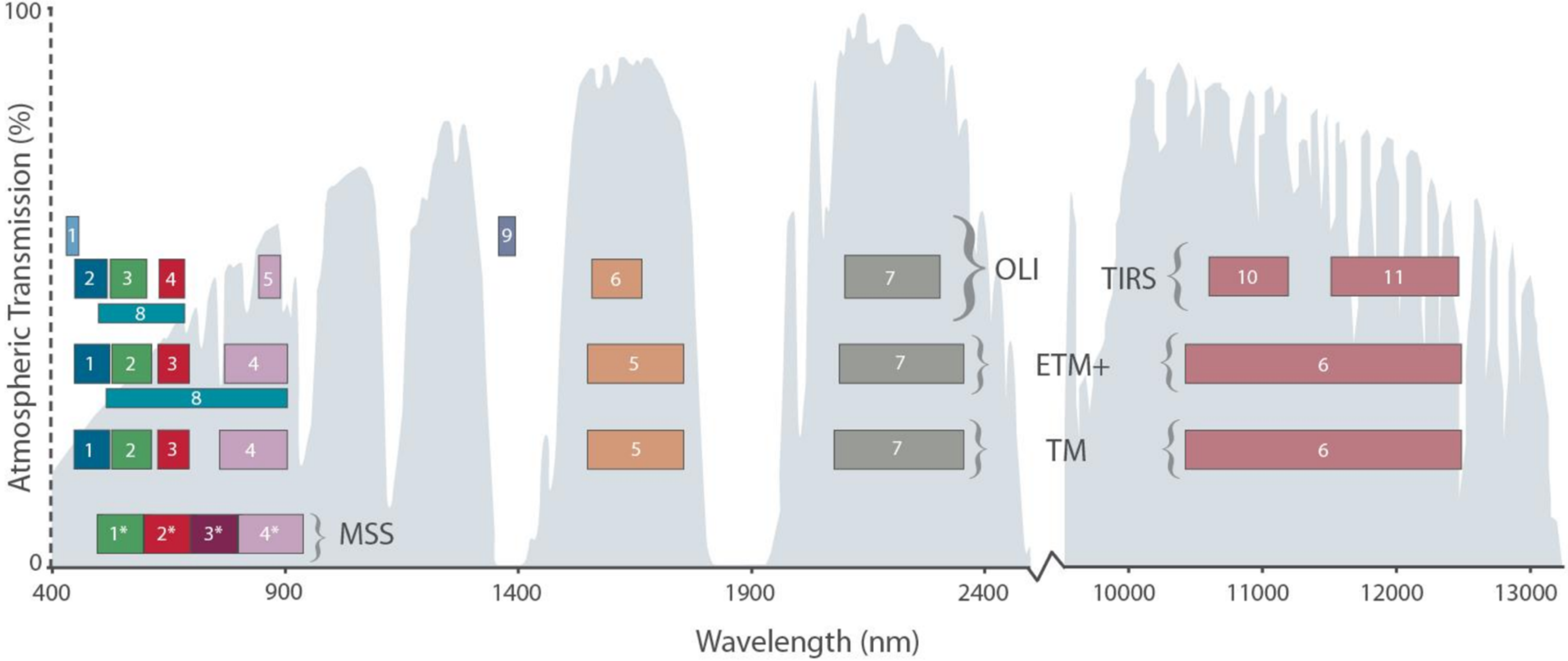

Intelsat 9

Landsat 8

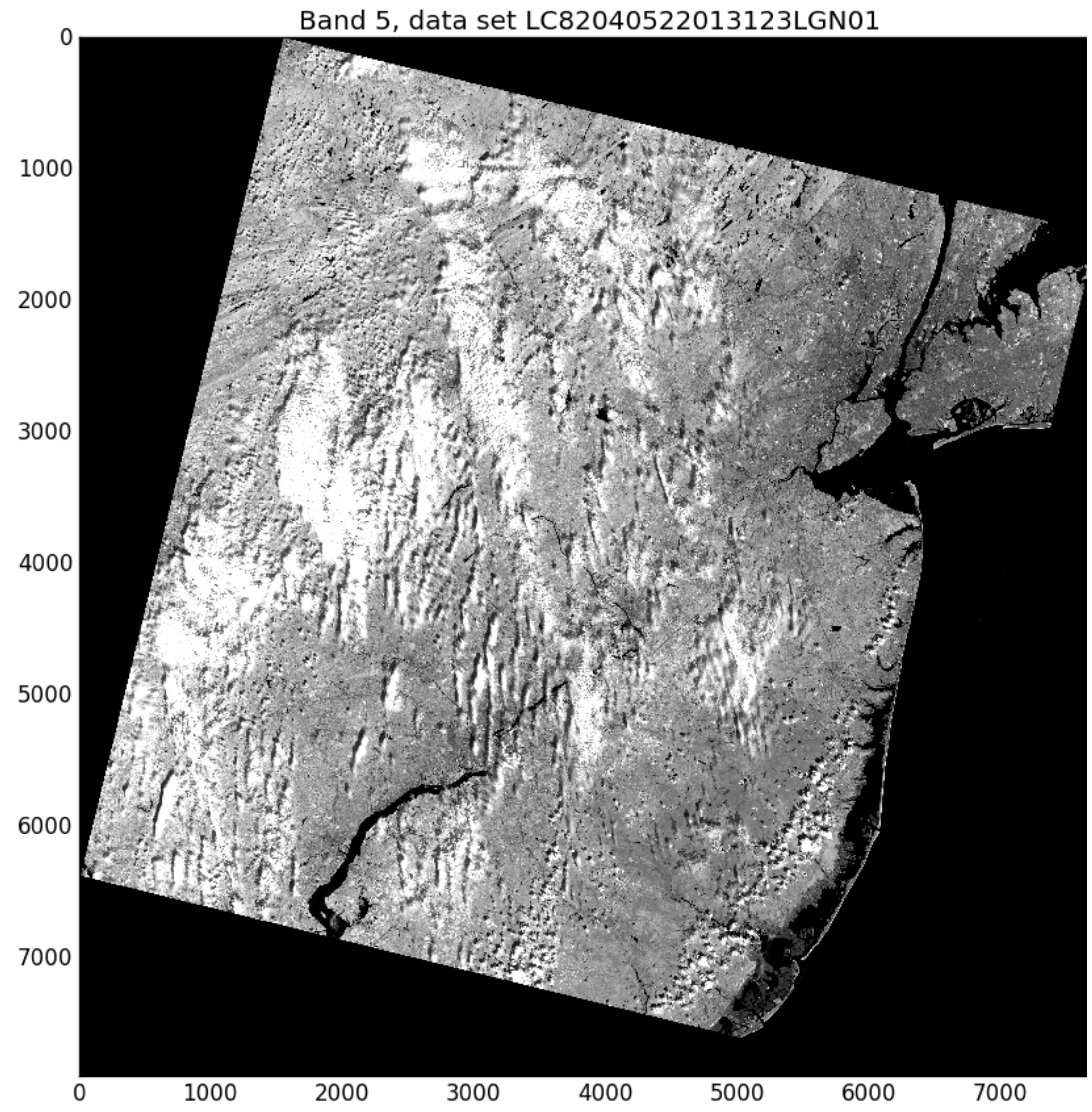
- Scene capture every 16 days
- Level 1 data is terrain corrected. Data is 16bit geotiff
- Data available from USGS Earth Explorer

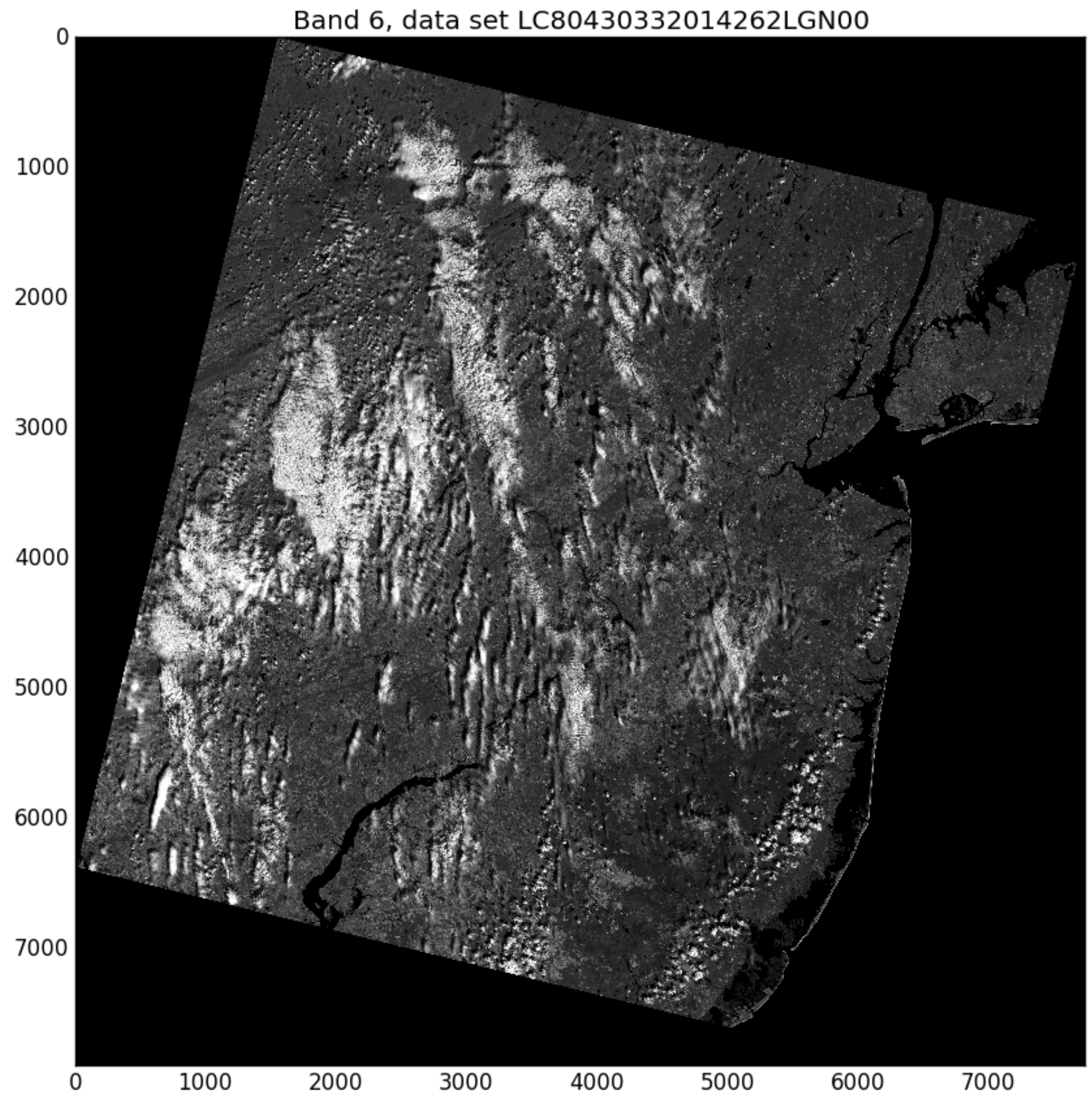
	Name	Wavelength	Resolution	Description
Band 1	Aerosol	433-453nm	30m	Used to estimate aerosols for atmospheric correction. Also captures violet useful for organic
Band 2	Blue	450-515nm	30m	
Band 3	Green	525-600nm	30m	
Band 4	Red	630-680nm	30m	
Band 5	NIR	845-885nm	30m	
Band 6	SWIR	1560-1660nm	30m	
Band 7	SWIR	2100-2300nm	30m	
Band 8	Panchromatic	500-680nm	15m	Collects all visible spectrum at the same time
Band 9	Cirrus	1360-1390nm	30m	Strong atmospheric absorption due to pretense of water vapor. Used to detect cirrus clouds
Band 10	Thermal Infrared (TIRS) 1	10600-11190nm	100m	Collected at 100m but resampled to 30m
Band 11	Thermal Infrared (TIRS) 2	11500-12510nm	100m	Collected at 100m but resampled to 30m

- https://github.com/nejohnson2/research-notes/blob/master/satellite_imagery.md

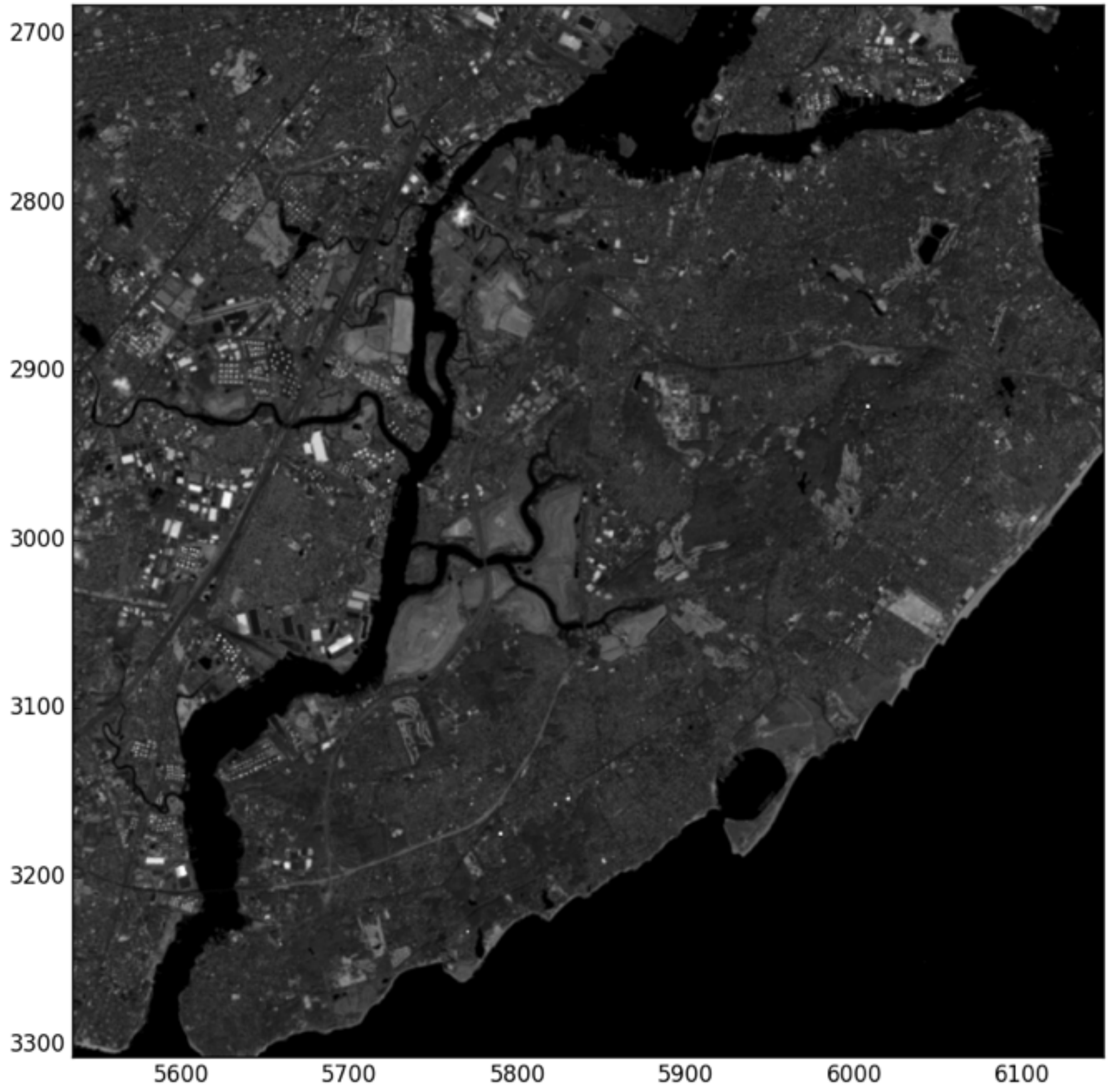


100
0
Atmospheric Transmission (%)
1
9
2
3
4
5
6
7
8
OLI
TIRS
10
11
1
2
3
4
8
5
7
ETM+
6
1
2
3
4
5
7
TM
6
1*
2*
3*
4*
MSS
400
900
1400
1900
2400
10000
11000
12000
13000
Wavelength (nm)

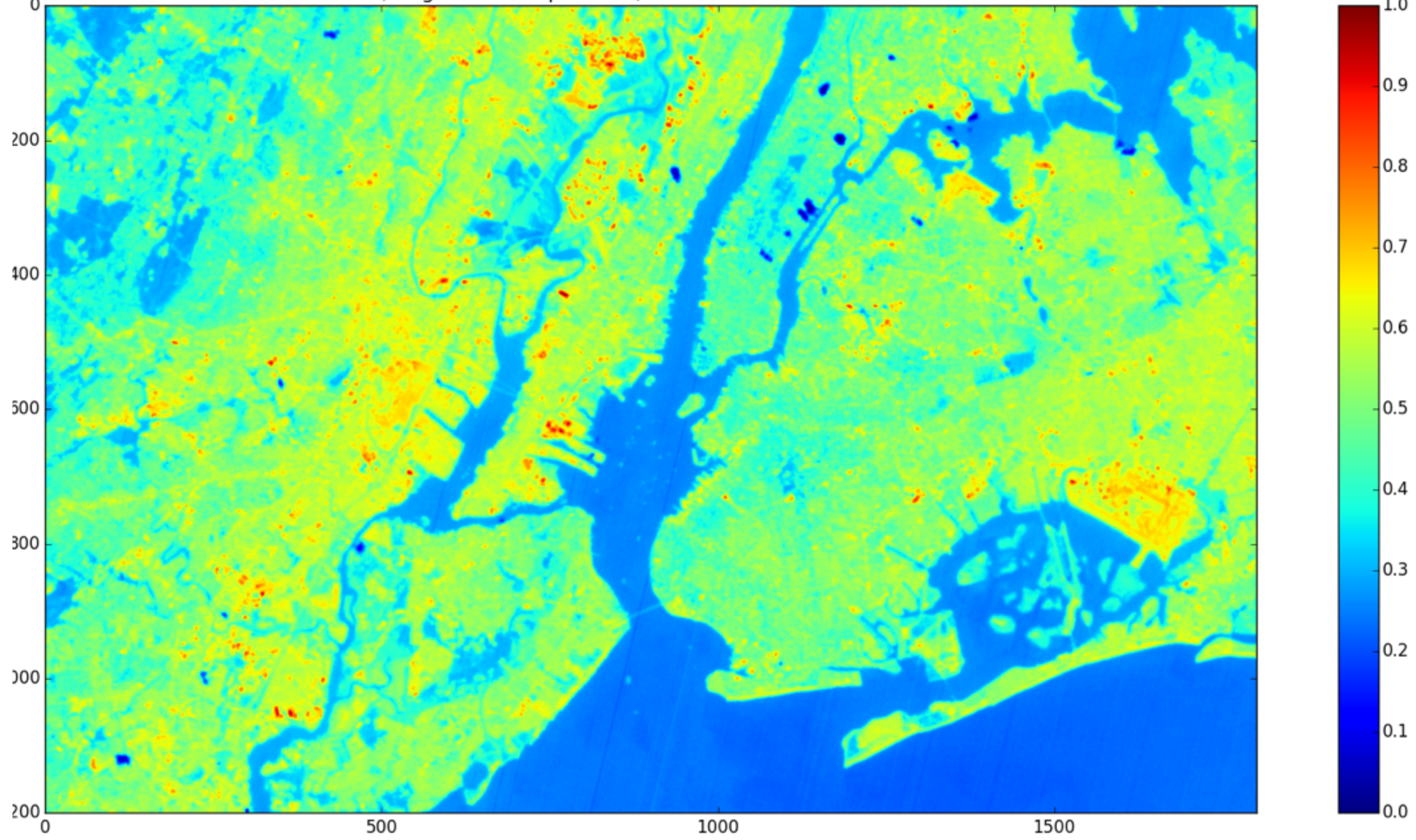

Band 5, data set LC82040522013123LGN01
0
1000
2000
3000
4000
5000
6000
7000
0 1000 2000 3000 4000 5000 6000 7000


Band 6, data set LC80430332014262LGN00
0
1000
2000
3000
4000
5000
6000
7000
0 1000 2000 3000 4000 5000 6000 7000

Band 6, data set LC80430332014262LGN00



Band 10, brightness temperature,data set LC80080292014065LGN00

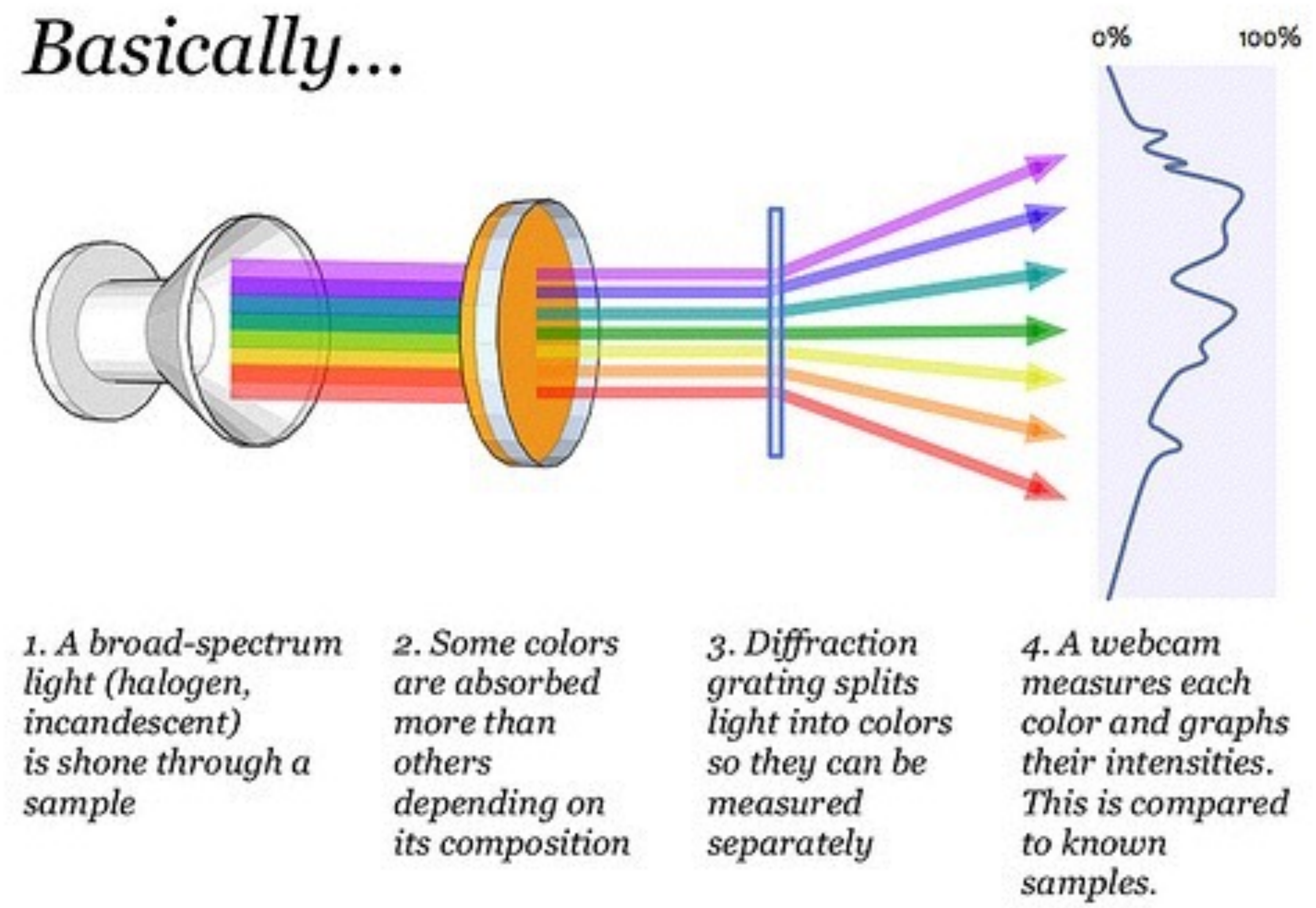


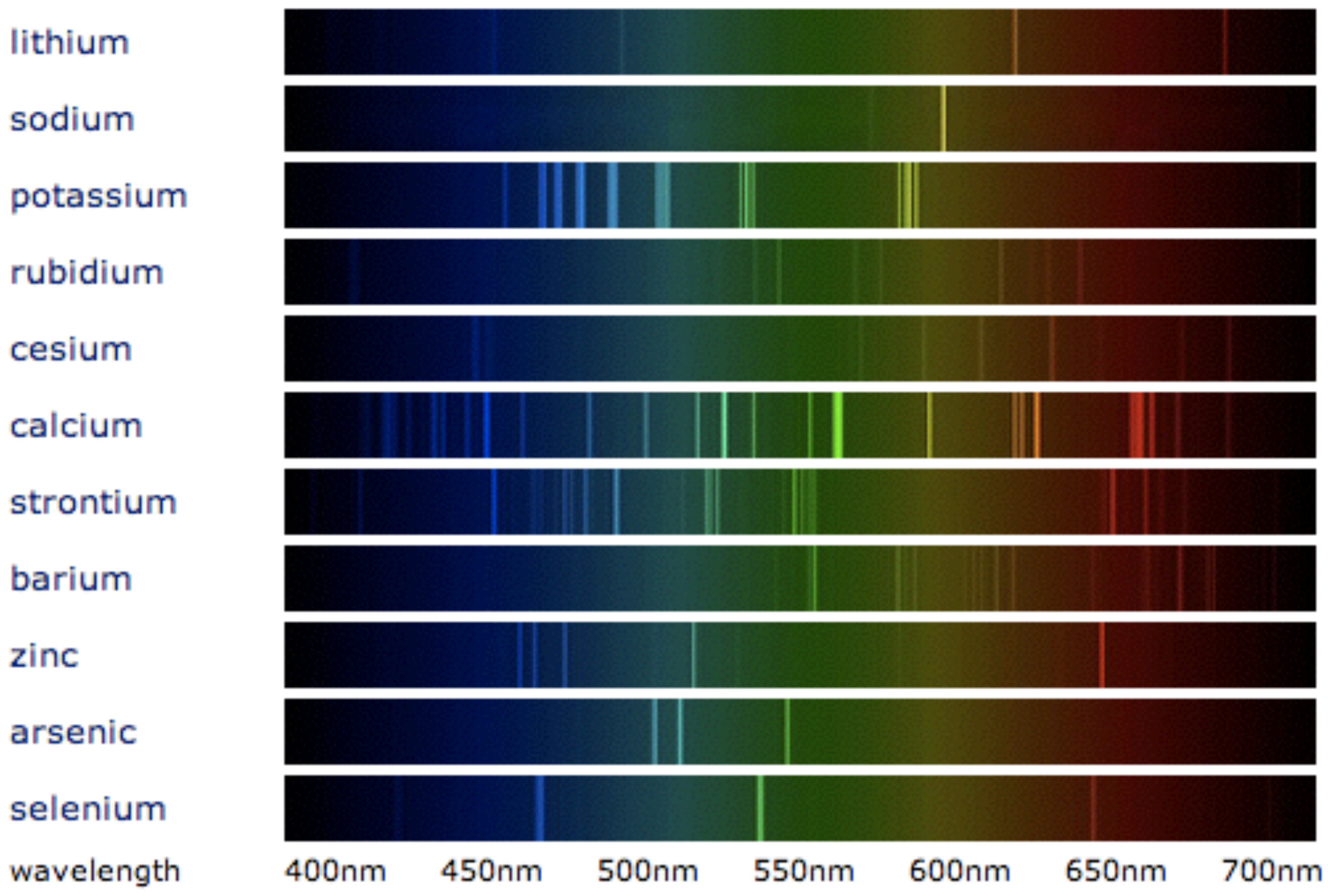
Part III - Hands on! Build and Calibrate

Spectrometer Workshop

- Build a Public Lab portable spectrometer
- Collect test images
- Upload Images to spectralworkbench.org
- Calibrate with Spectral workbench tools

What is spectrometry?



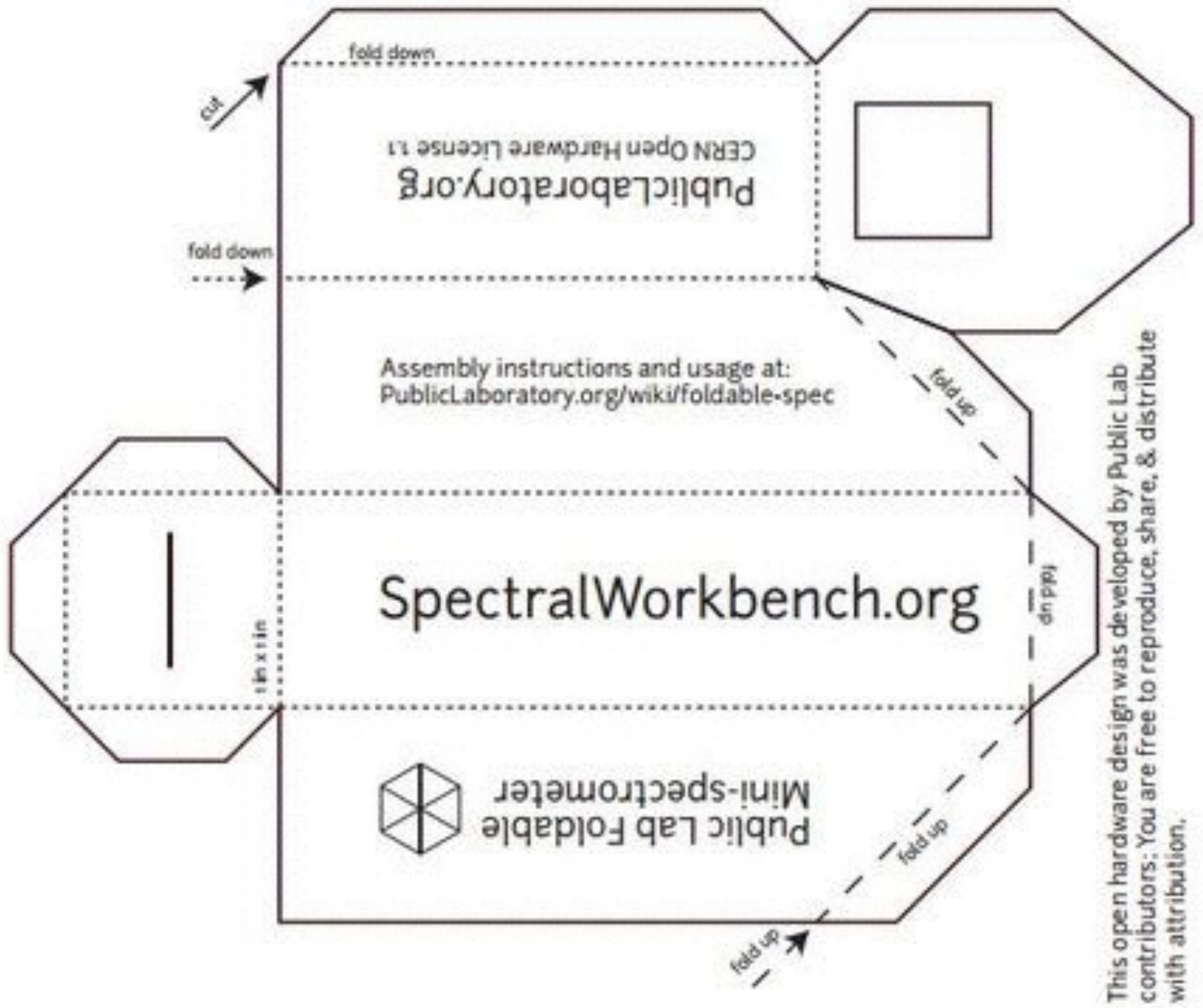


Build Chamber

- light enters the small slit at one end which creates light traveling in parallel lines from the source

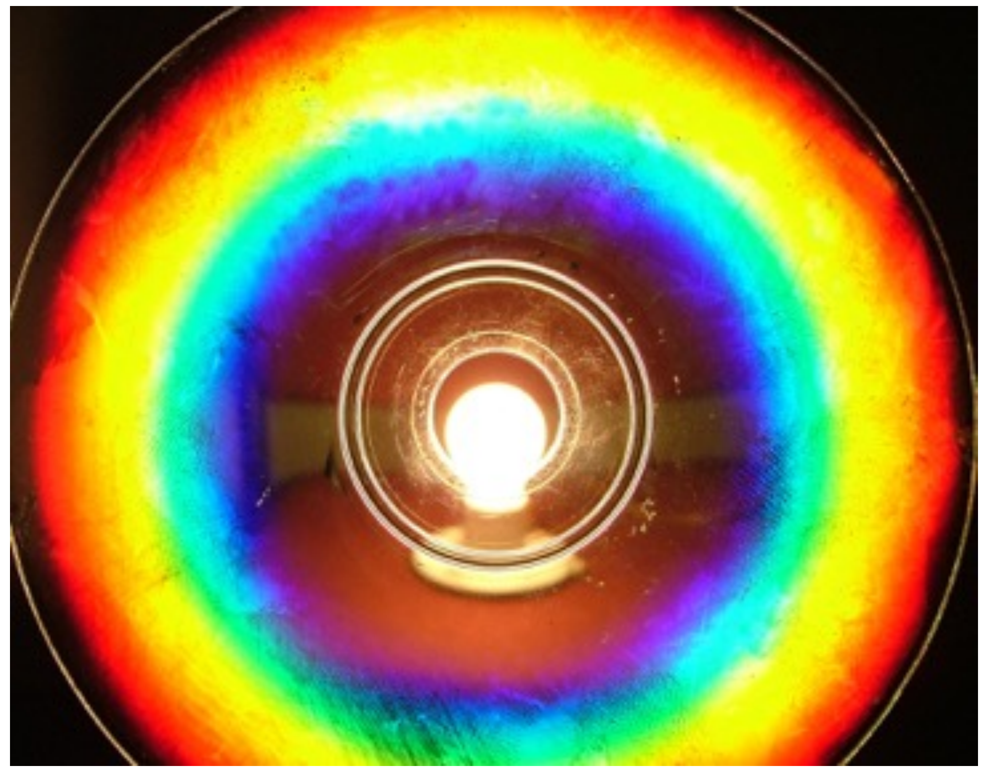
- smaller slit provides greater resolution; the tradeoff is less light

- the inside surfaces of the spectrometer are non-reflective black to reduce stray light



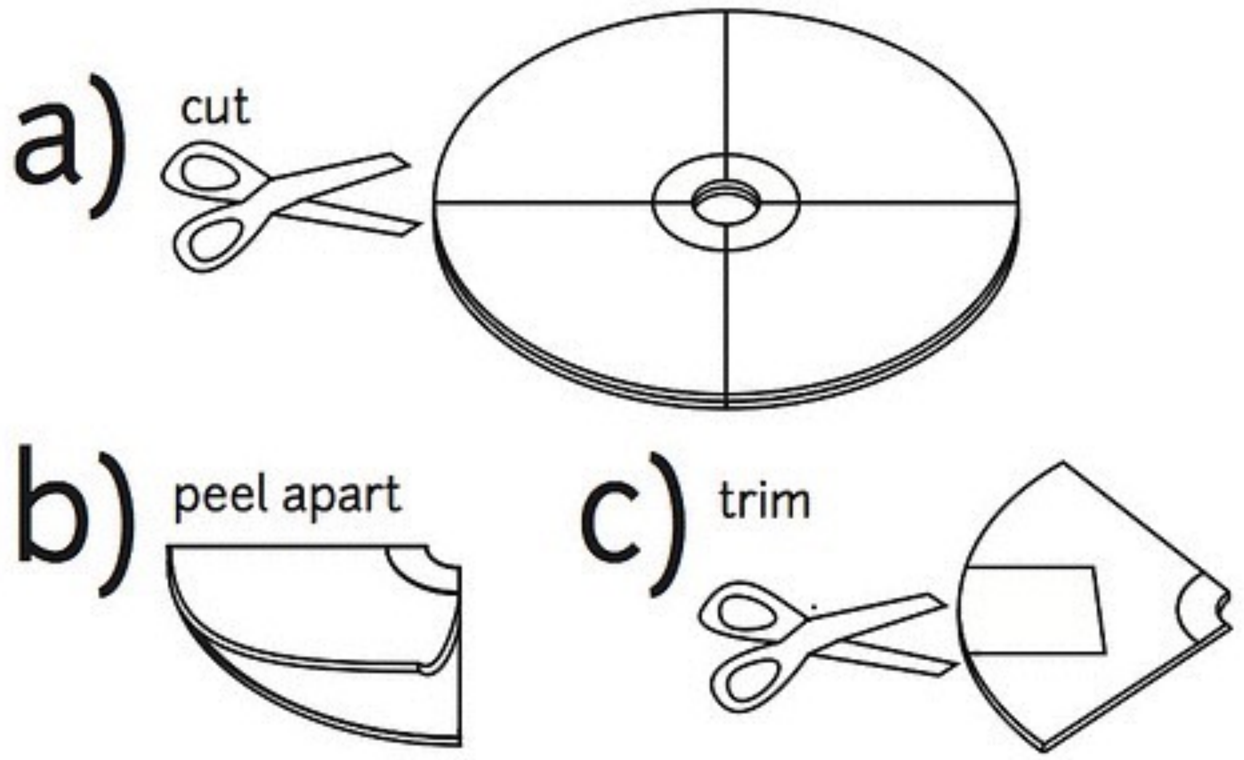
Prepare Diffraction Grating

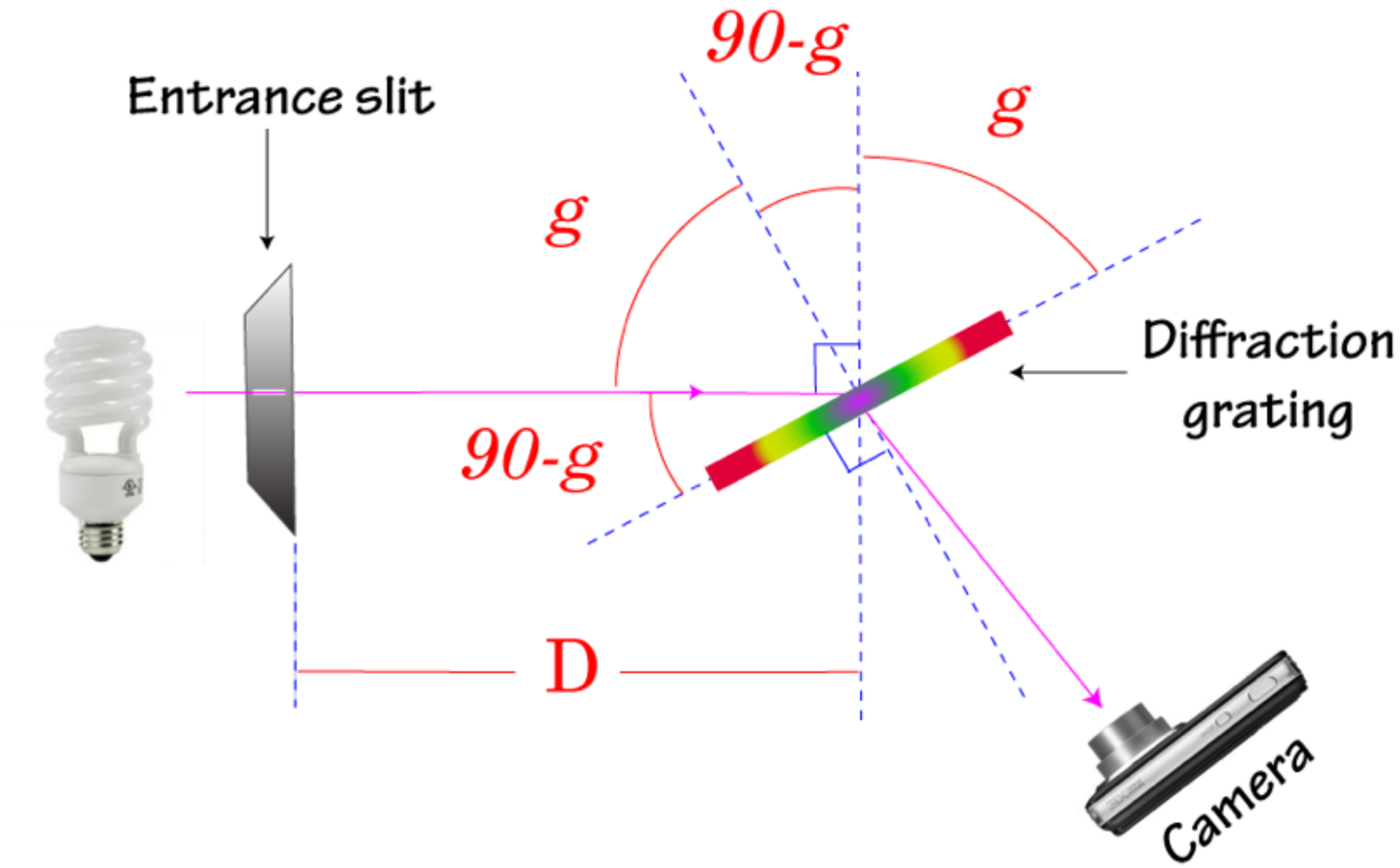
- The lower polycarbonate layer of a DVD-R contains spiral grooves molded into one side that can provide an optimally transparent diffraction gradient for a spectrometer



- Split the DVD-R layers.

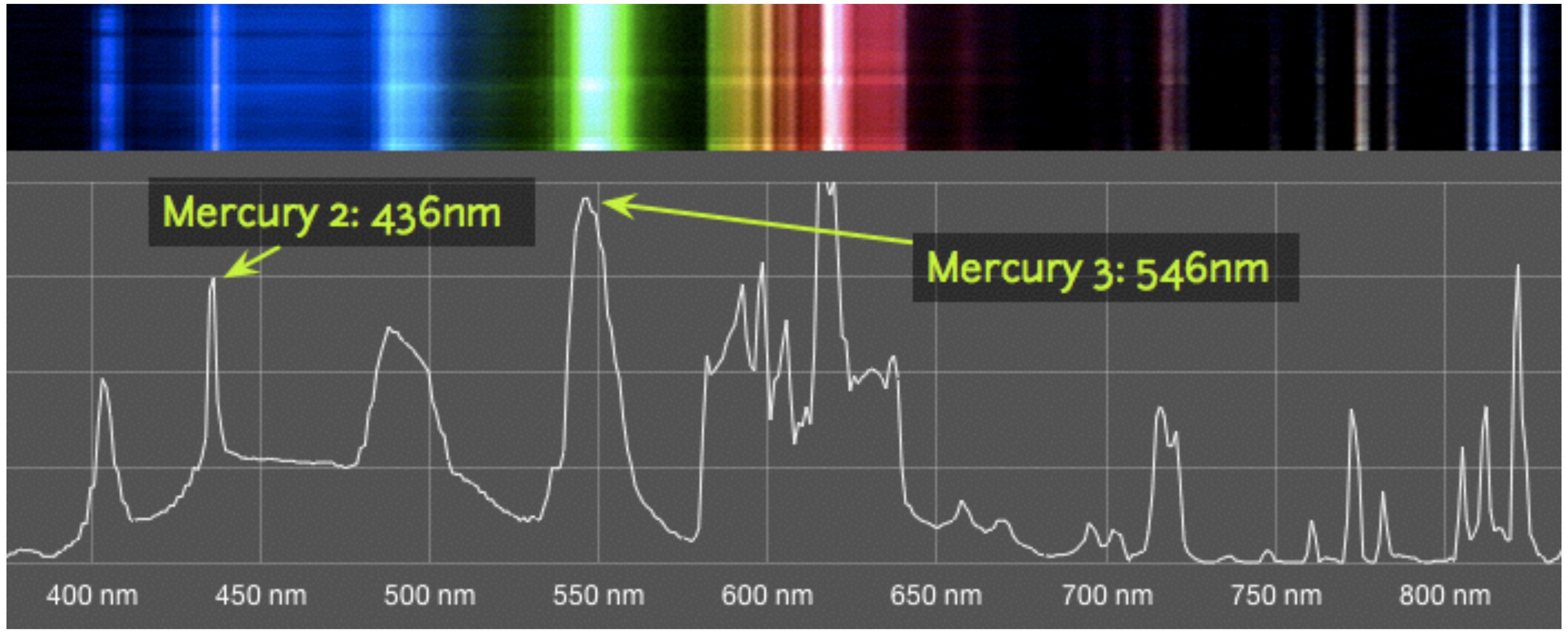
- Cut out a square piece





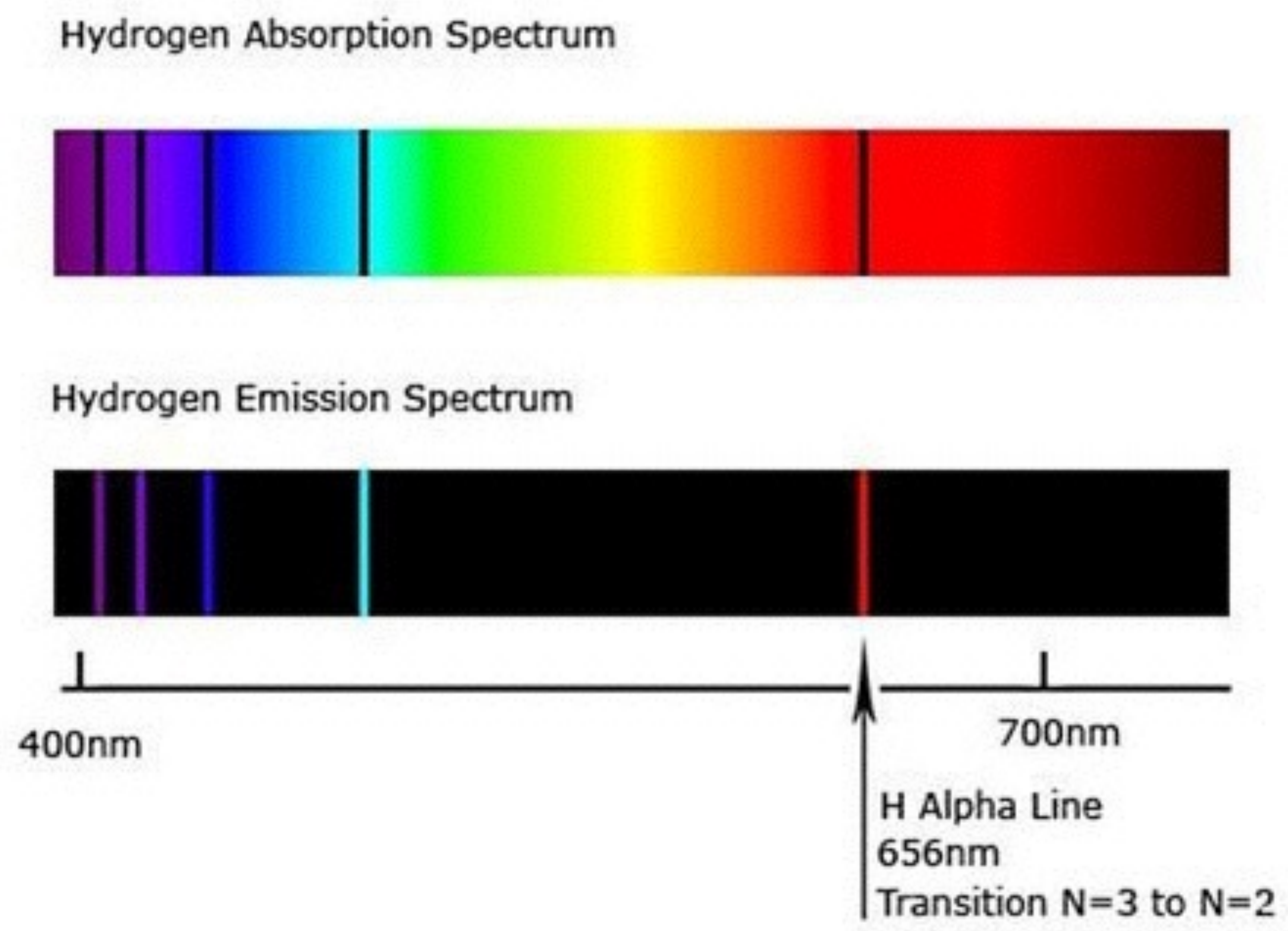
Calibration

- mapping pixel values from an image to wavelengths of light
- CFL bulbs produce a very distinct spectrum (caused by mercury vapor in the bulb) - specifically peaks at 435.8nm and 546.1nm
- we can use these two known peaks as calibration points and adjust our spectrum
- how often should you calibrate?

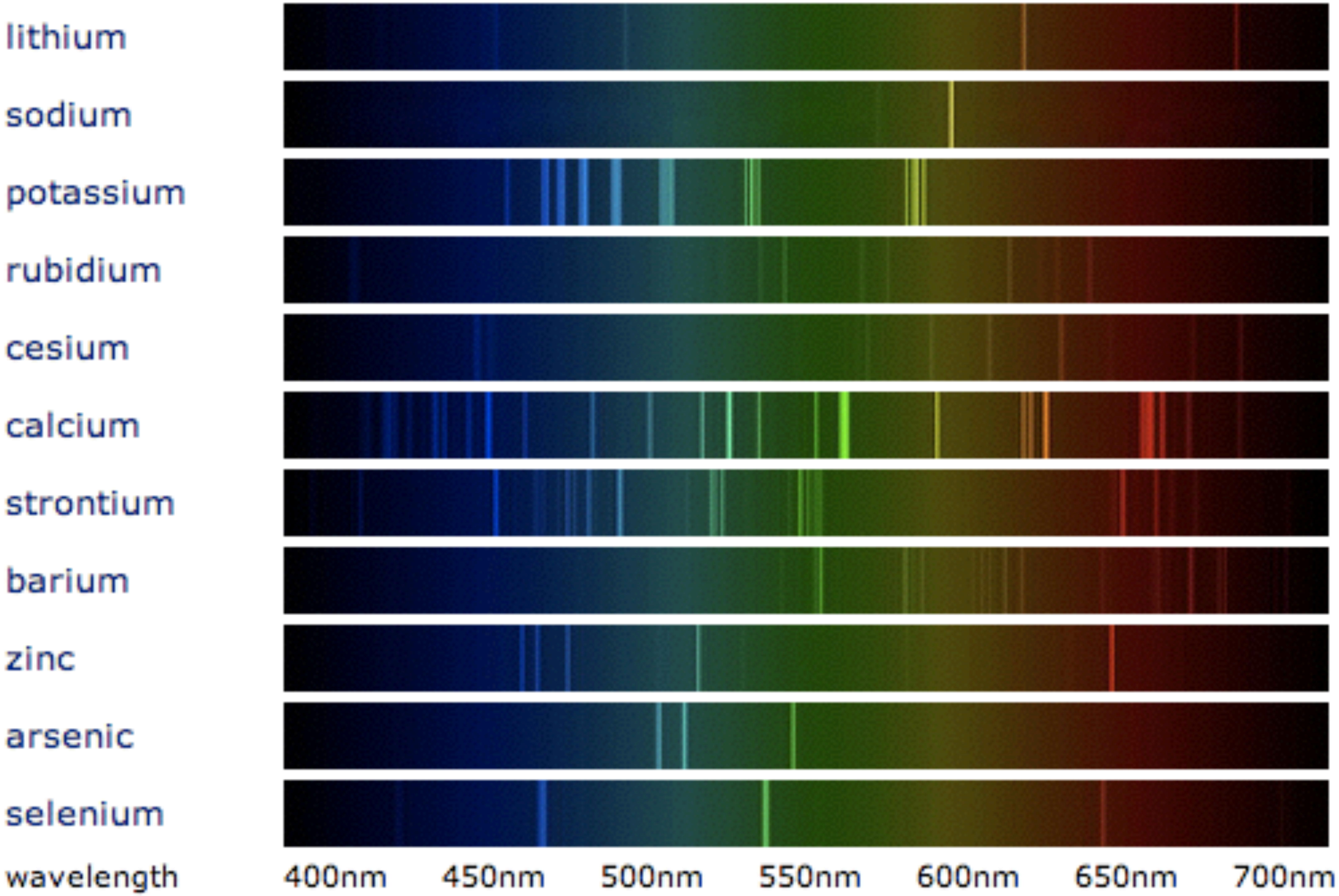


Spectral Analysis Techniques

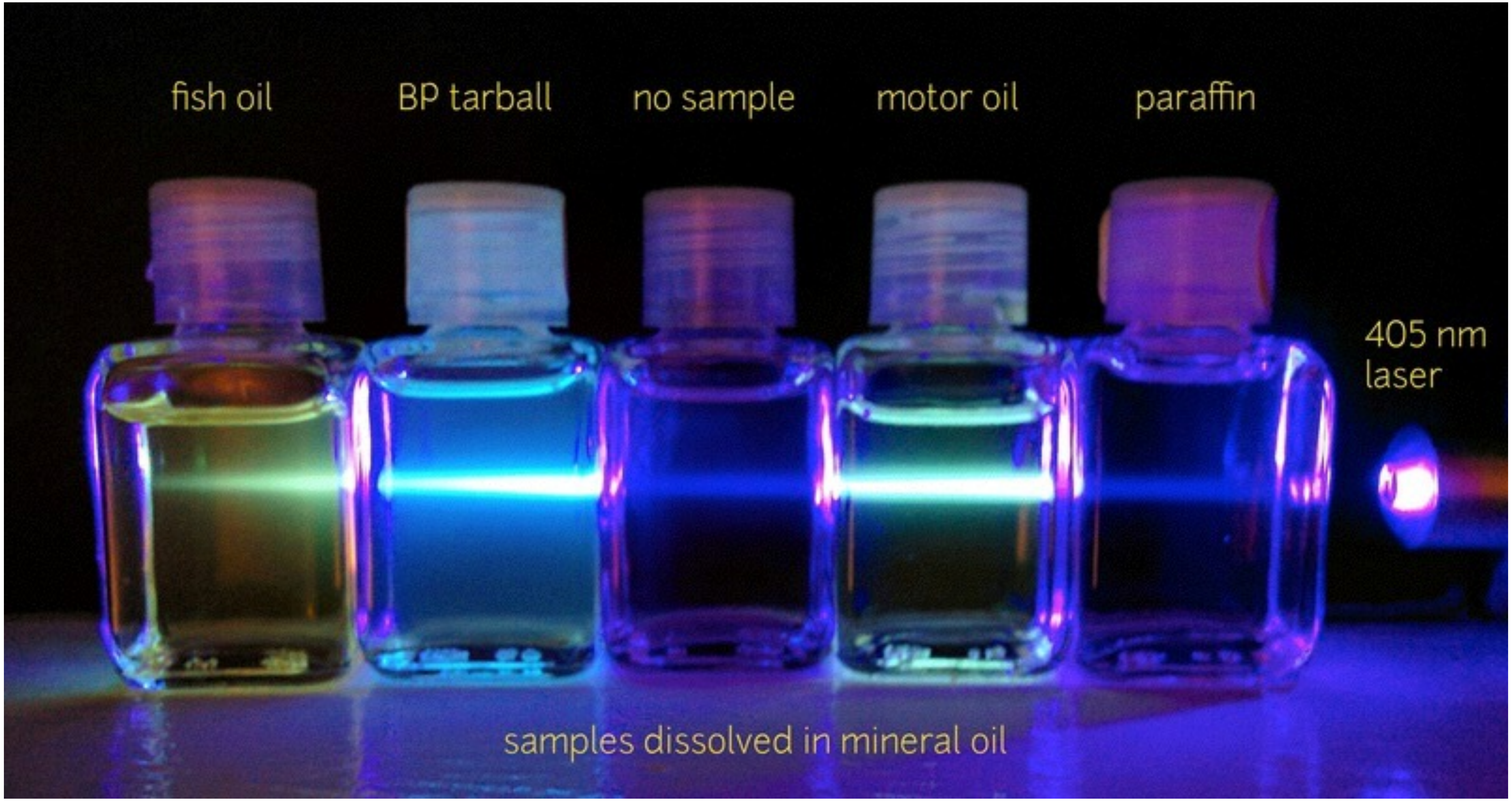
- Absorption spectroscopy
    - measure a reference spectrum using a full-spectrum white light source (and any container that will be used for the sample
    - measure a second spectrum with sample
    - subtract the reference from the sample to determine absorption
- Emission spectroscopy
    - directly sample a light source and identify elements present through peak identification



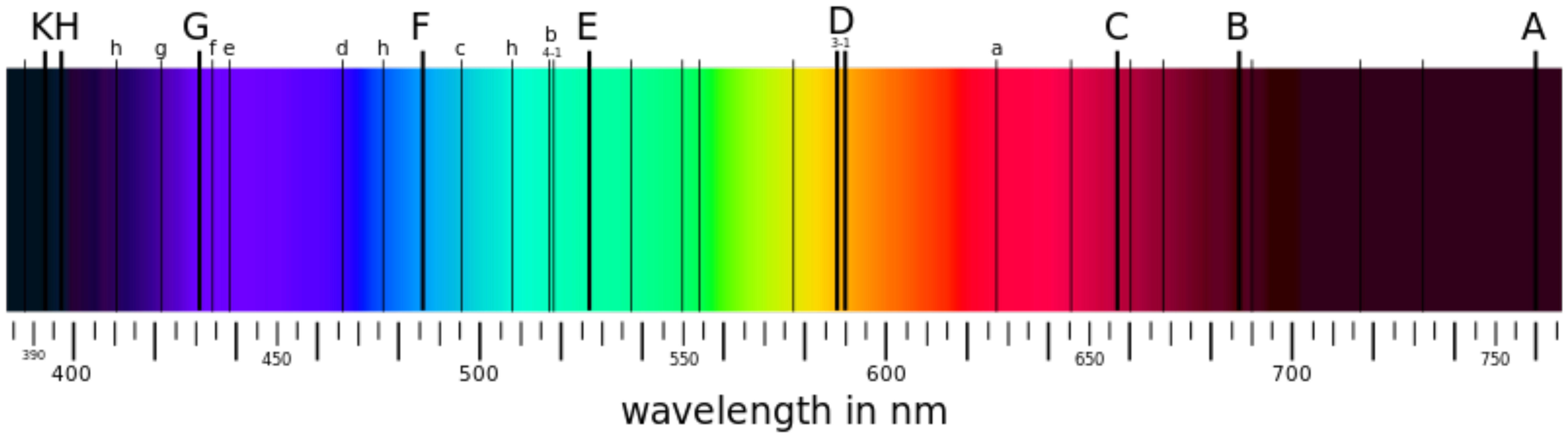
Flame Spectroscopy

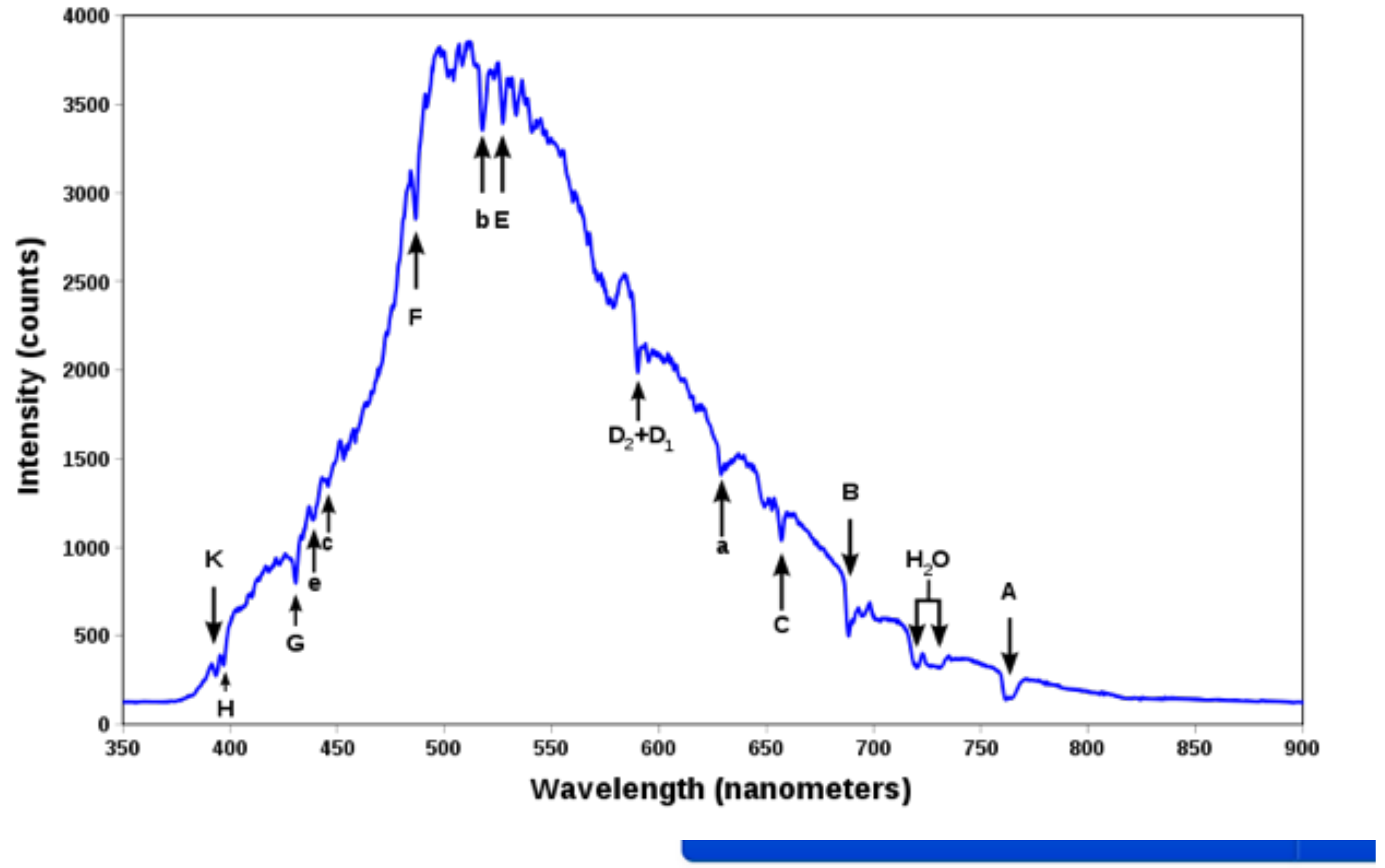


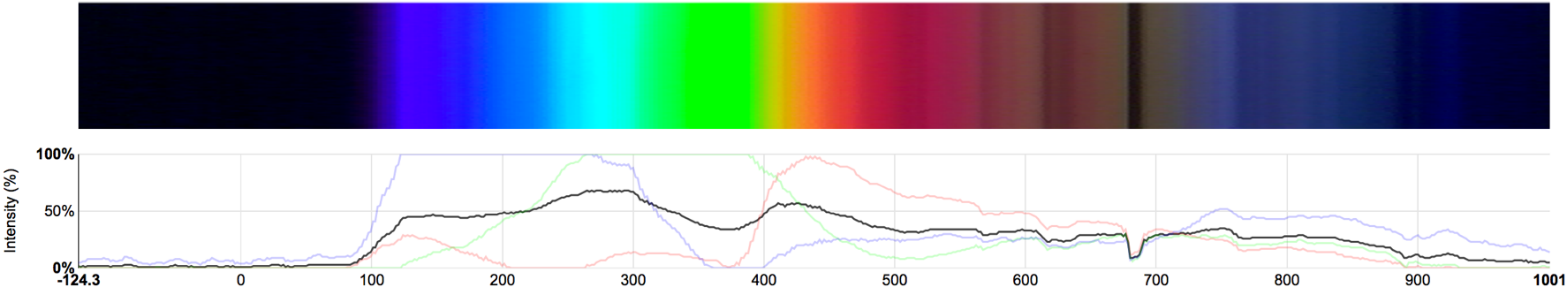
Oil Sampling



Fraunhofer Lines







atmosphere over pfizer, brooklyn

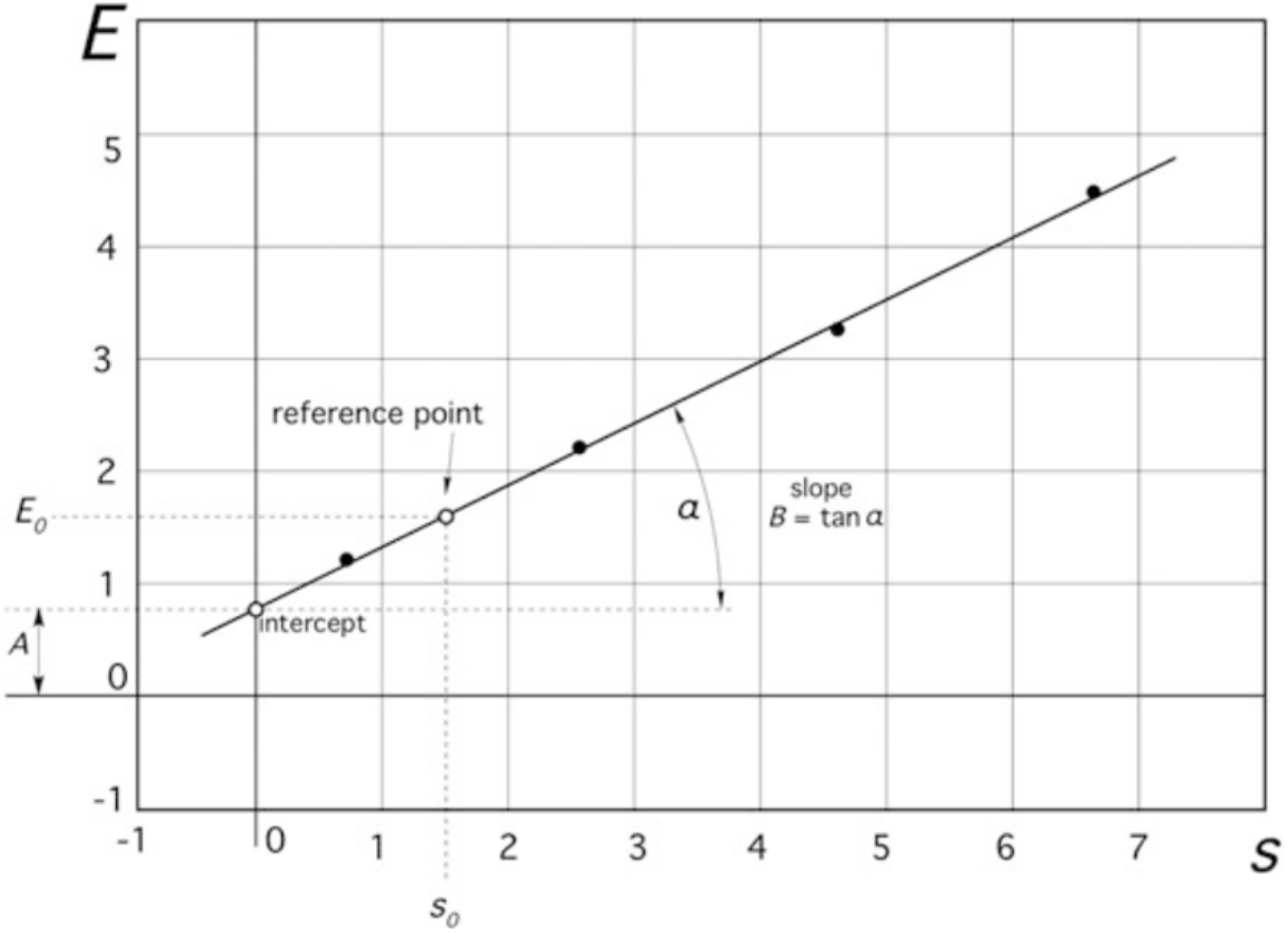
SENSOR CHARACTERISTICS

- Each sensor has a 'characteristic curve' or **transfer function** (E) that describes the ideal input-output (stimulus-response) relationship.

- The simplest transfer function is linear:

$$E = A + Bs$$

- ***E*** is the sensor output which becomes 'known' during measurement and represents the stimulus (***s***). ***A*** is the sensor's offset value and ***B*** is it's sensitivity (slope)



Next Steps

- Capture spectra of NYC's lights
- Improve the foldable spectrometer:
    - use a different camera, different diffraction grating, modified chamber with smaller slit