



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



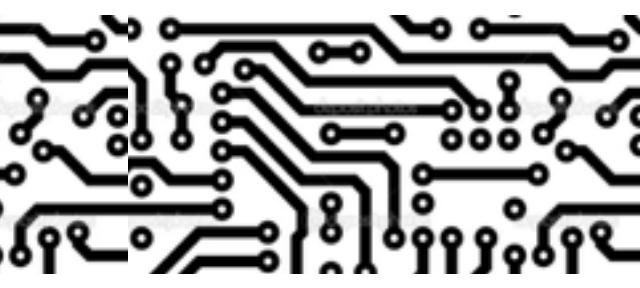
Bottom-up Techniques

- 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:

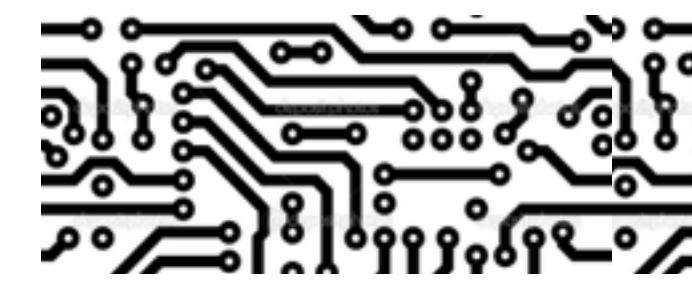
Where does data come from?

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

–Tom Igoe



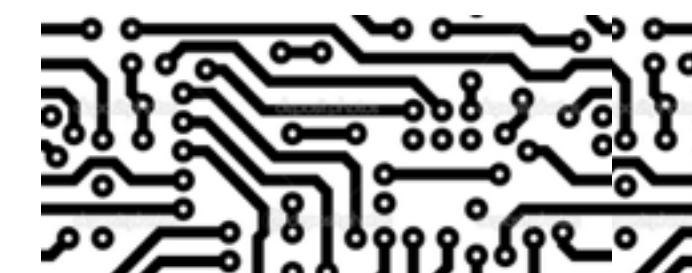
SENSORS



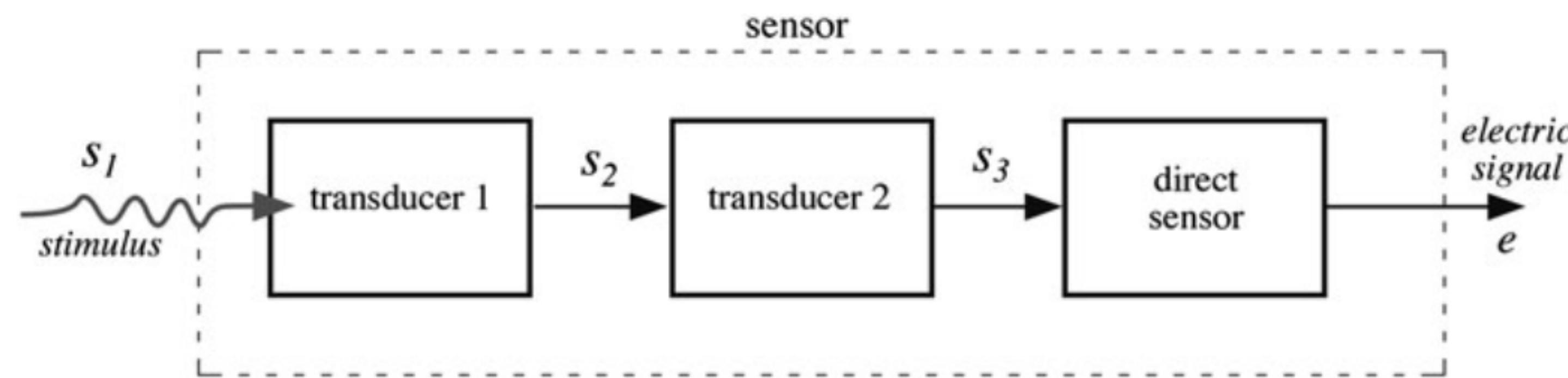
- A **sensor** is a device which detects some characteristic of its environment and provides a corresponding **electrical output**.
- A sensor's output signal maybe in the form of **voltage, current** or **charge**
- These can further be described in terms of: **amplitude, polarity, frequency, phase**

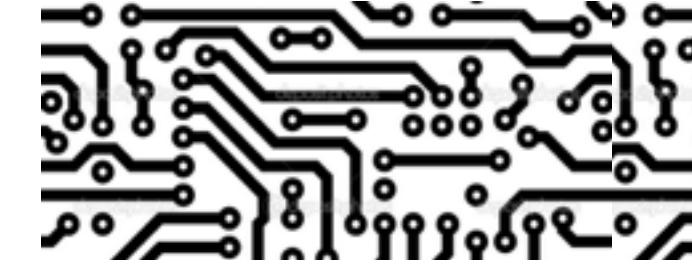
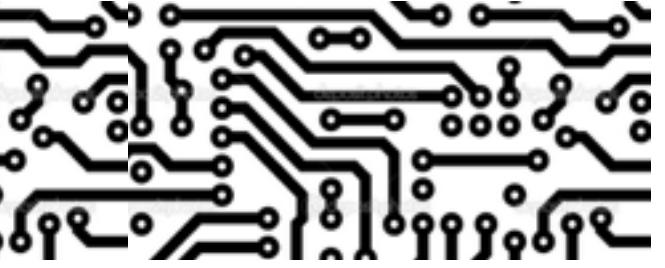


SENSOR SYSTEMS



- 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**.

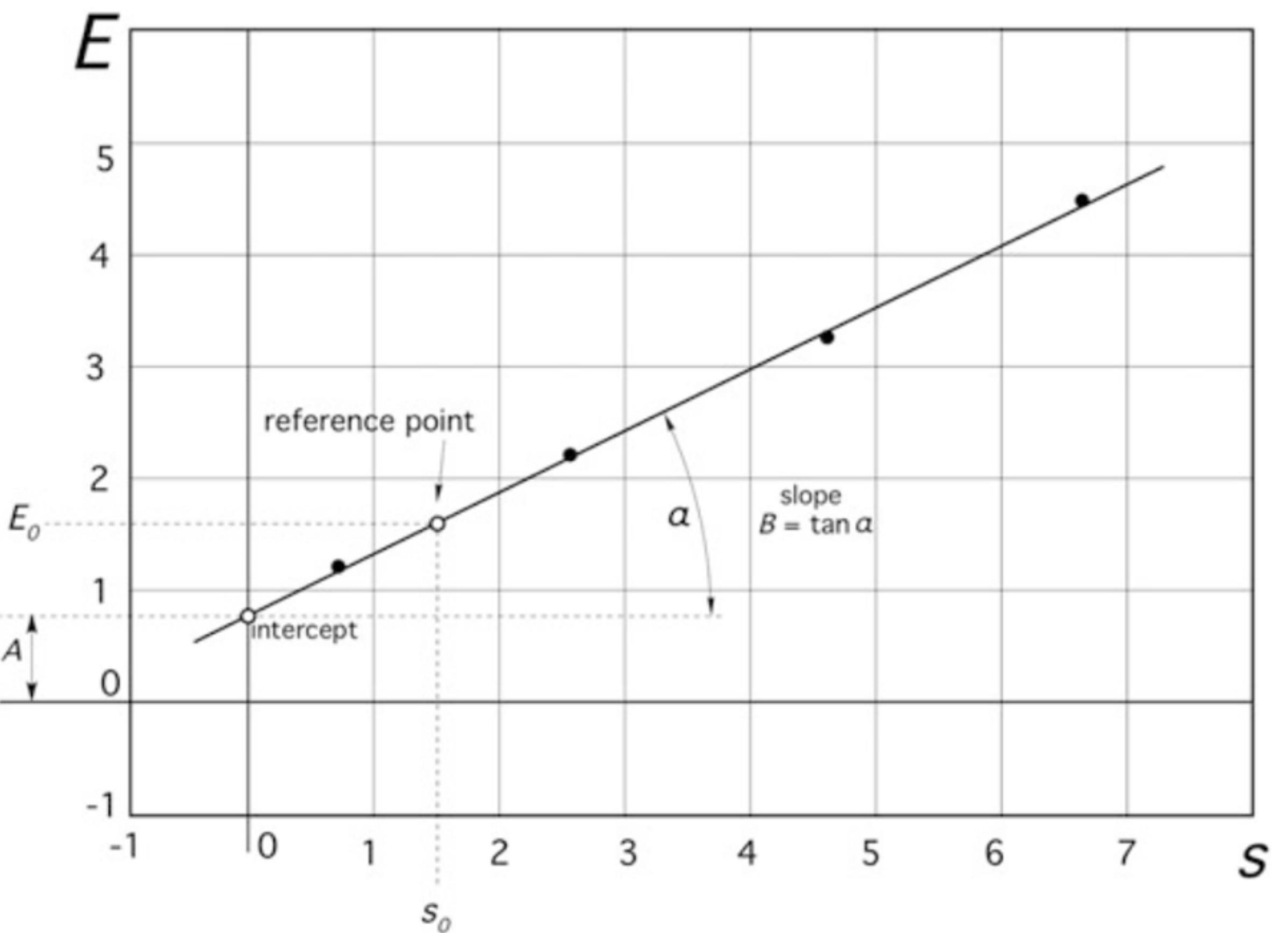
How do you interpret those measurements?

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:

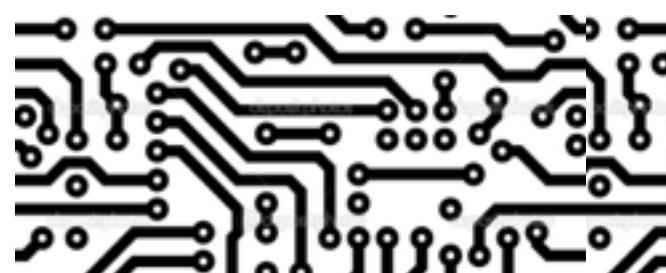
$$E = A + Bs$$

- 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)

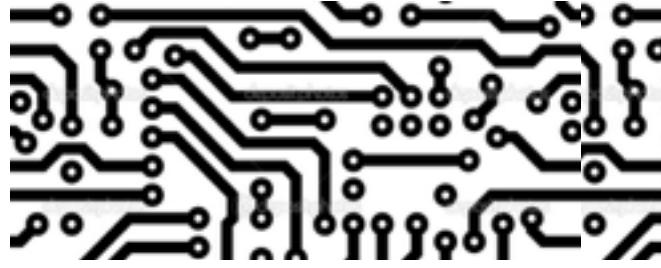
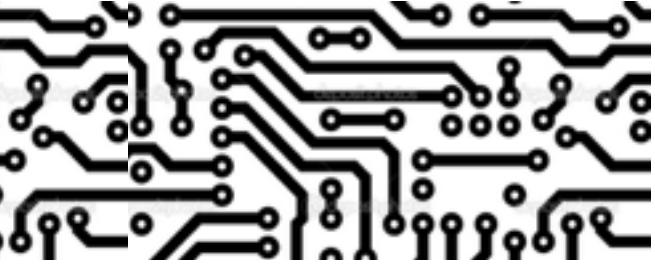




SENSOR CHARACTERISTICS



- **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



- Accelerometer
- Gyroscope
- Magnetometer



6-axis sensors



- eCompass
- IMU



9-axis sensors



- Absolute Orientation Sensor
- Application Specific Sensor Nodes (ASSNs, incl. µC)



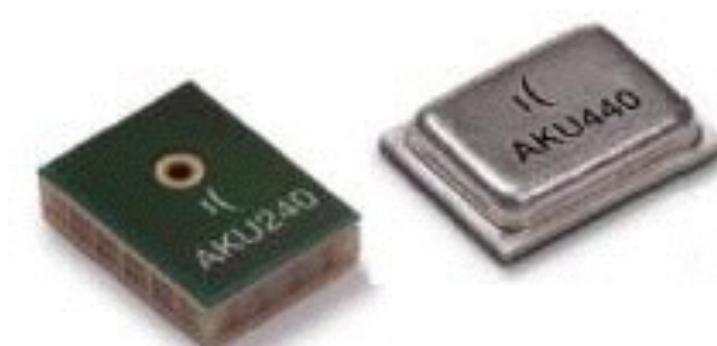
environmental



- Barometric Pressure Sensor
- Integrated Environmental Unit



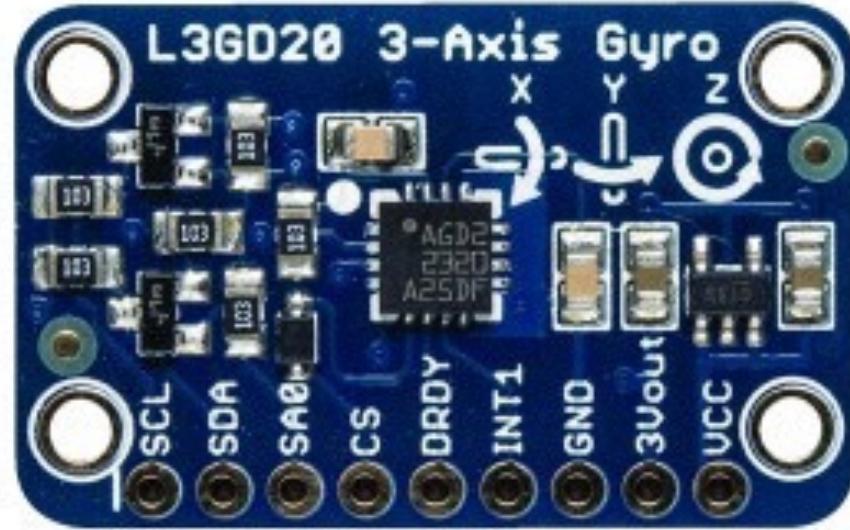
microphones



- Analog and digital MEMS microphones (Akustica)
- High quality voice input for mobile devices



Tilt, Acceleration, Position, and Orientation



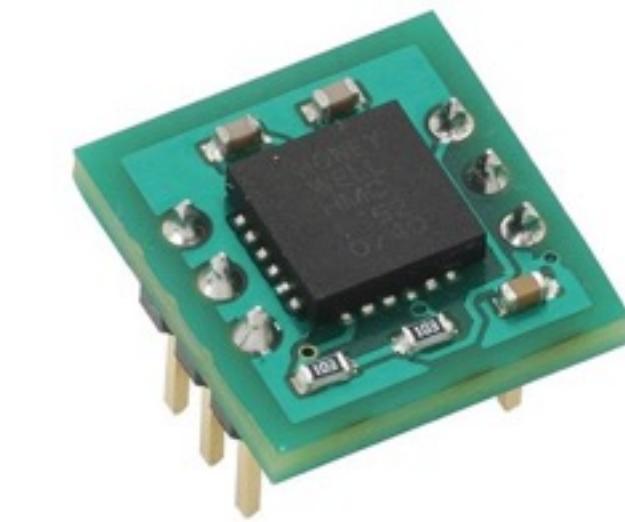
Gyrometer



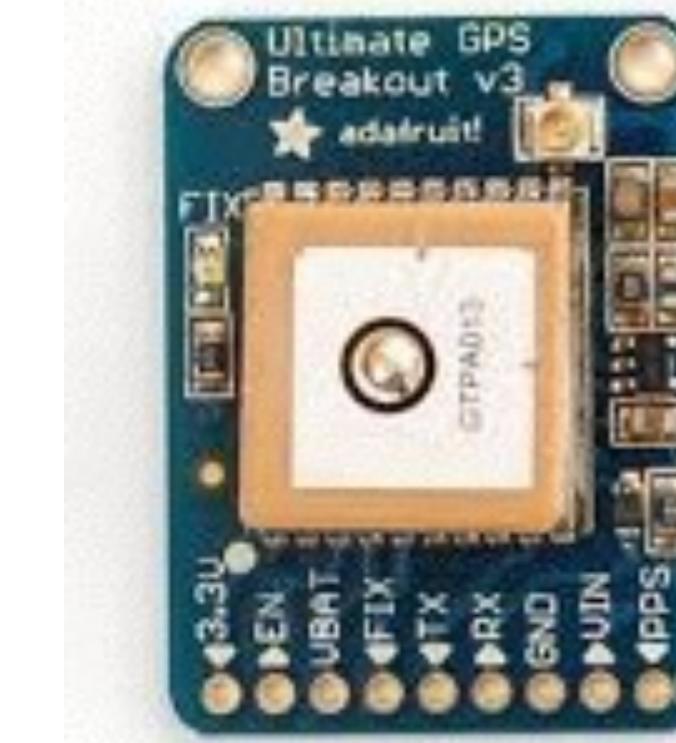
Tilt



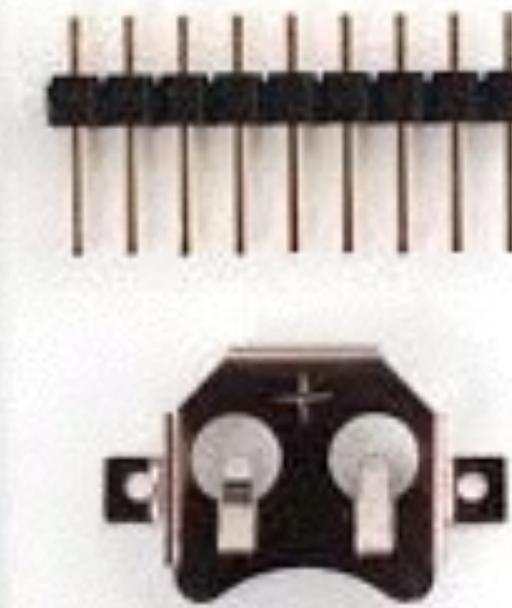
Accelerometer

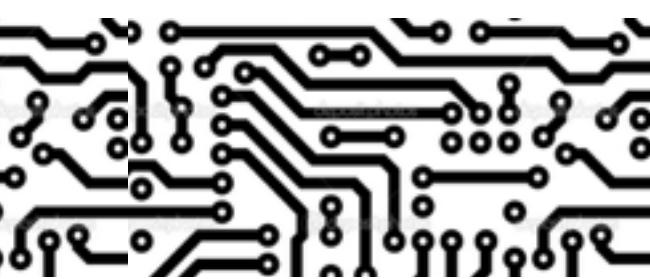


Magnetoresistive
(Compass)

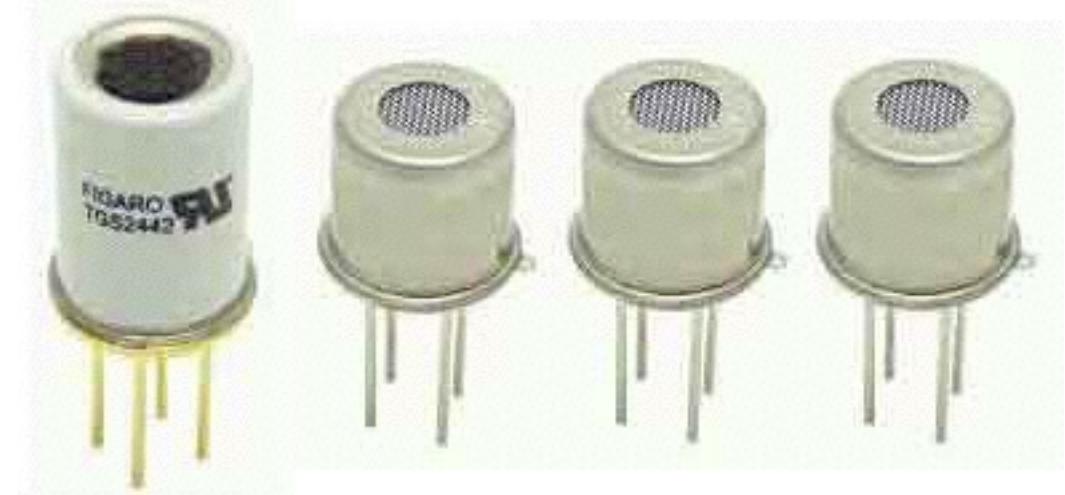
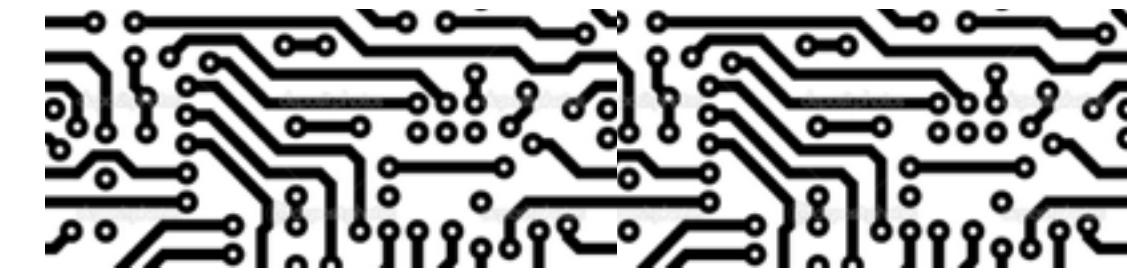


GPS Location

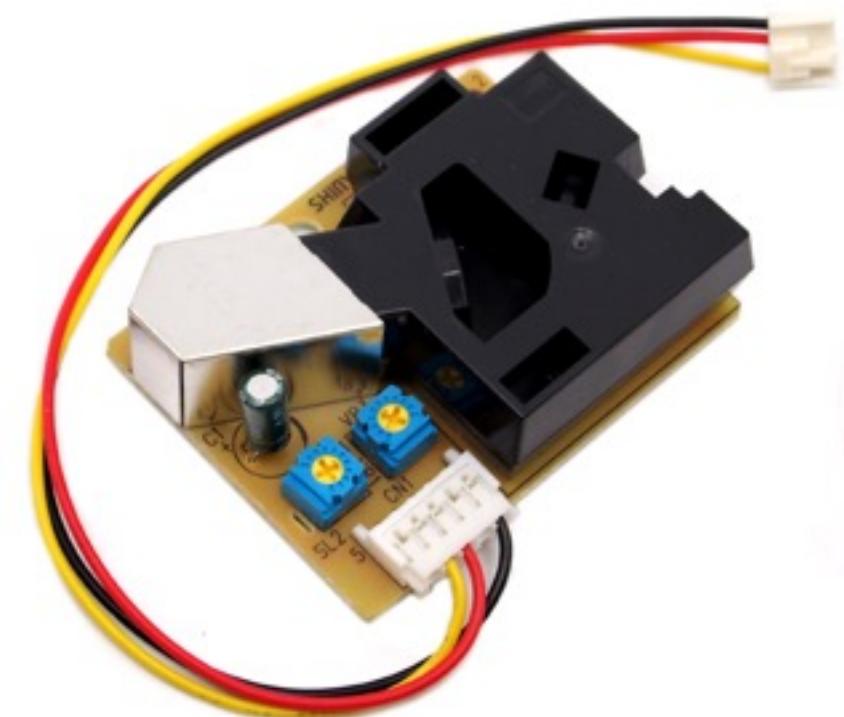




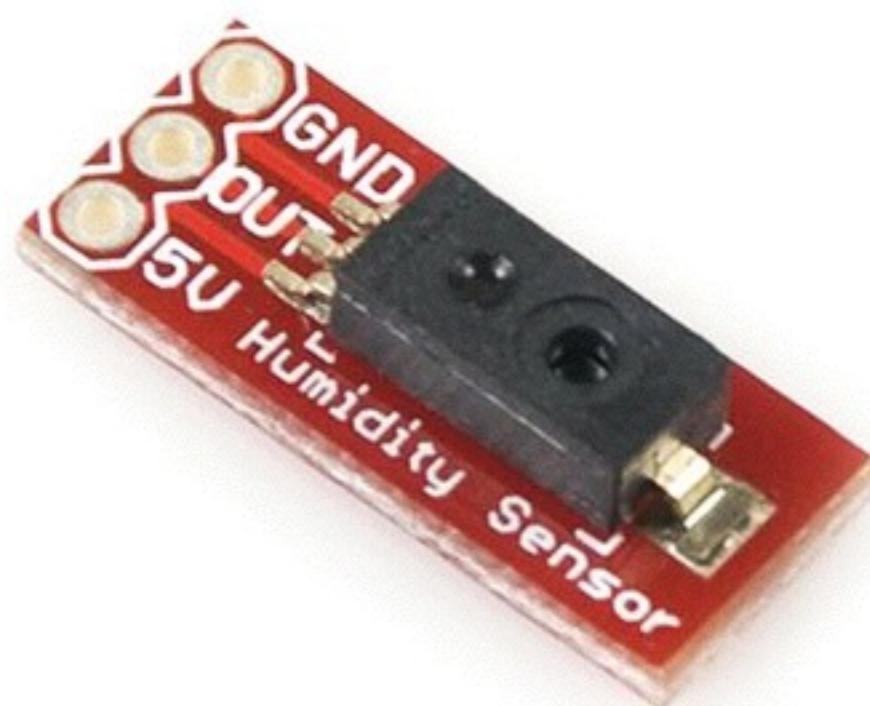
ENVIRONMENTAL



Gas



Dust



Humidity

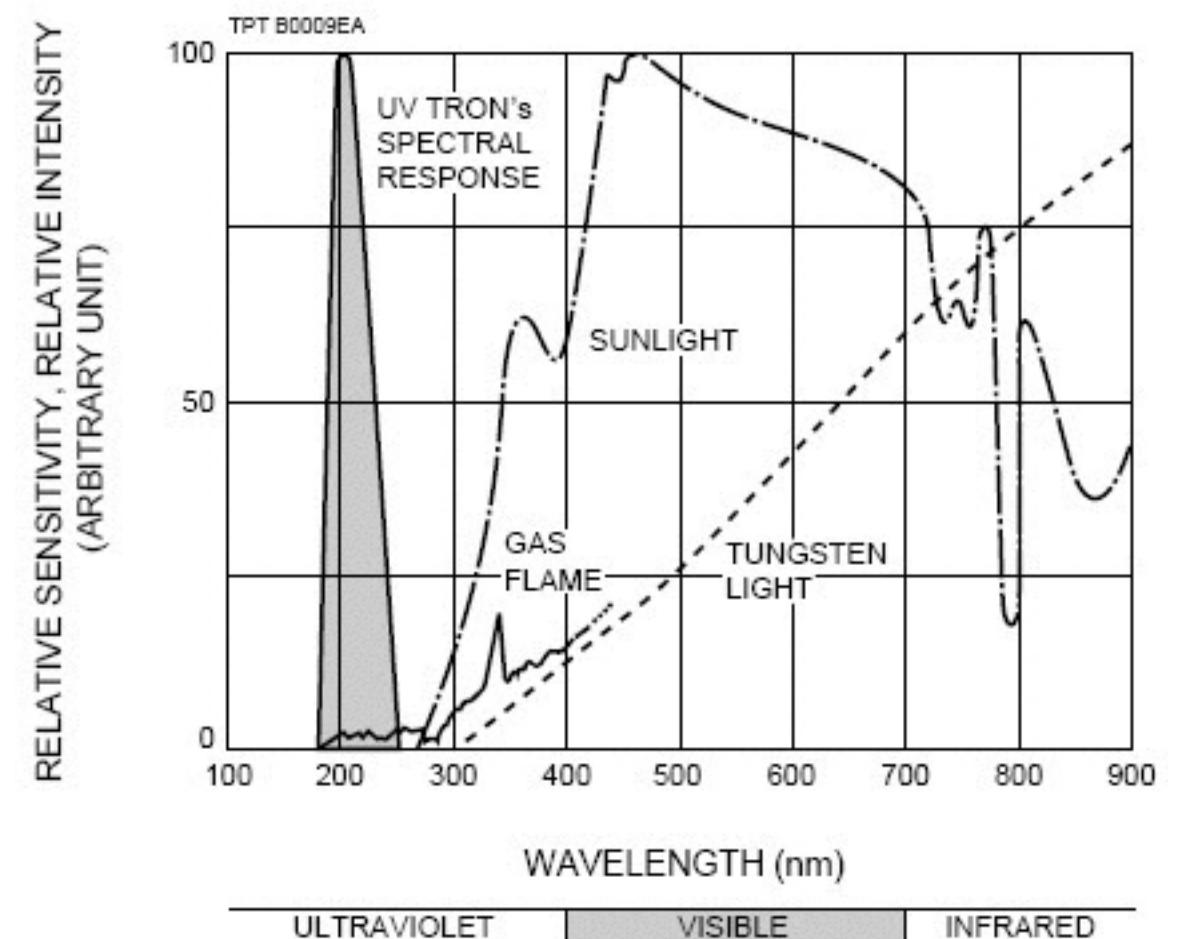


Temperature

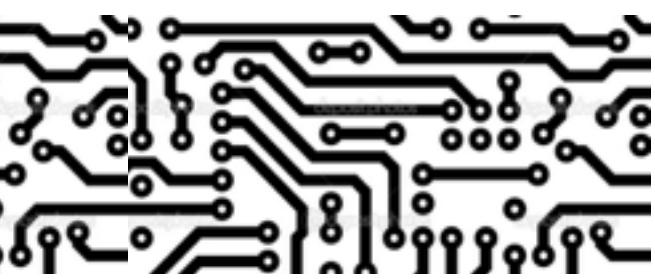


Anemometer

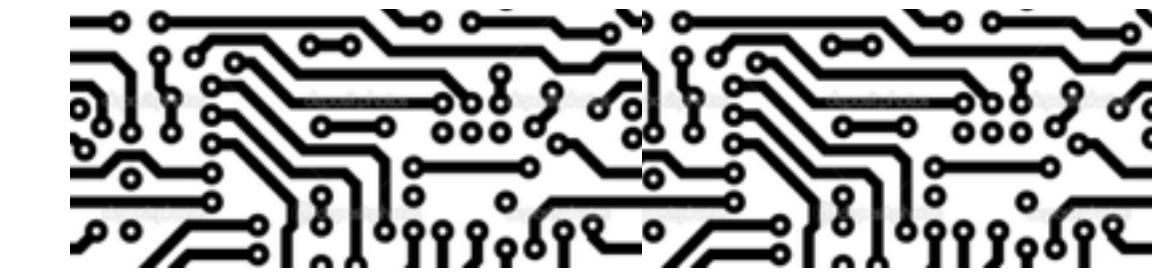
UV TRON's Spectral Response and Various Light Sources



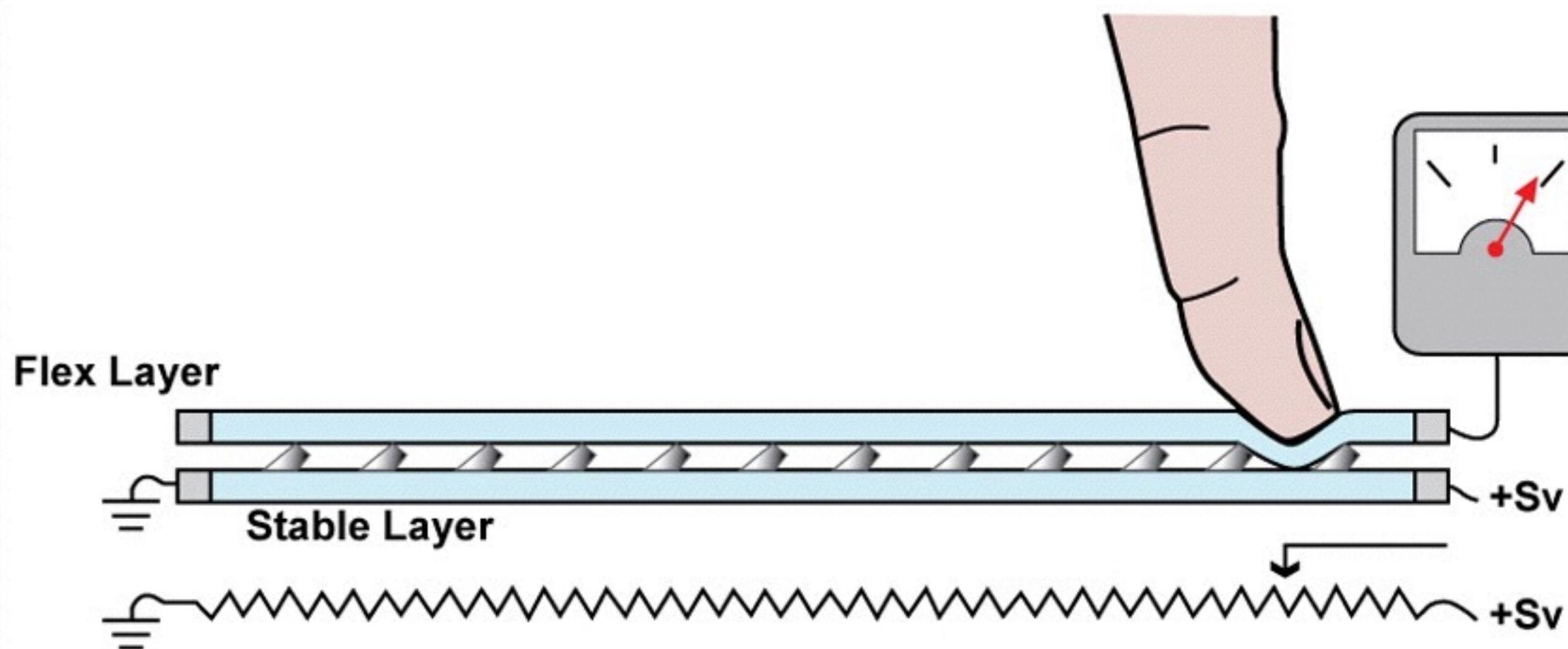
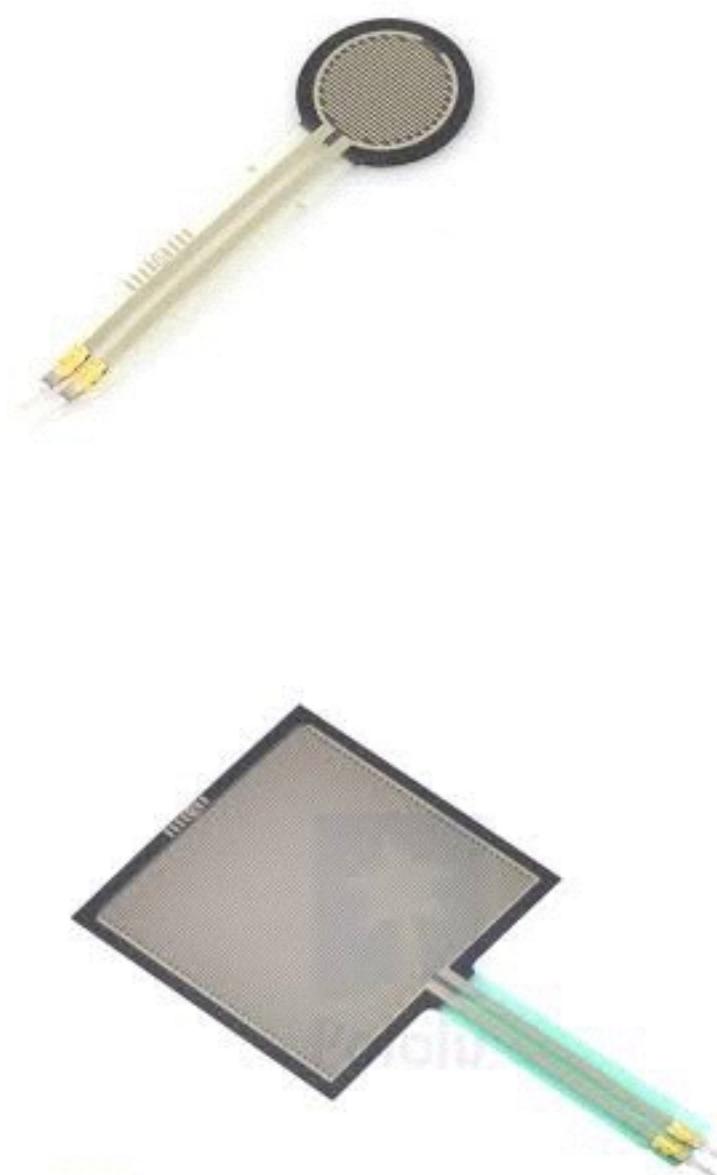
Flame



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

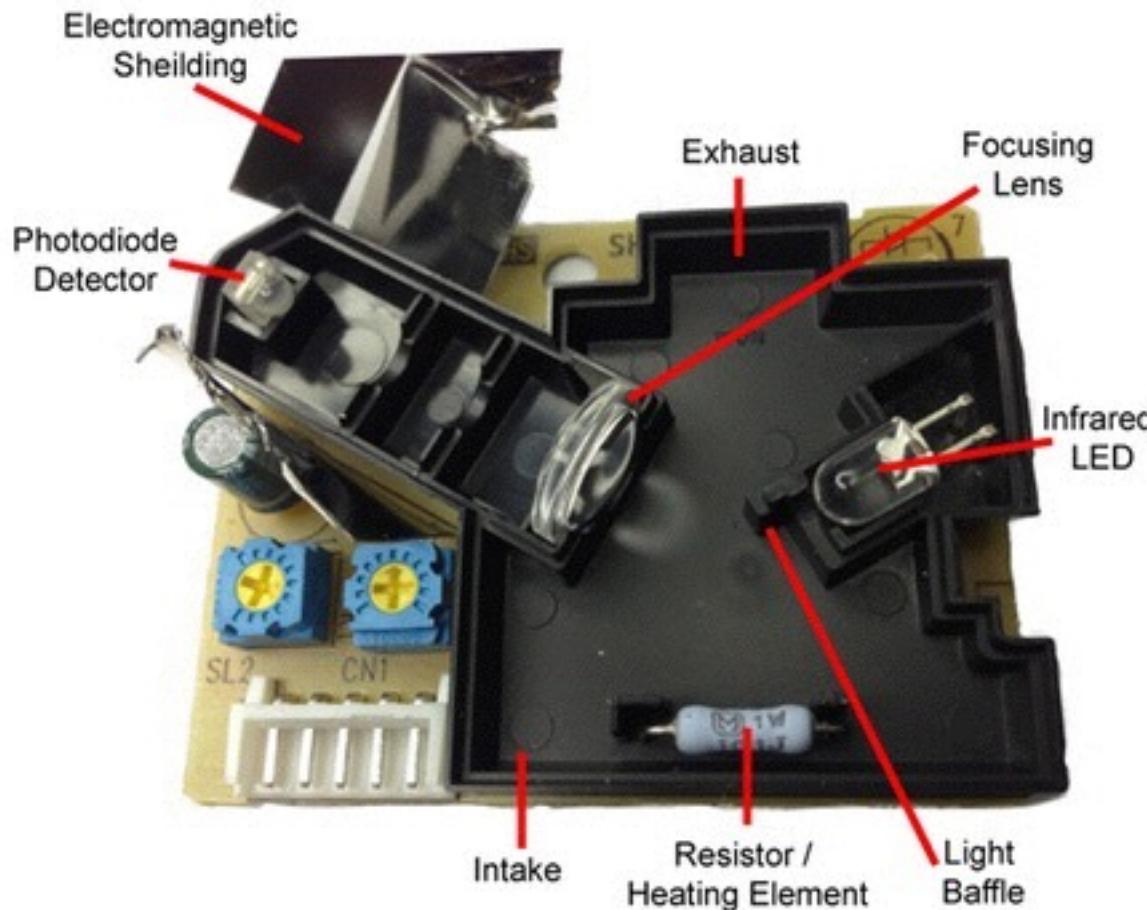


OPTICAL/LIGHT SENSORS

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



Luminosity



Dust Sensor



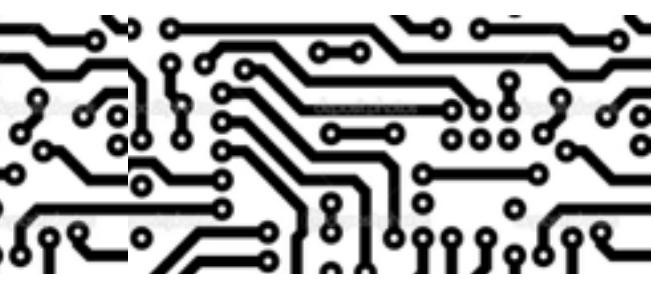
LidarLite



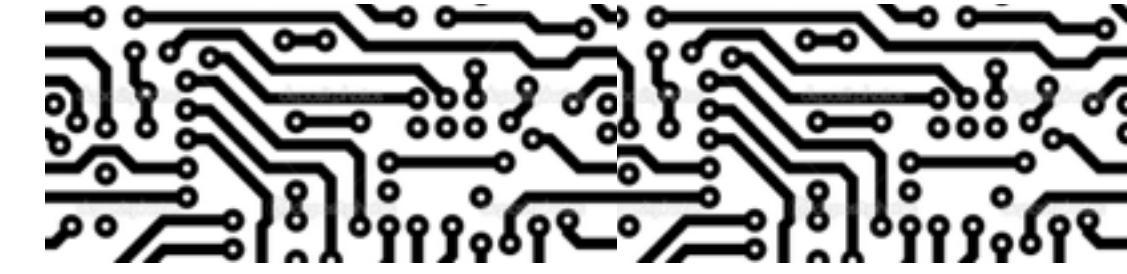
IR Distance



Pulse Sensor



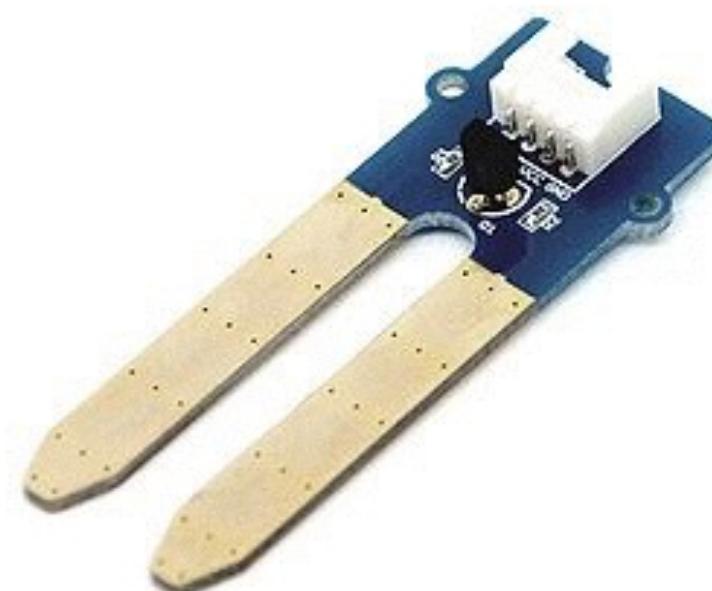
CHEMICAL SENSING



- often used for measuring concentrations, compositions and absorption



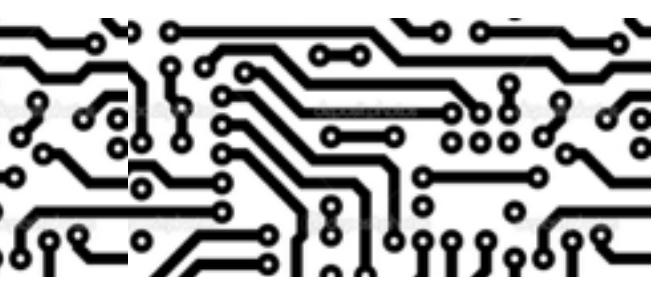
Conductivity



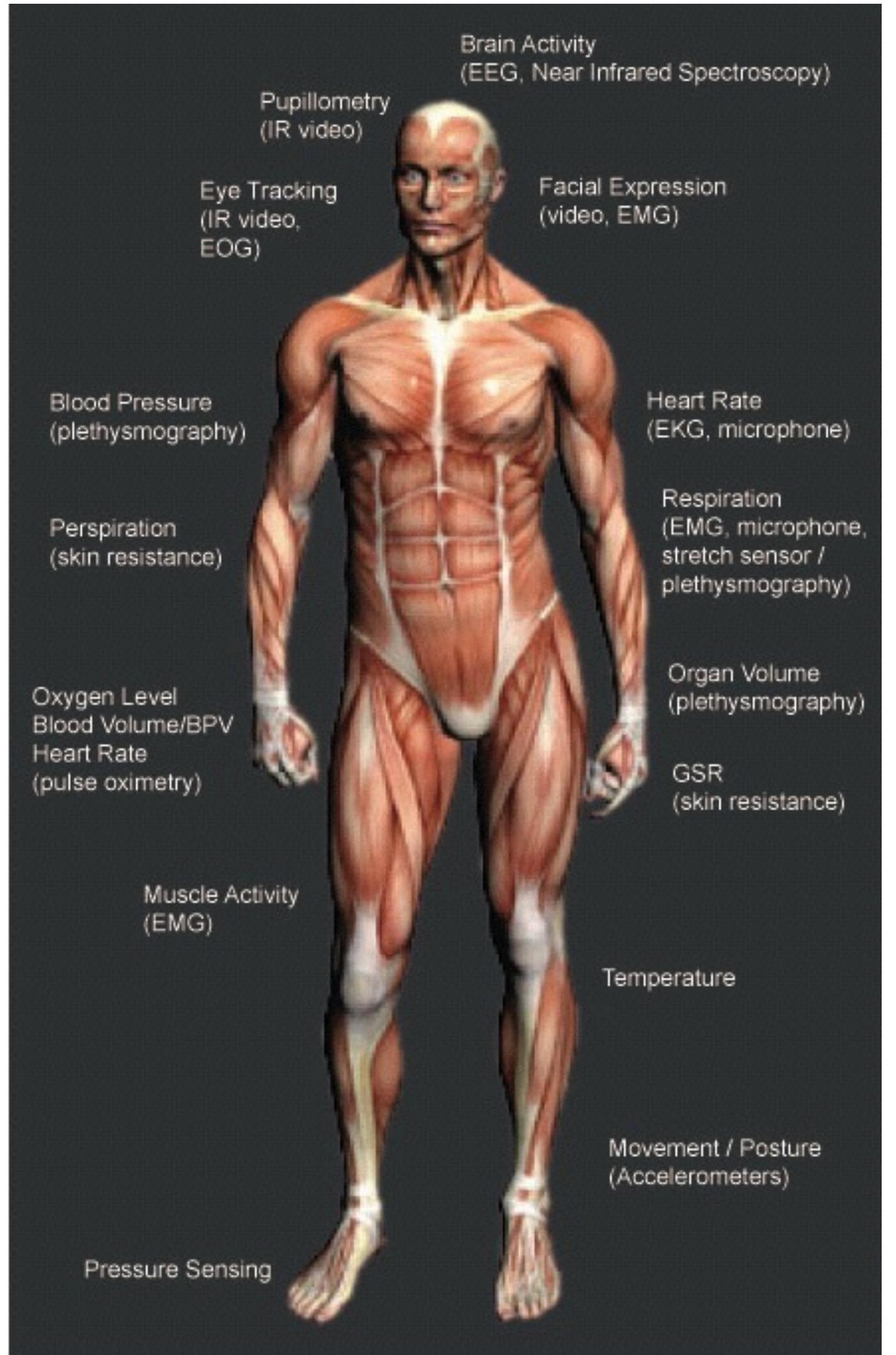
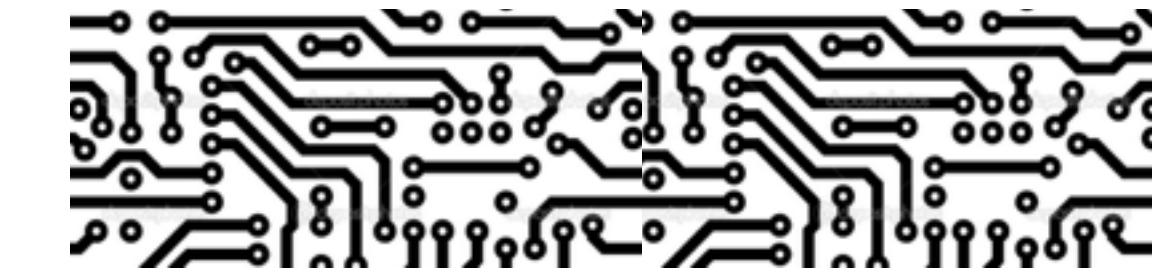
Moisture



Gas Sensors



BIOMETRIC



EEG



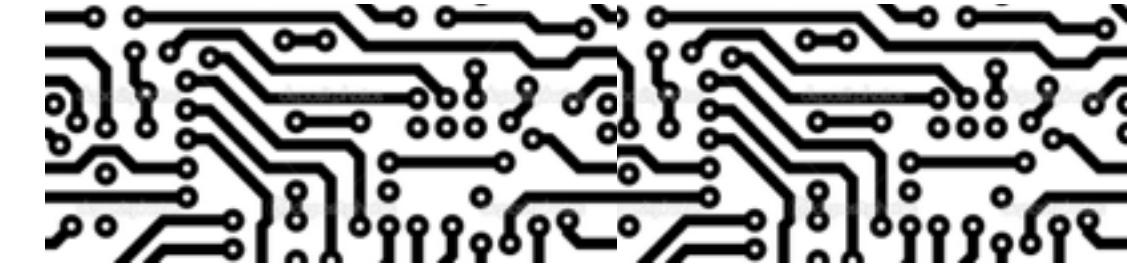
Stretch



Pulse Sensor

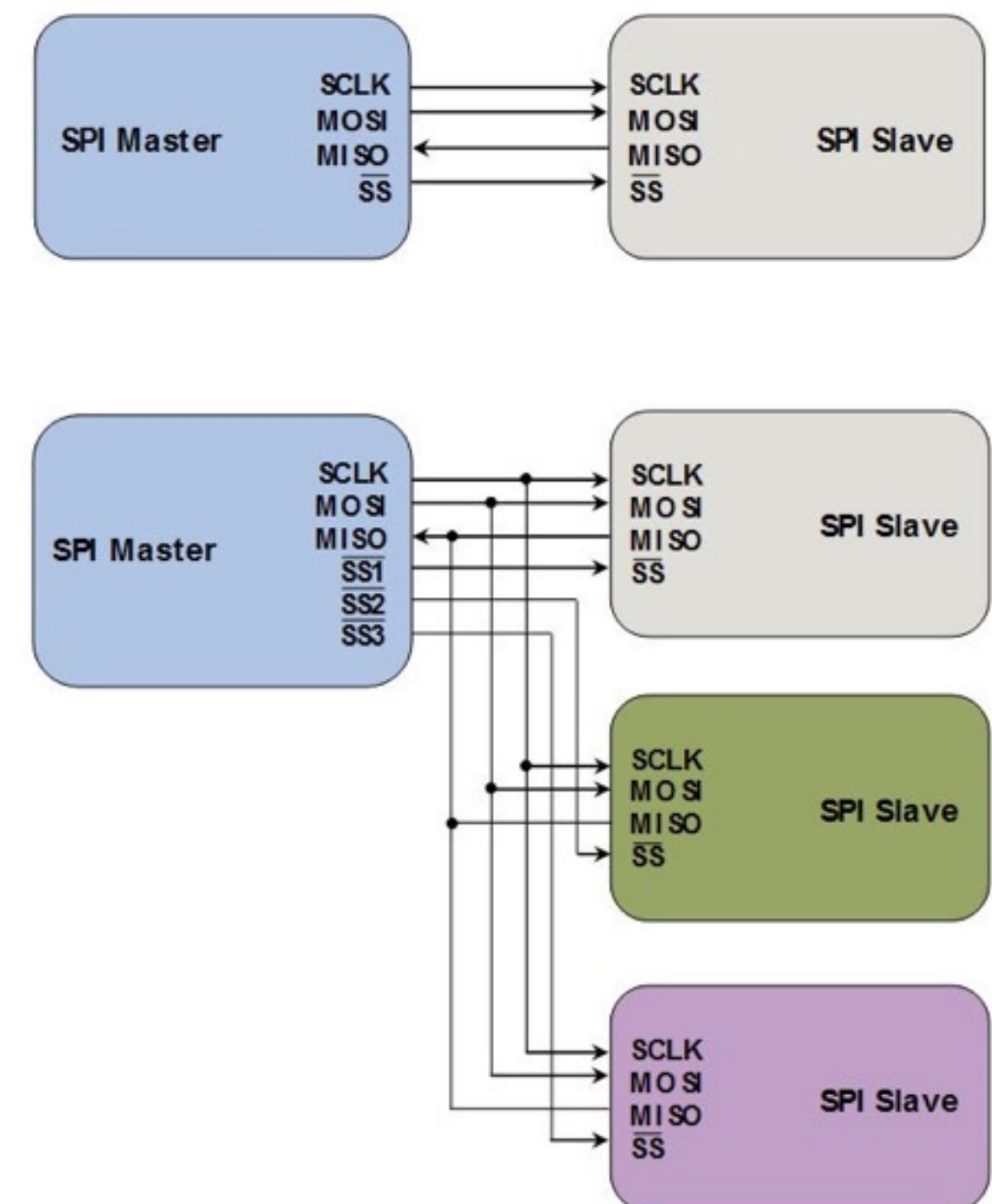


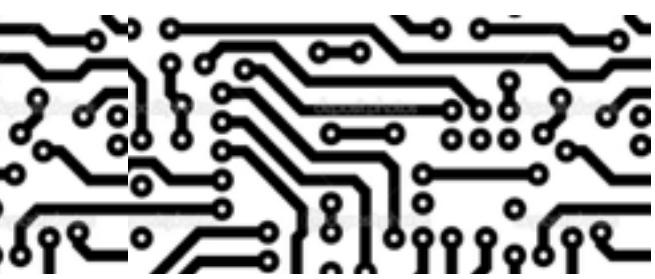
COMMUNICATION



- **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.

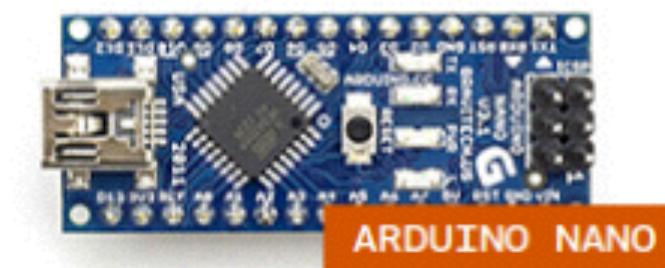
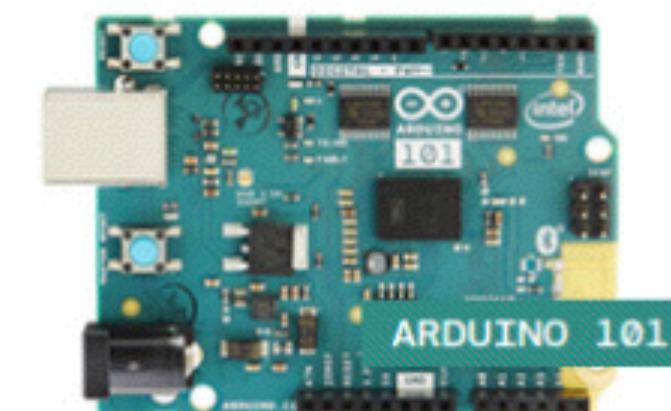




ARDUINO



- 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



The screenshot shows the Arduino IDE interface with the title bar "Blink | Arduino 1.0". The main window displays the "Blink" example code:

```
/*
  Blink
  Turns on an LED on for one second, then off for one second, repeatedly.

  This example code is in the public domain.
*/

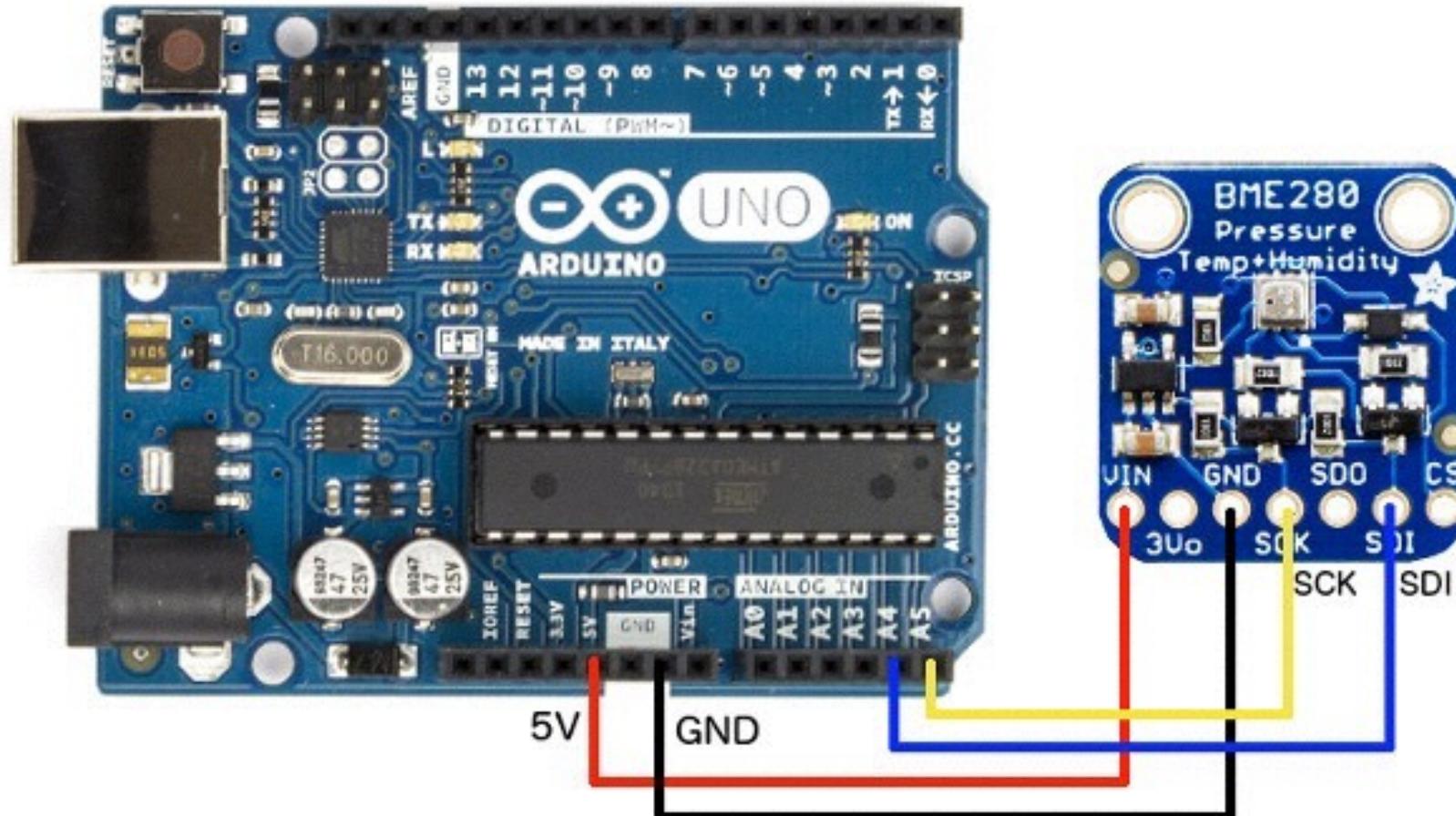
void setup() {
  // initialize the digital pin as an output.
  // Pin 13 has an LED connected on most Arduino boards:
  pinMode(13, OUTPUT);
}

void loop() {
  digitalWrite(13, HIGH);      // set the LED on
  delay(1000);                // wait for a second
  digitalWrite(13, LOW);       // set the LED off
  delay(1000);                // wait for a second
}
```

At the bottom of the IDE, it says "1" and "Arduino Uno on /dev/tty.usbmodemfd131".

EXAMPLE SETUP

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



bme280test | Arduino 1.6.12

```
#include <Wire.h>
#include <SPI.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BME280.h>

#define SEALEVELPRESSURE_HPA 1013.25

Adafruit_BME280 bme; // I2C

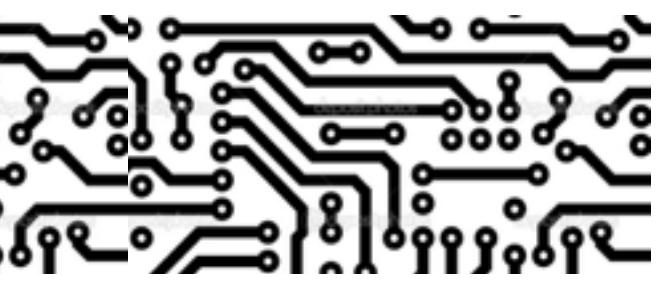
void setup() {
  Serial.begin(9600);
  Serial.println(F("BME280 test"));

  if (!bme.begin()) {
    Serial.println("Could not find a valid BME280 sensor, check wiring!");
    while (1);
  }
}

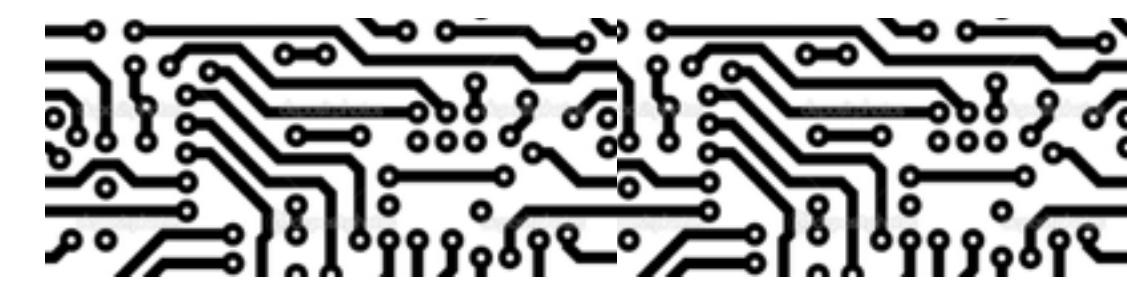
void loop() {
  Serial.print(bme.readTemperature());
  Serial.print(bme.readPressure() / 100.0F);
  Serial.print(bme.readAltitude(SEALEVELPRESSURE_HPA));

  Serial.print(bme.readHumidity());
  delay(2000);
}
```

6 Adafruit Metro on /dev/cu.SLAB_USBtoUART



HARDWARE PLATFORMS

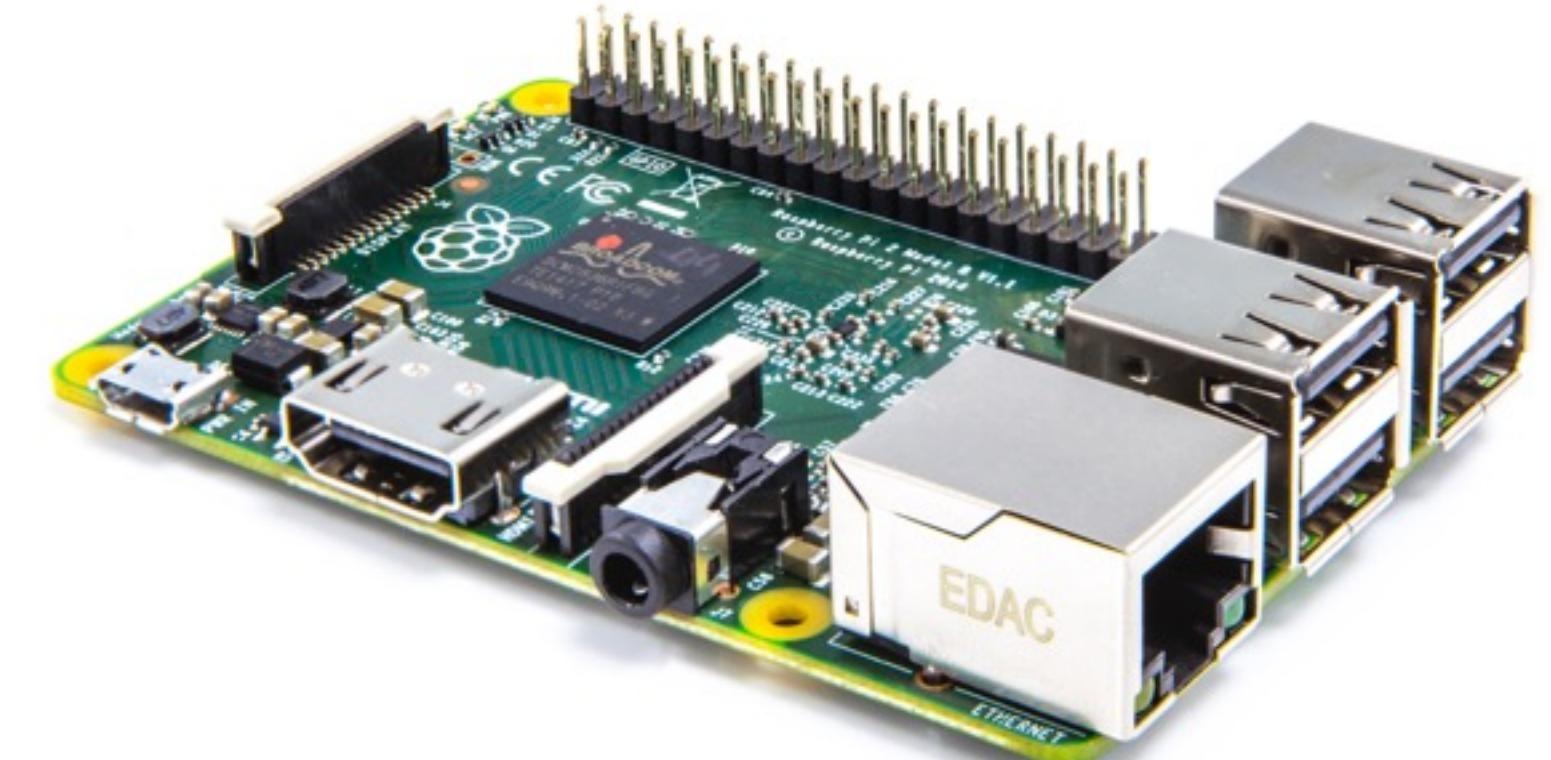


Arduino

VS



BeagleBone



Raspberry Pi

Sensor Calibration + Data Quality

What data quality do you need?

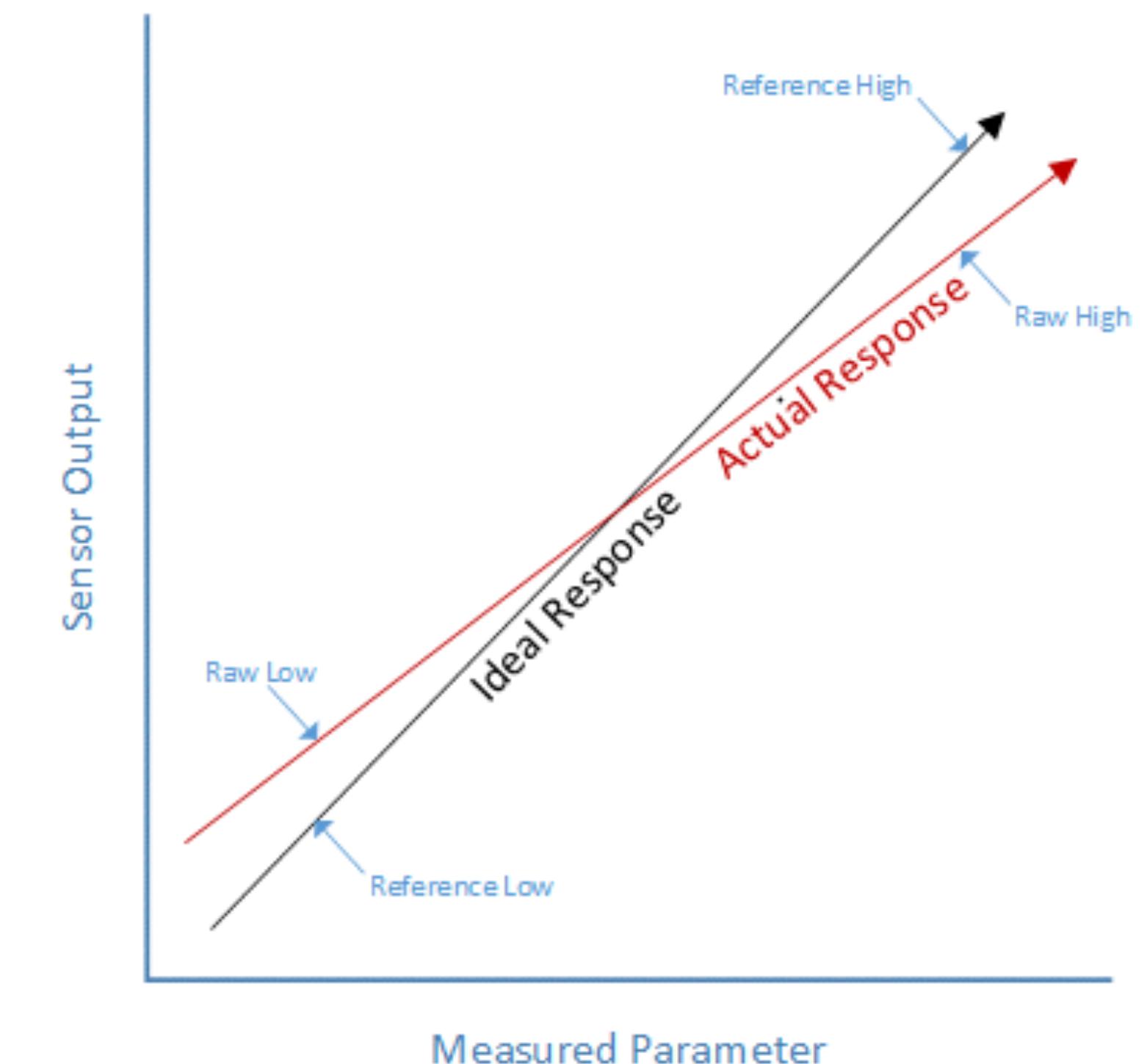
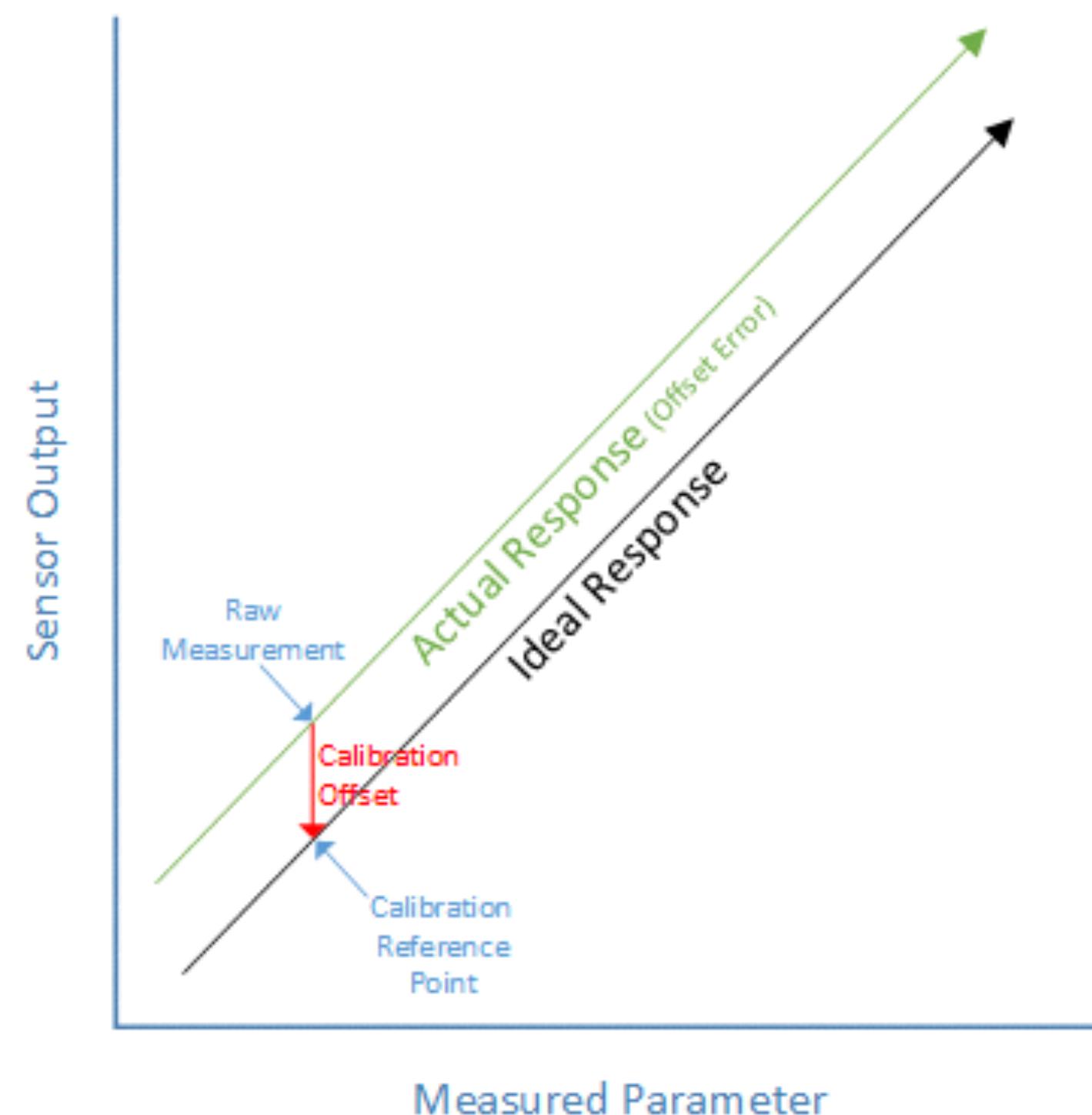
- What's the question your trying to answer?
- Small data can sometimes be more important

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.

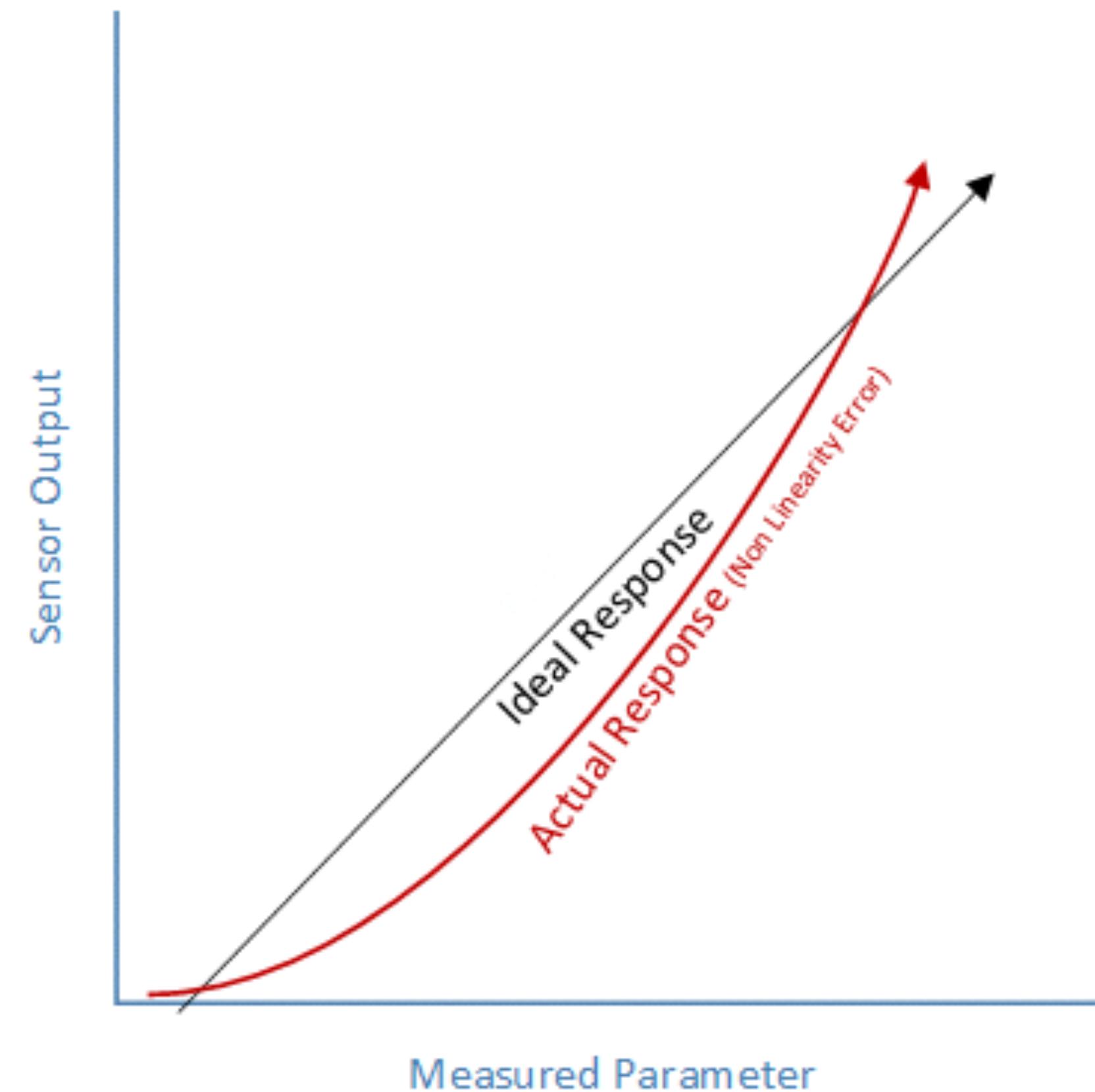
Calibration Methods

- 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,



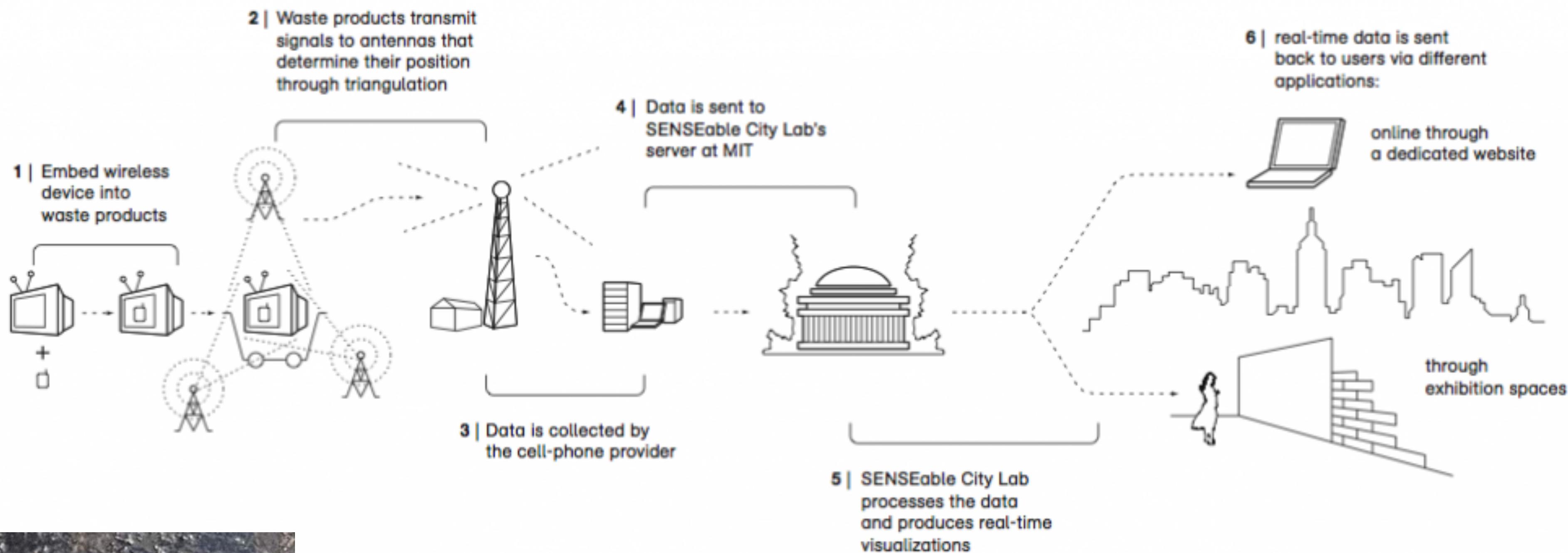
Calibration Methods

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

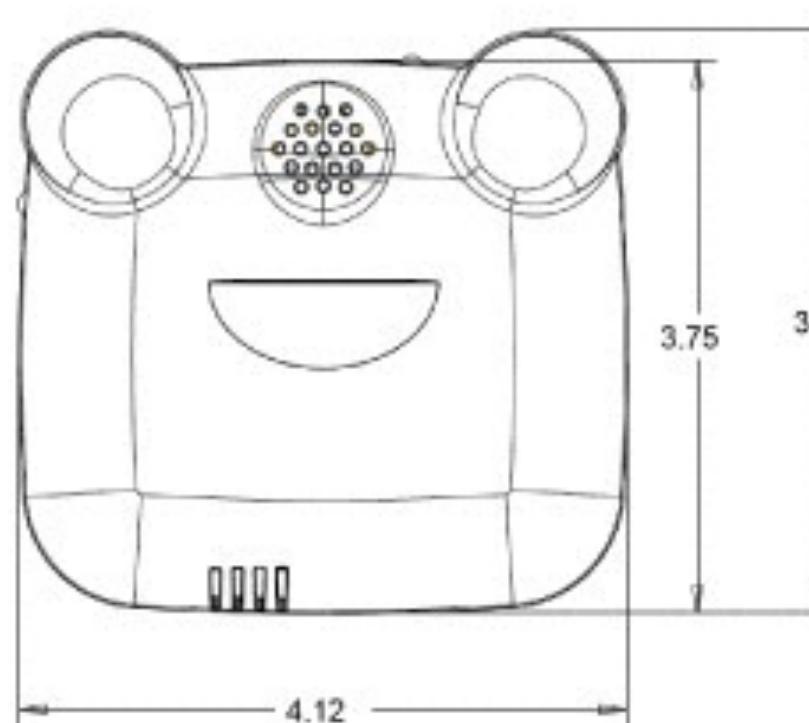
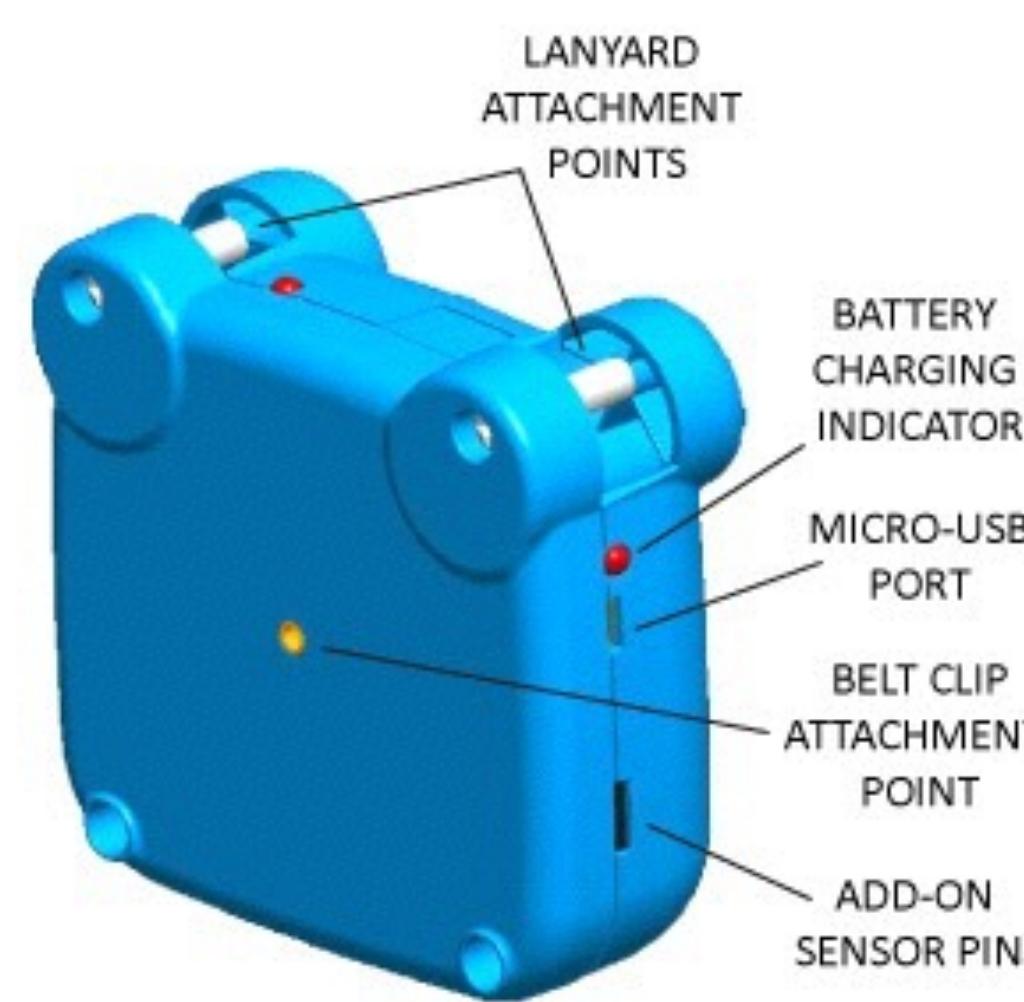
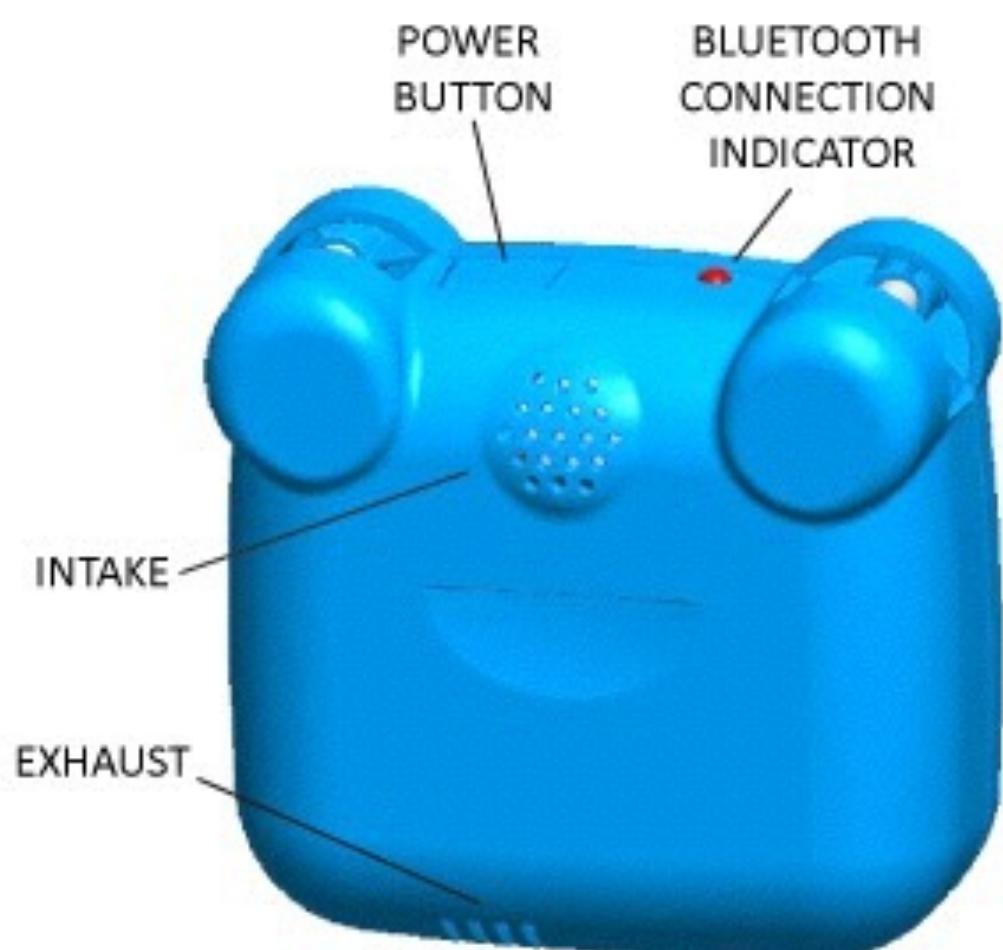


Urban Sensing Examples

MIT TRASH TRACK



AIRBEAM



HABITAT MAP

The screenshot shows the homepage of the HabitatMap website. At the top, there is a navigation bar with links: Home, About, Maps, Forums, Profiles, Blog, and Donate. To the right of the navigation bar, there are links for Log In, Create a Profile, and Contact Us. A large green starburst graphic in the center says 'GET YOUR AIRBEAM ON KICKSTARTER!' with a Kickstarer logo. Below the starburst, there are three main sections: 'Be Aware of Your Environment' (yellow background), 'Flag Things That Impact Quality of Life' (green background), and 'Share' (yellow background). To the right of these sections, there is a 'Recent Activity' sidebar listing recent user profiles and map uploads. At the bottom, there are three 'Featured Maps' cards: 'Drip, Drop, the Water Don't Stop' (New York City water system map), 'Creek Speak: Voices from Newtown Creek' (oral history project map), and 'Where Does My Toilet Flush To?' (sewage overflow map).

Home | About | Maps | Forums | Profiles | Blog | Donate

Log In • Create a Profile • Contact Us

FARMER'S MARKET

GET YOUR AIRBEAM ON KICKSTARTER!

Recent Activity

- pmerriam started a profile
- steadyprocleaning1 started a profile
- AirBeam test map
- terry.gordon@nyumc.org started a profile
- tedsmithphd started a profile
- niestalk started a profile
- Las Condes
- Assaf96 started a profile
- HumbertoGainey started a profile
- Fort Greene Farmer's Market
- Michael King
- NYC Commercial Waste Transfer Stations

Be Aware of Your Environment

Look, Listen and Watch

Flag Things That Impact Quality of Life

Start a Profile, Add a Map Marker and Create Your Own Map

Start a Thread or Join a Discussion

Share

Share a Marker or Map with Friends, Fellow Activists, Colleagues, or Classmates

Bring HabitatMap Home

Add a Map to your Website or Blog

Donate

Become a Friend and Support Our Quest for Sustainable Cities

Drip, Drop, the Water Don't Stop

This is the Green School's map of the New York City water system. The students used HabitatMap's "Go With the Flow" toolkit to master maps based research methods and apply them to uncover the workings of New York City's water storage, filtration, delivery, and disposal infrastructures. They learned that the water system in place today has been shaped as much by social forces - people's habits, needs, and demands - as it has been by people's labor and the physics of water itself.

Creek Speak: Voices from Newtown Creek

Creek Speak is an oral history project that uses HabitatMaps to present the stories of people and places near Newtown Creek. To listen to peoples stories or read about some of the places they mention simply click on a marker. The Creek Speak Project is not intended to prove causality between the environmental burdens in Newtown Creek neighborhoods and public health concerns. Rather, its purpose is to highlight and document the experiential knowledge of individuals who are inside narrators of day-to-day life in these communities.

Where Does My Toilet Flush To?

Every day, nine million New Yorkers discharge 1.5 billion gallons of liquid waste into their sewer system. Underground and out of sight their urine, feces, and food scraps combine with litter and pollution from the street. This nasty brew then navigates 6,000 miles of pipe towards two possible futures: decontamination at one of 14 treatment plants or discharge into New York Harbor via one of 494 sewer overflow outfalls. A sewage overflow can be triggered by as little as a tenth of an inch of rain, which essentially means that almost every time it rains, your toilet flushes directly into New York Harbor.

Bridge Cam



[Watch Video](#)



dontflush.me

Leif Percifield



SAFE TO FLUSH SAFE TO FLUSH SAFE TO FLUSH SAFE TO FLUSH SAFE TO FLUSH



Open source technology for citizens' political participation in smarter cities

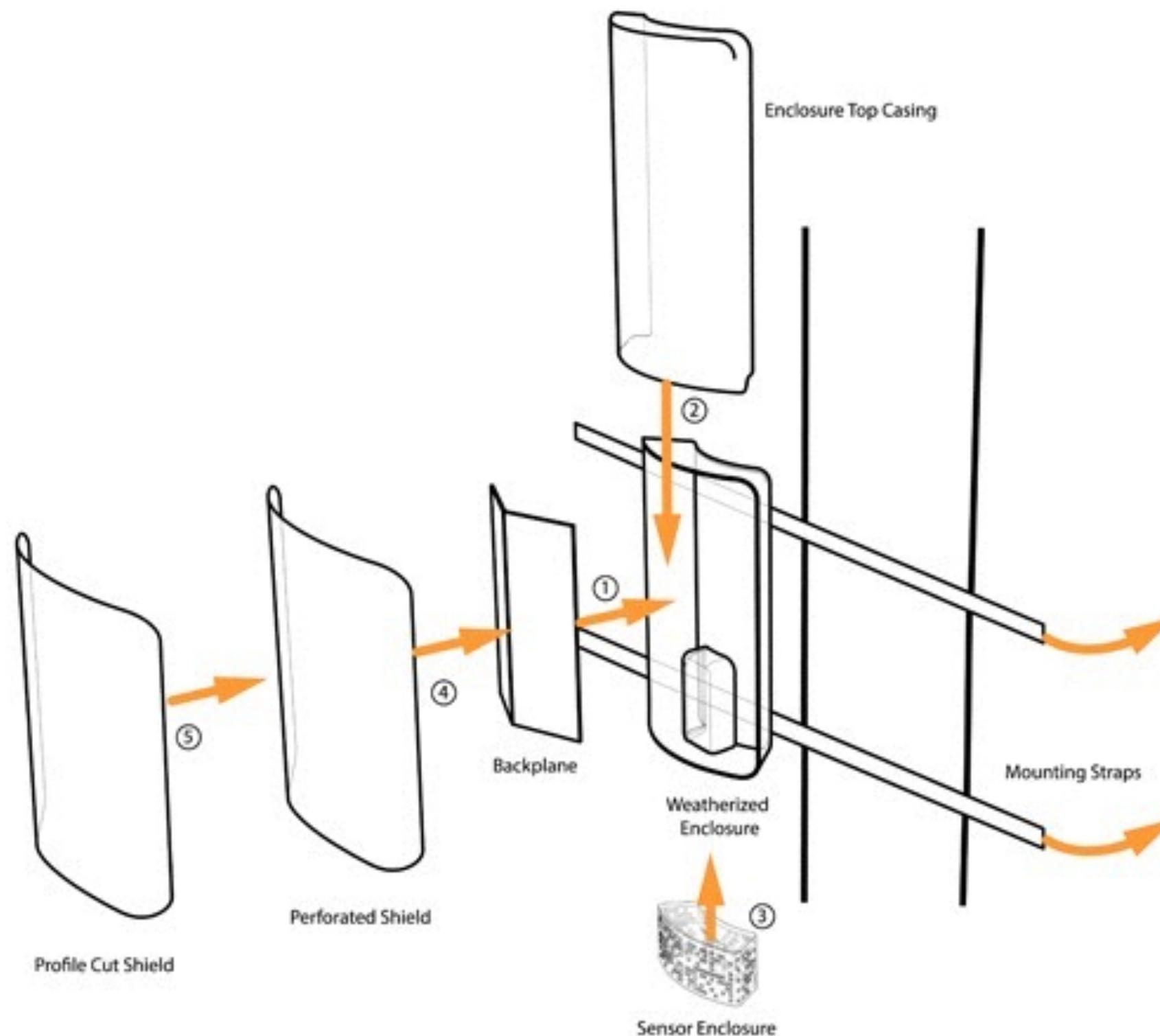
Based on geolocation, Internet of Things, Open Source hardware and software for data collection and sharing

SIGN IN

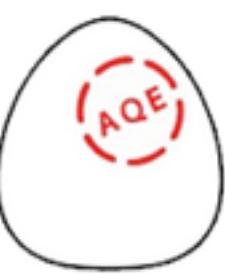
REGISTER

SMART CITIZEN

Array of Things: Chicago



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

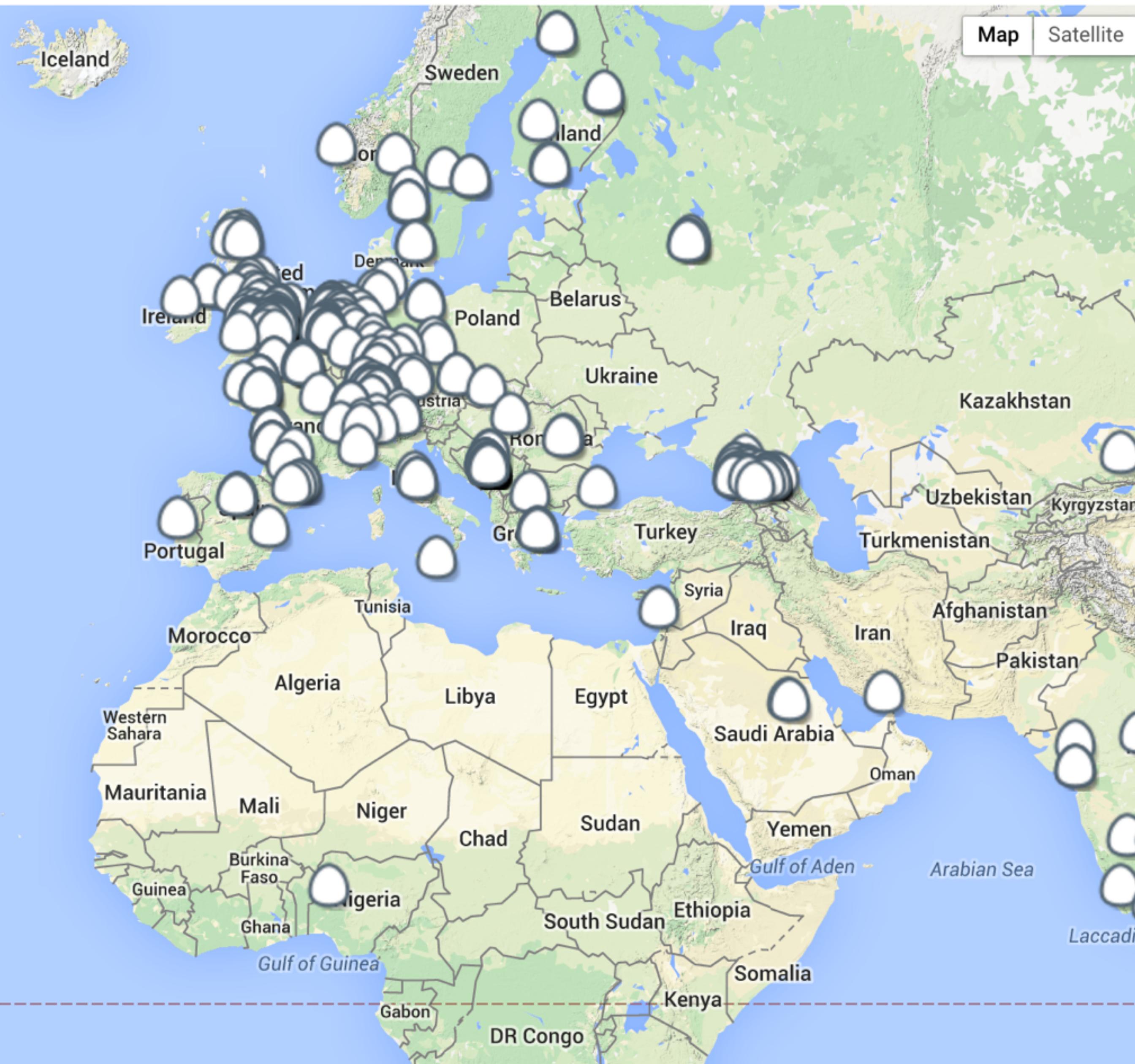
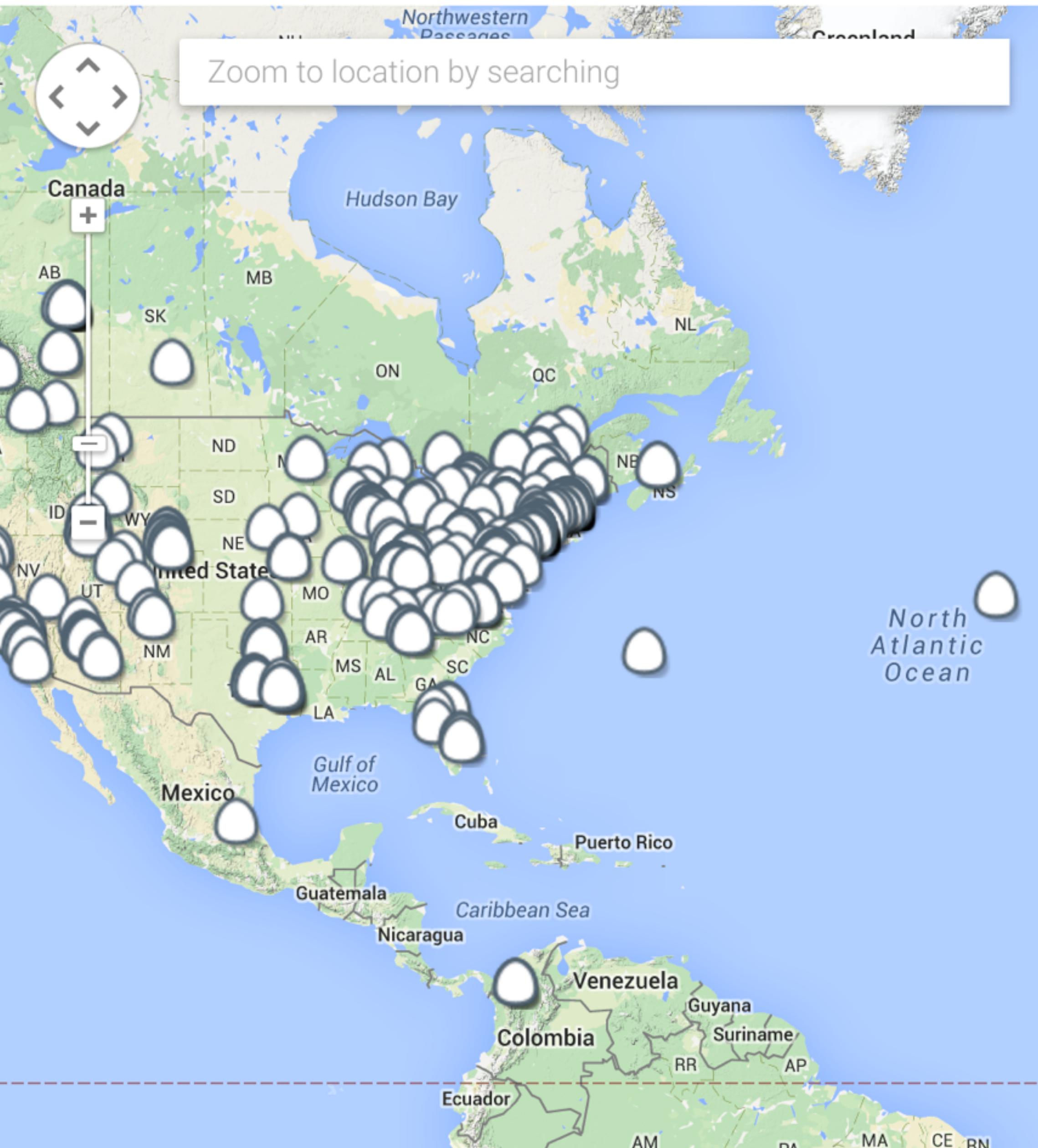


Air Quality Egg

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

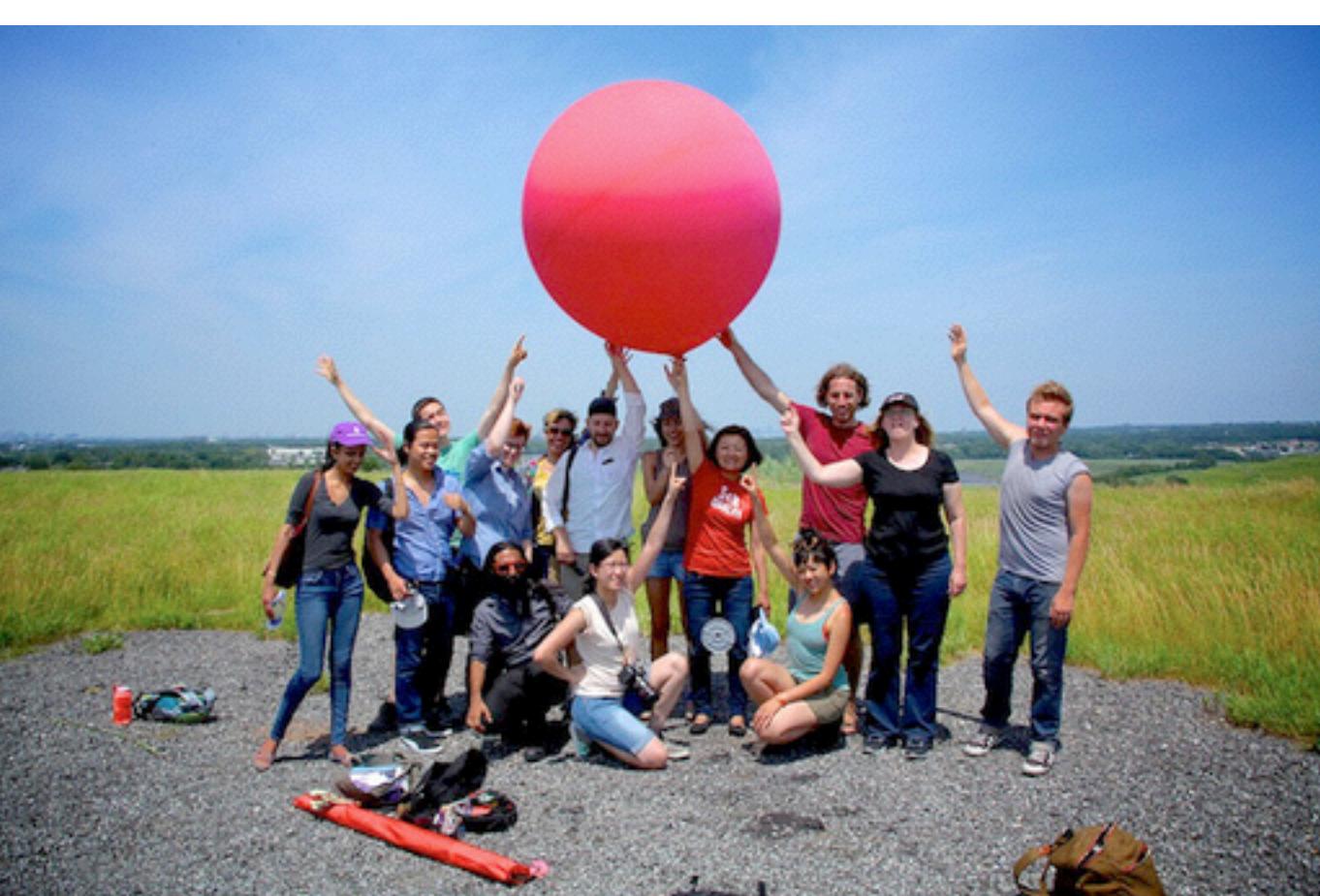
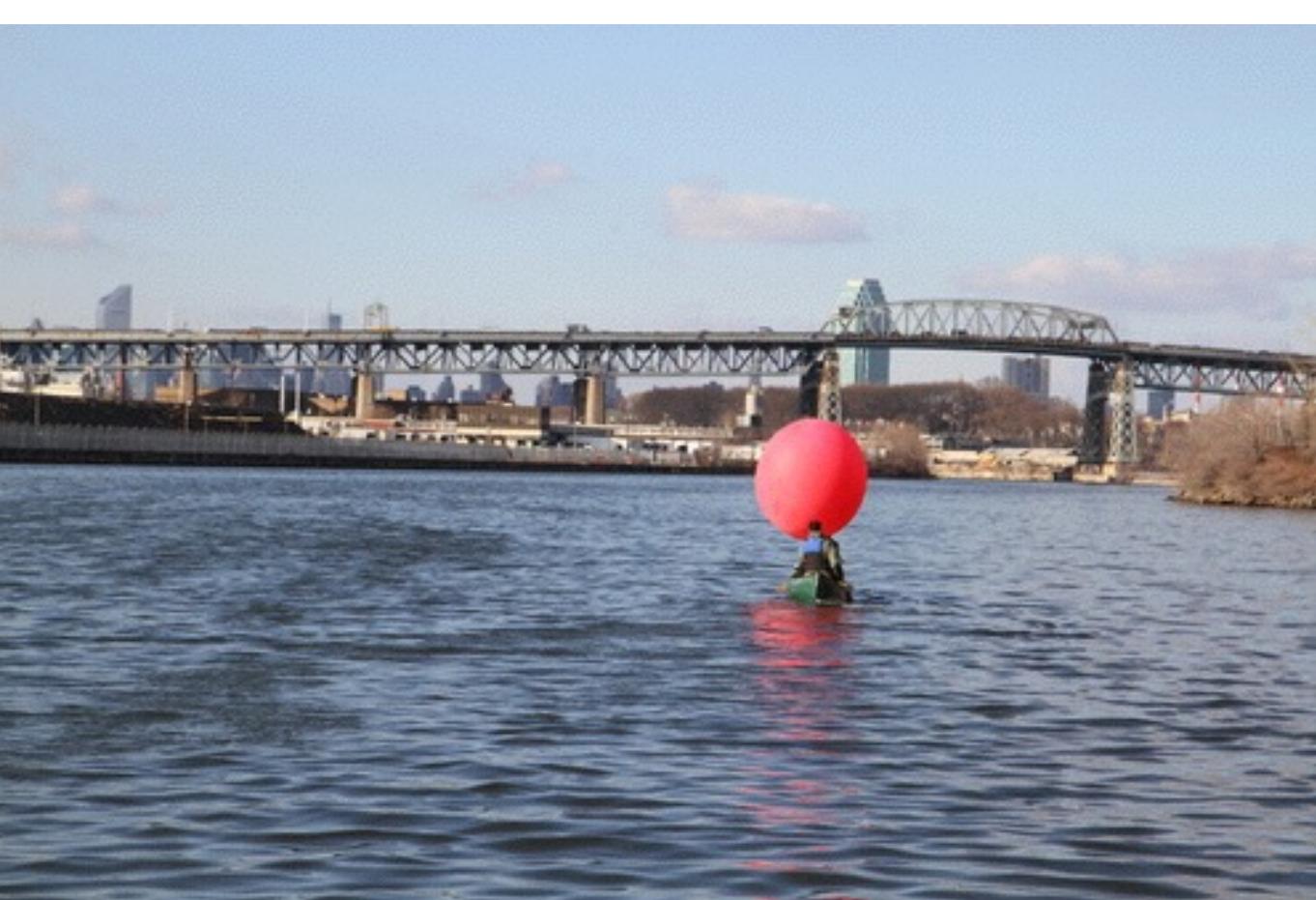
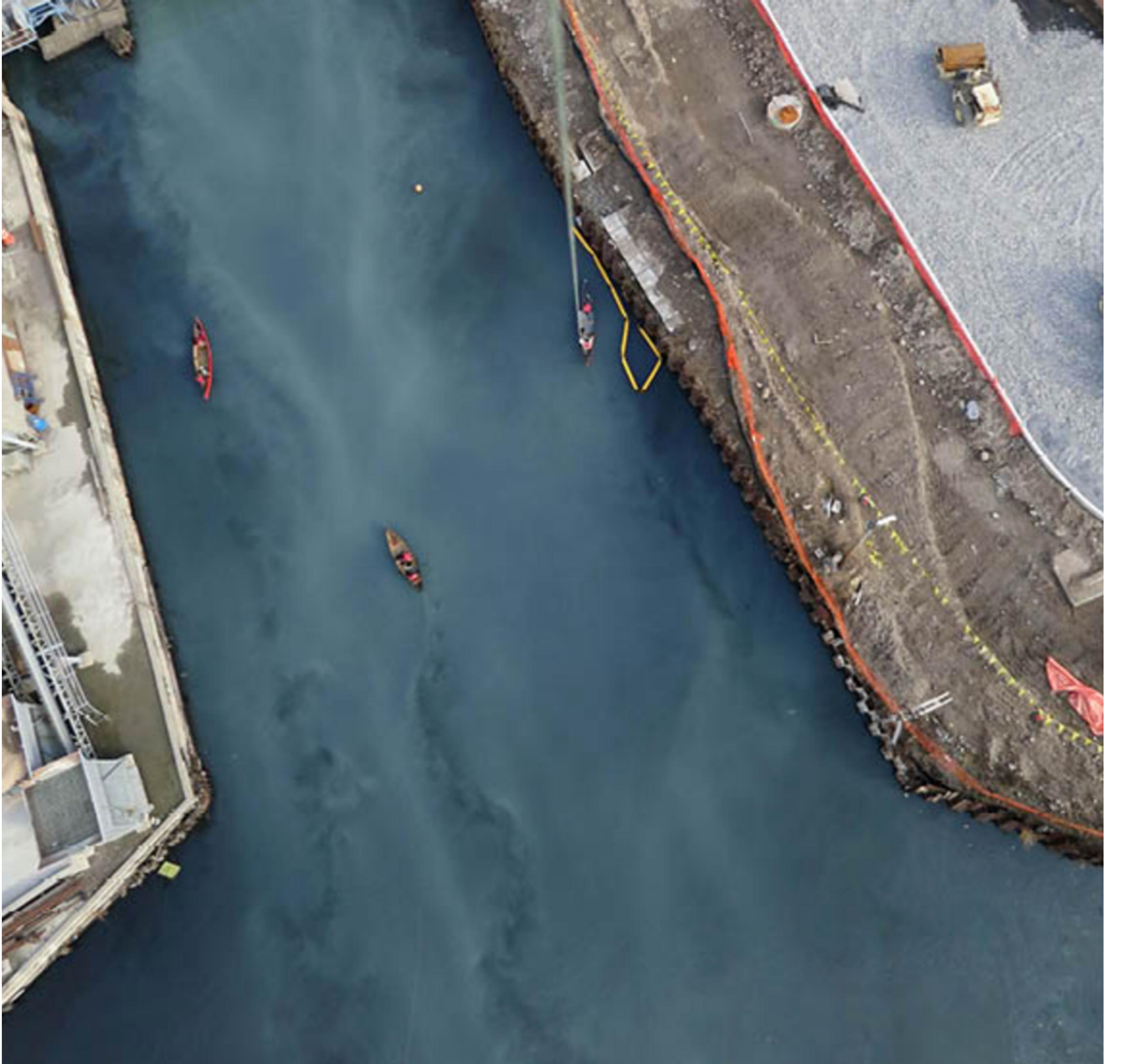


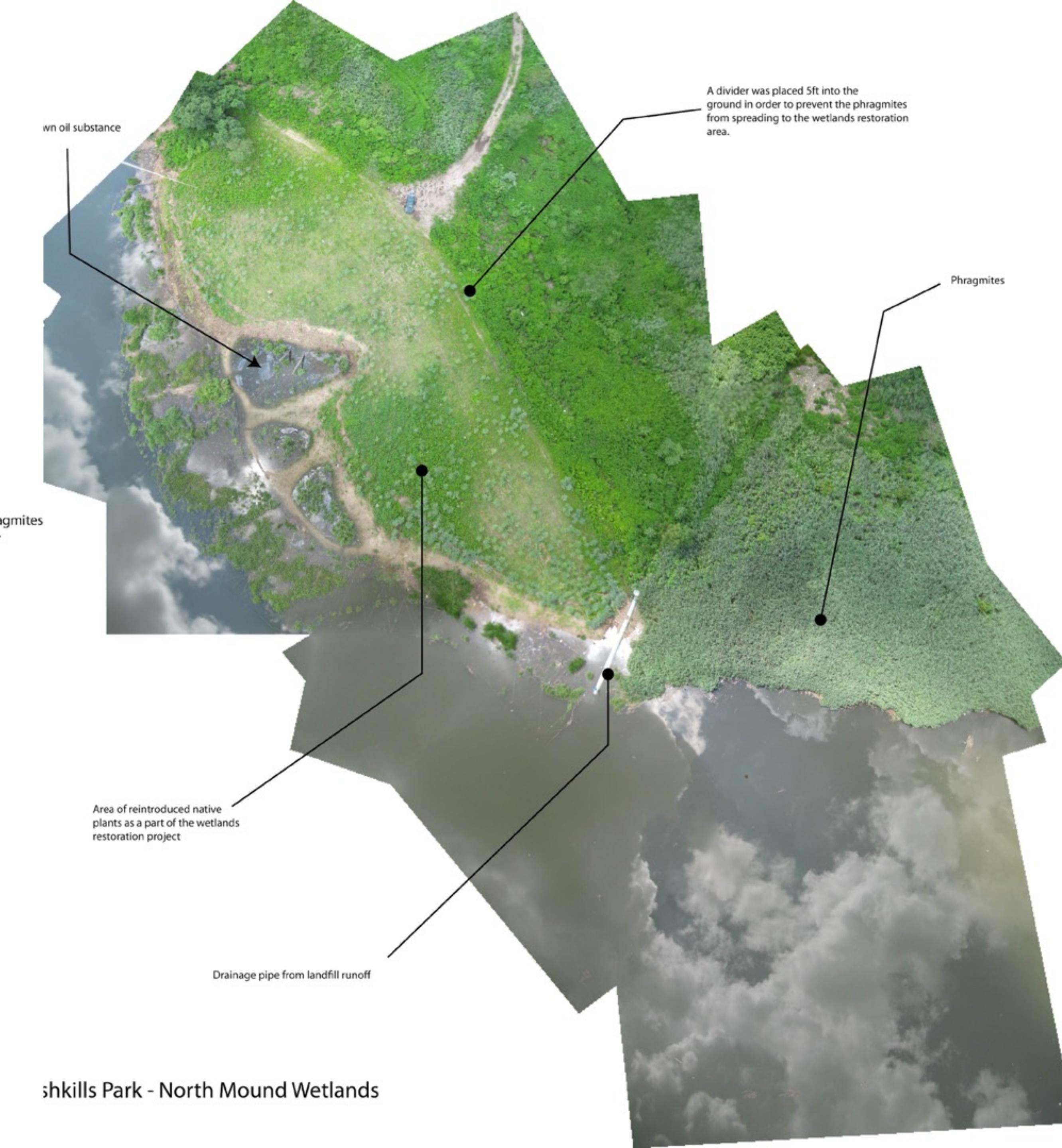
Part II - Low-cost Remote Sensing

Balloon Mapping



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





Freshkills Park - North Mound

Freshkills Park - North Mound Wetlands



Landfills + Satellites

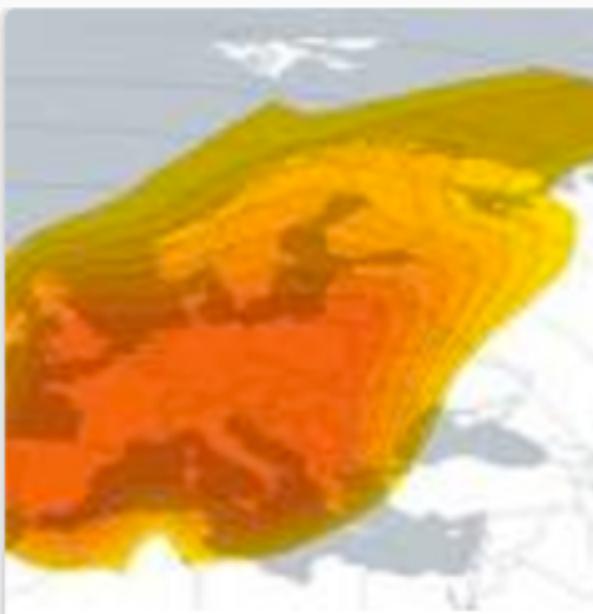




INFORMACIÓN DE LA CONFERENCIA

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?



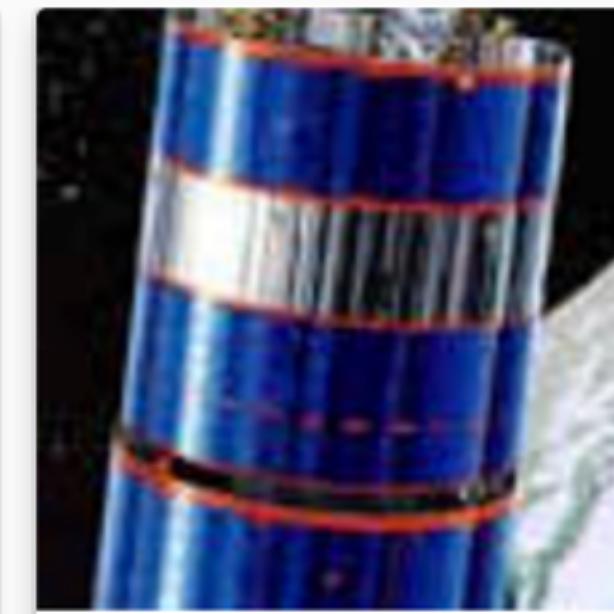
Eutelsat 5
West A



Yamal 202



Eutelsat 33C



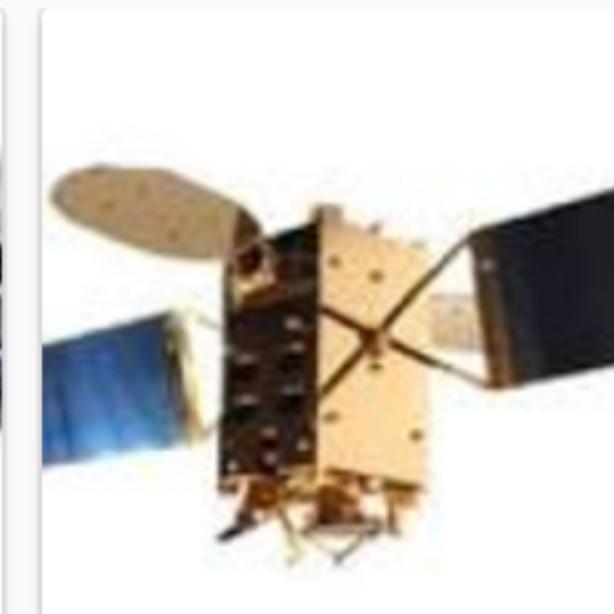
Eutelsat 31A



Cartosat-2



Intelsat 28



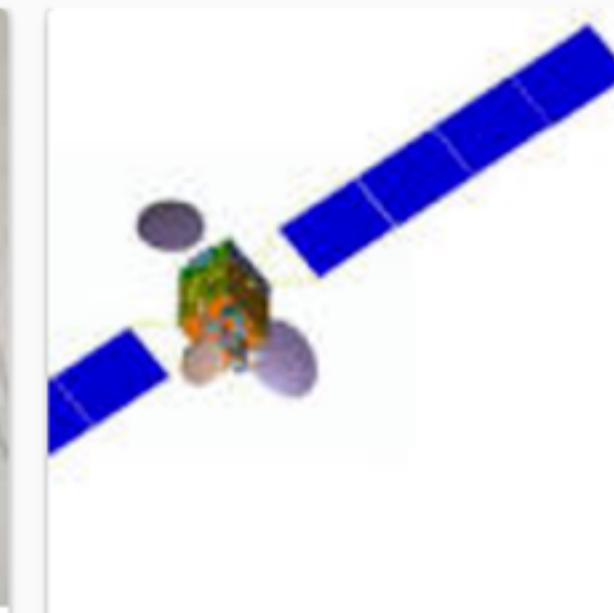
Venesat-1



GSAT-15



GOES 14



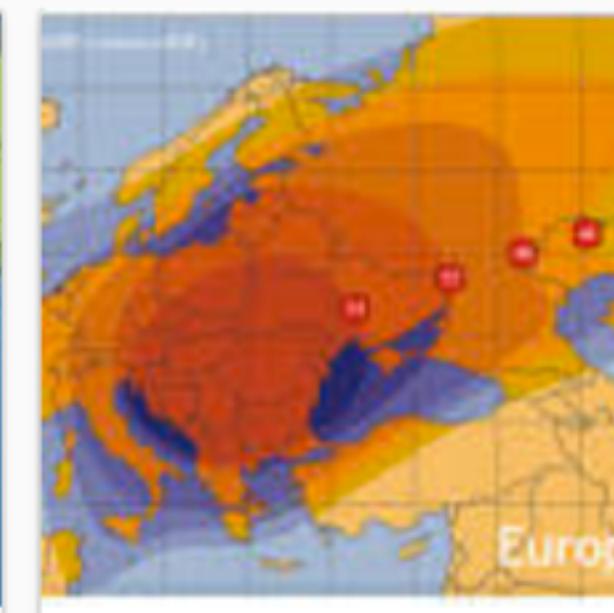
NigComSat-1



MEASAT-3



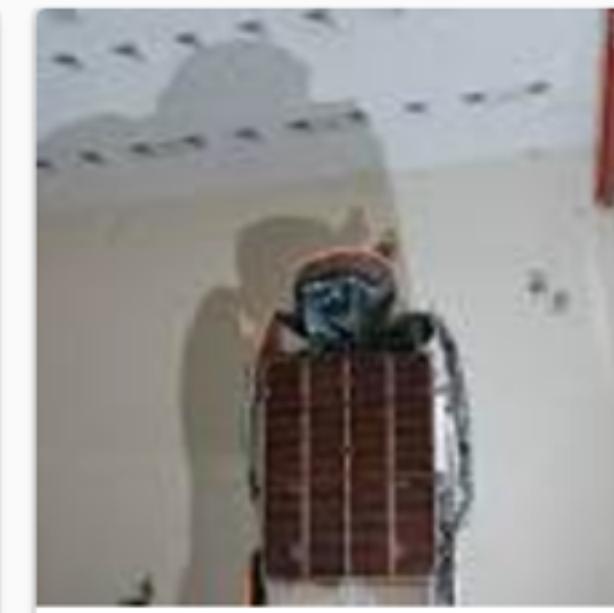
Intelsat 20



Amos-2



NSS-7



Intelsat 14



Chollian



GSAT-3



GSAT-10



Cartosat-1



Aqua



ACRIMSAT



Telstar 12



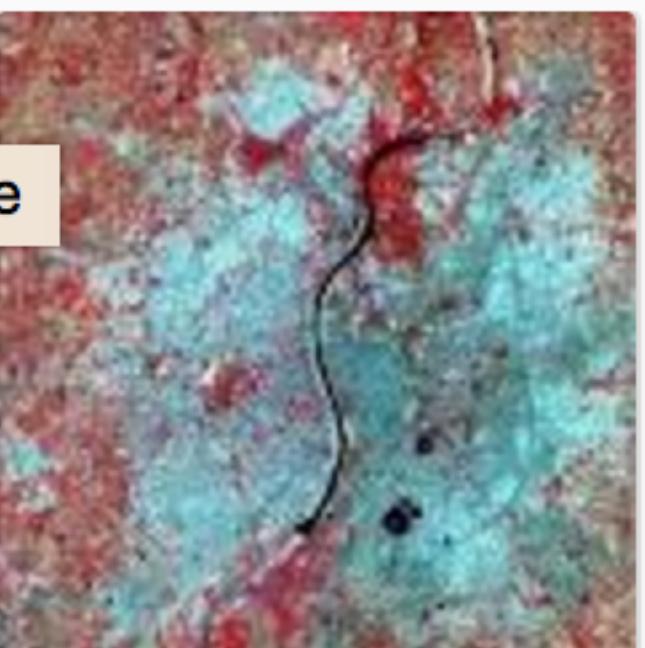
GSAT-14



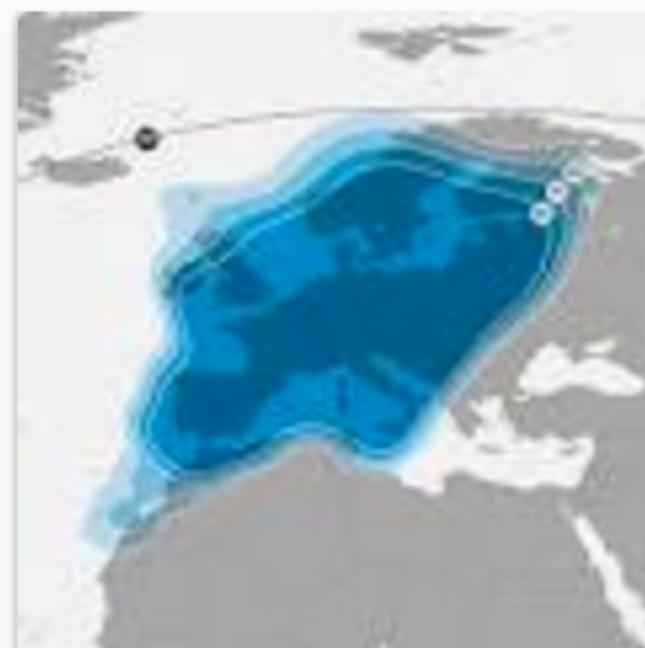
Intelsat 29e



GSAT-15



Resourcesat-1



Astra 2C



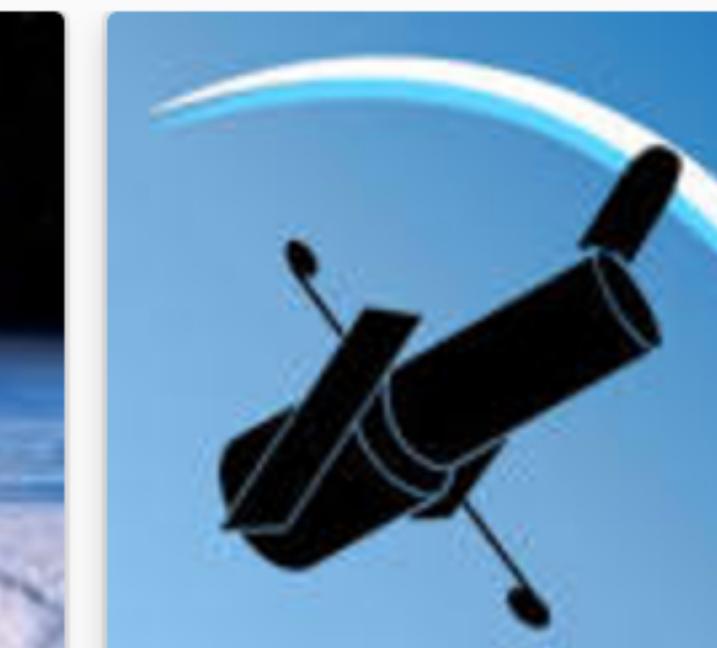
ARSAT-1



Sputnik 1



CloudSat



Hubble Space
Telescope



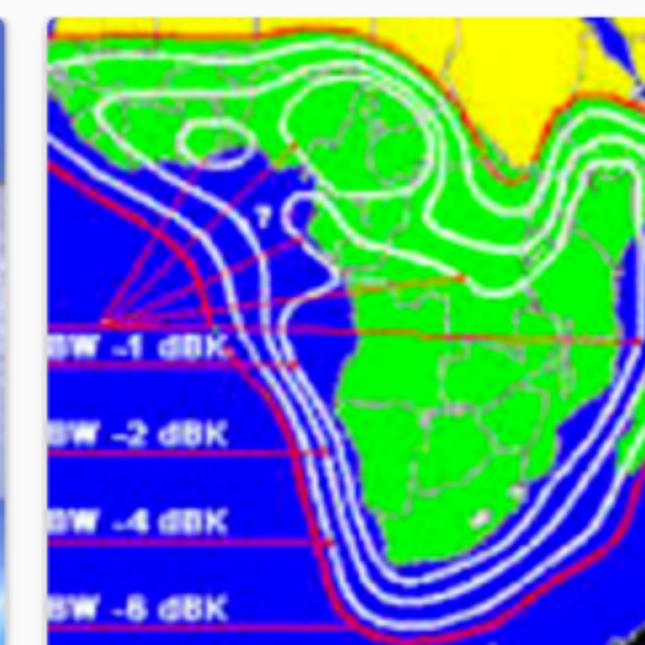
INSAT-4CR



Astra 4A



Kalpana-1



Eutelsat W3A



INSAT-3C



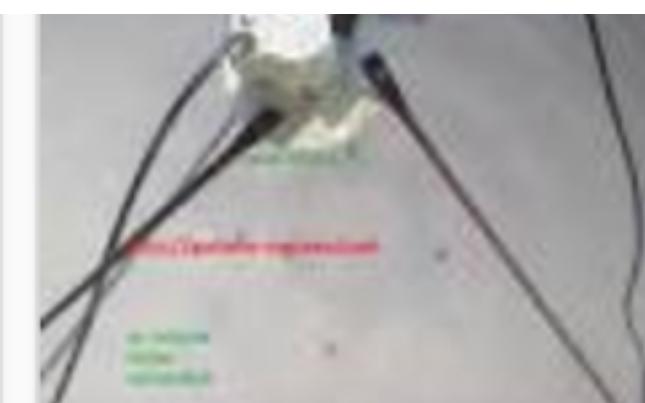
CALIPSO



Eutelsat 8
West C



Astra 3B



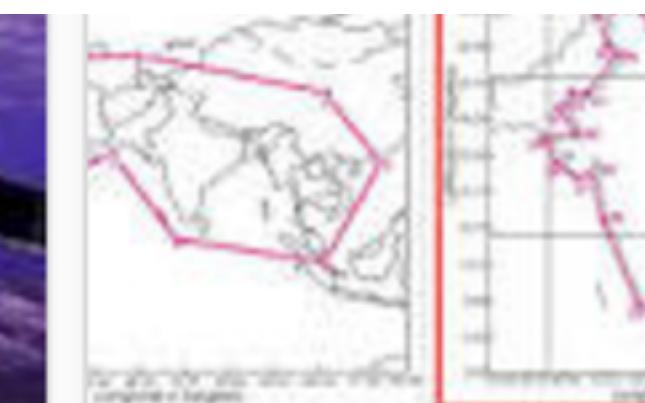
Paksat-1R



KazSat-1



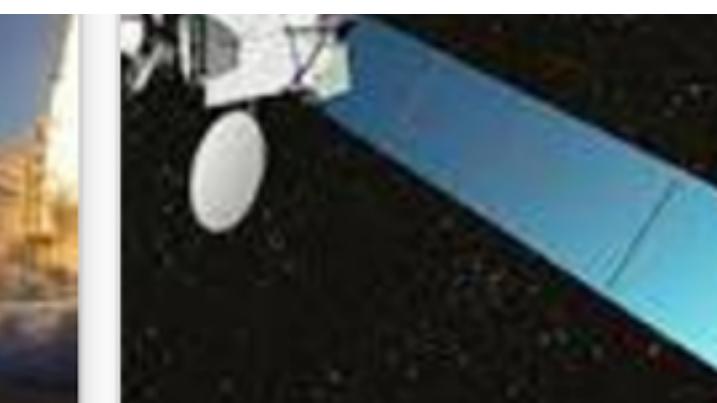
Advanced
Land
Observation ...



INSAT-4A



GSAT-7



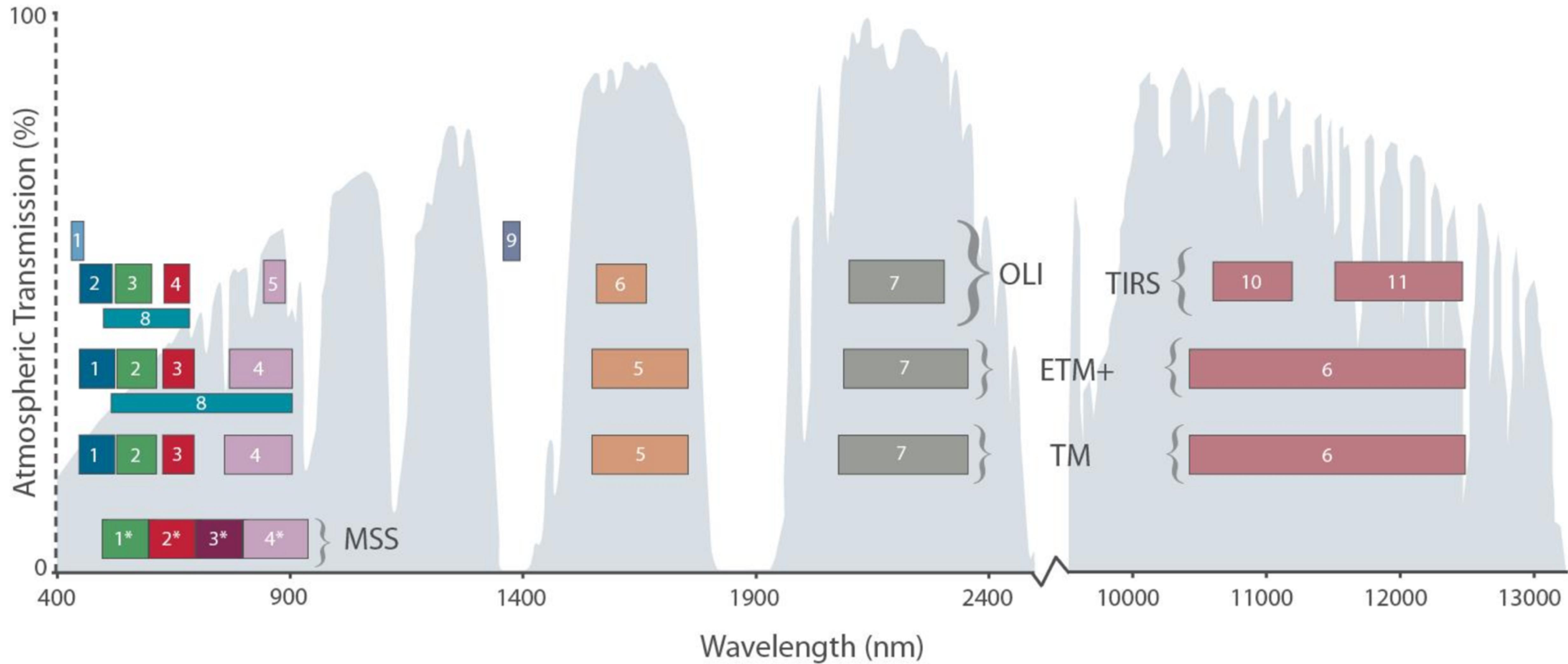
Intelsat 9

Landsat 8

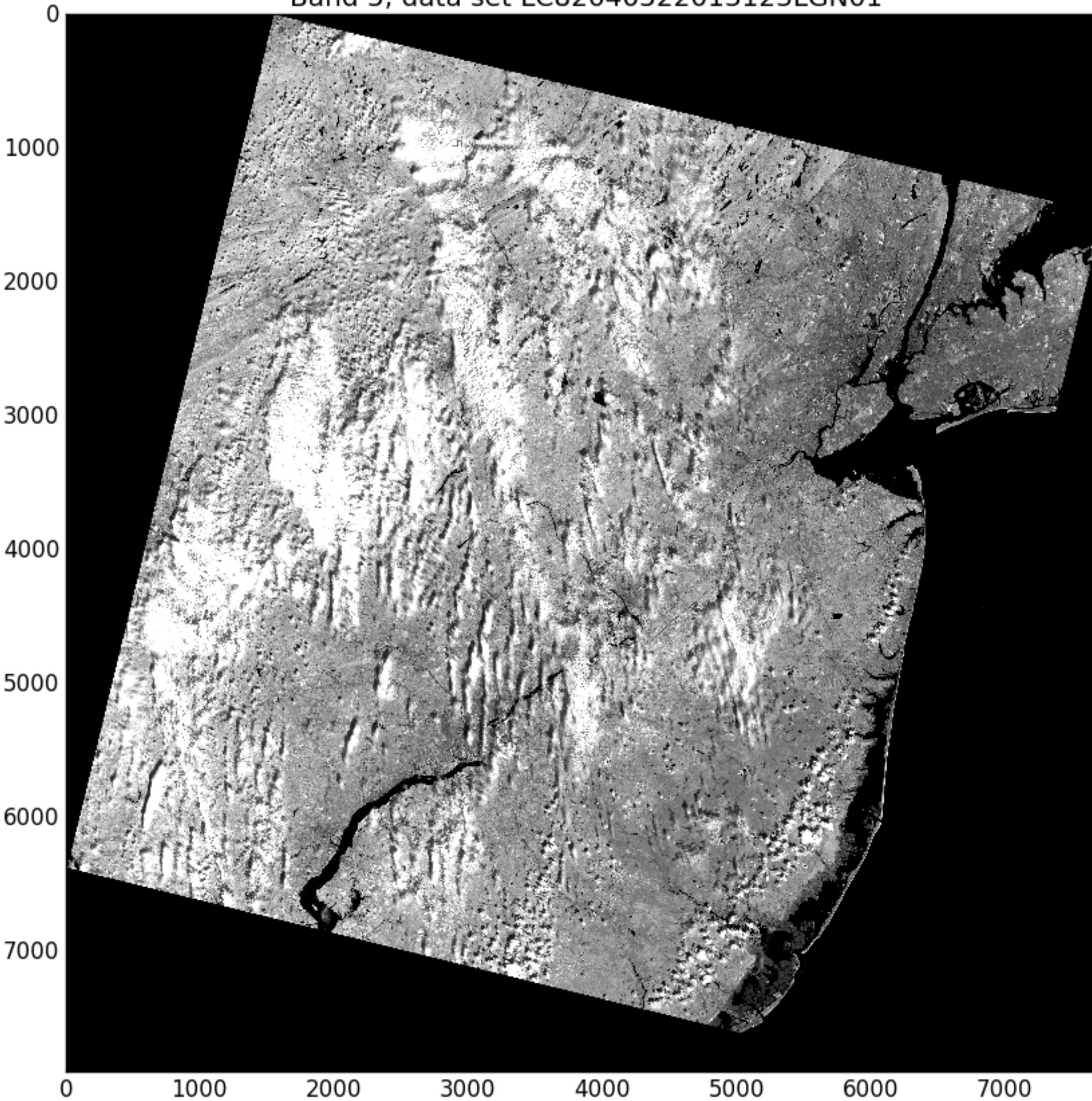
- Scene capture every 16 days
- Level 1 data is terrain corrected. Data is 16bit geotiff
- Data available from USGS Earth Explorer

	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 <small>same time</small>
Band 9	Cirrus	1360-1390nm	30m	Strong atmospheric absorption due to presence 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

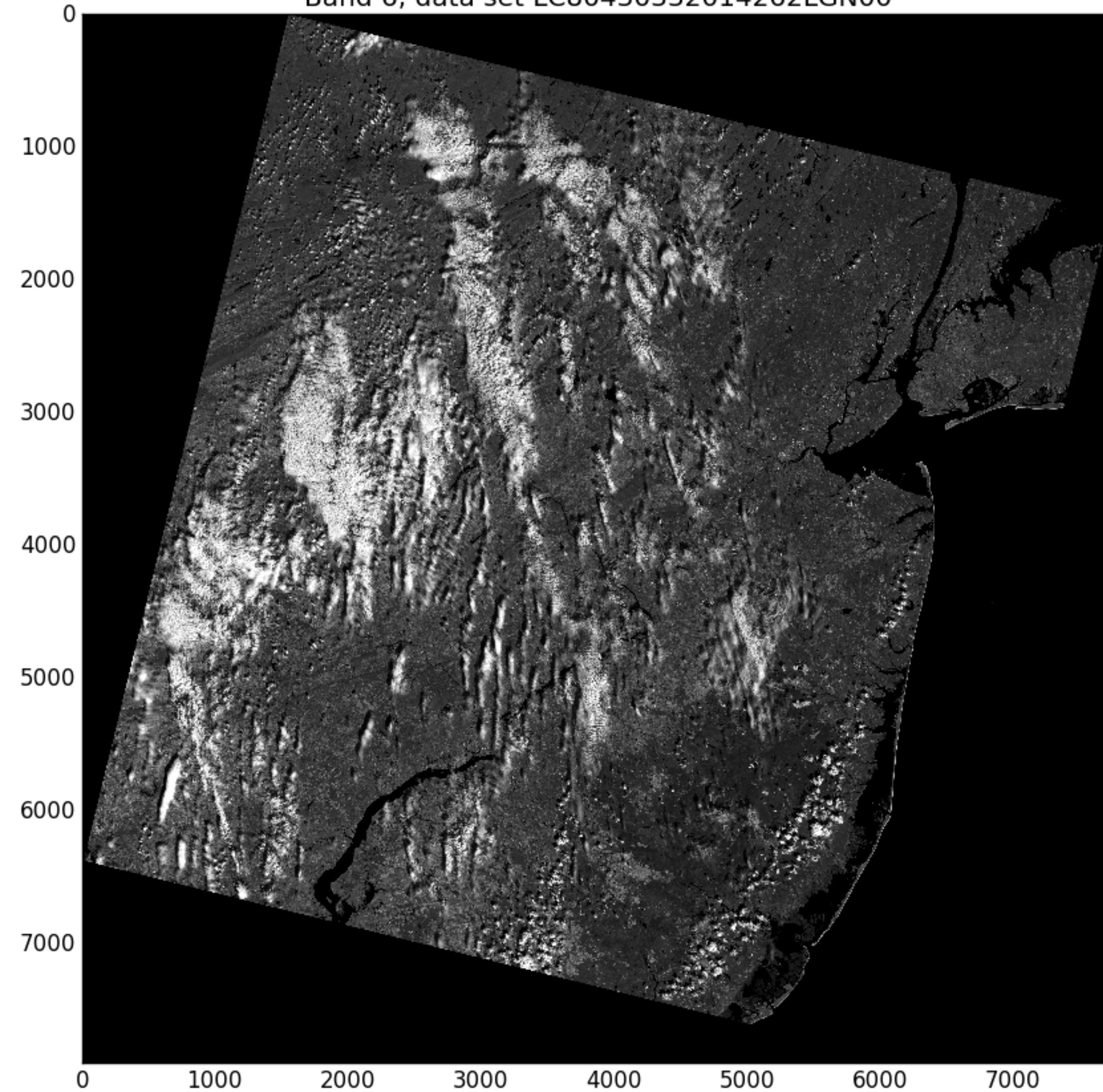
- https://github.com/nejohnson2/research-notes/blob/master/satellite_imager.md



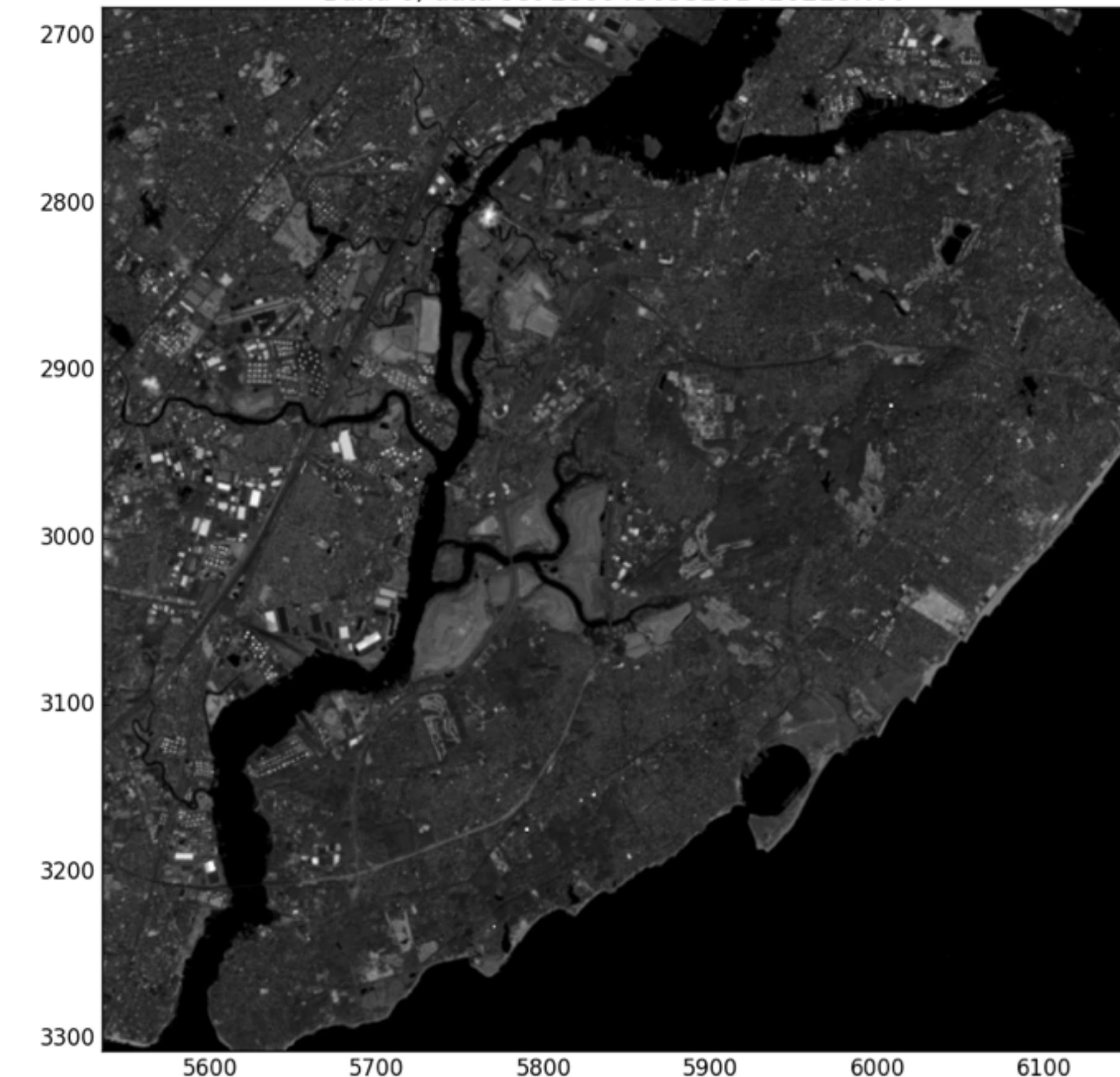
Band 5, data set LC82040522013123LGN01



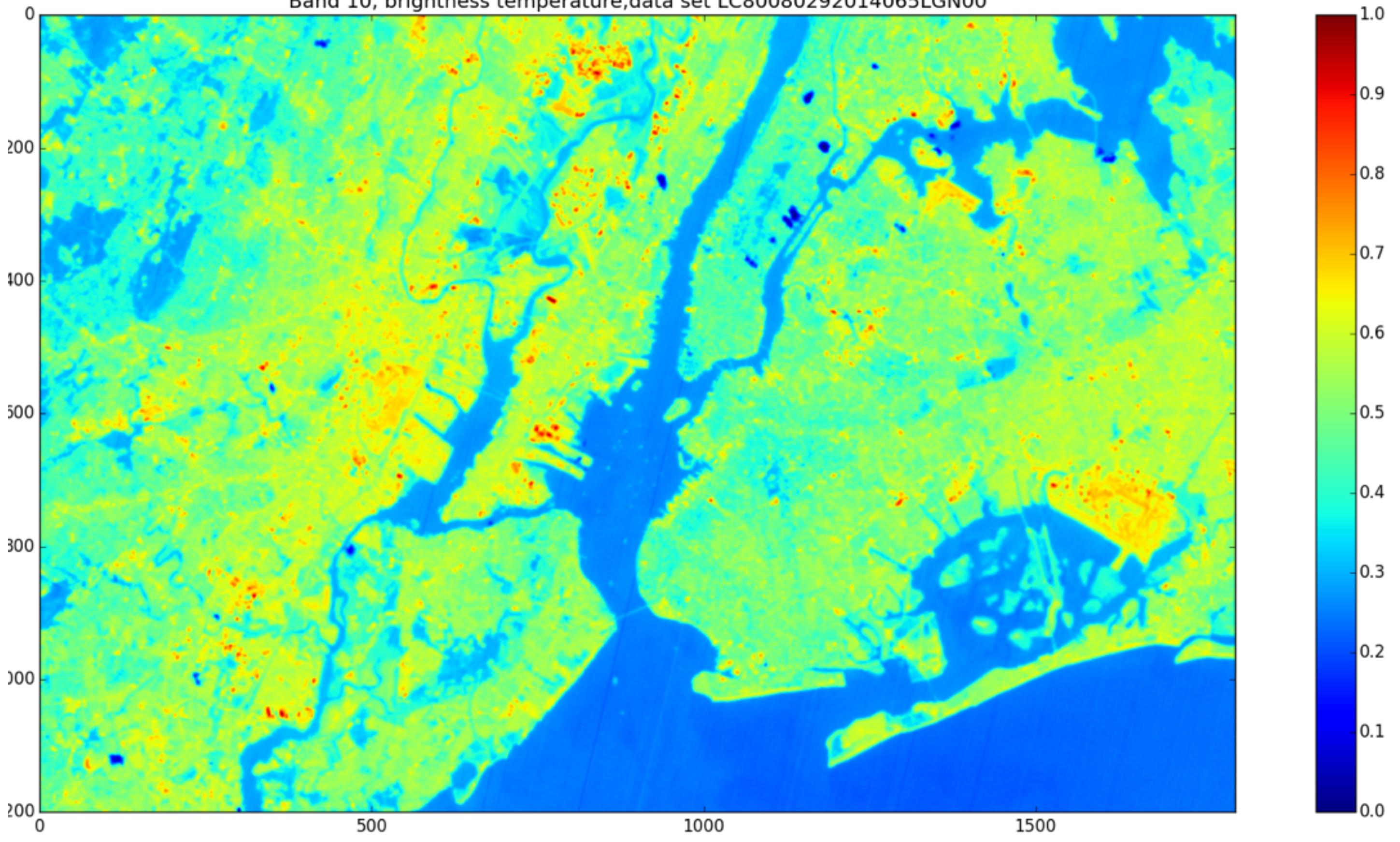
Band 6, data set LC80430332014262LGN00



Band 6, data set LC80430332014262LGN00



Band 10, brightness temperature,data set LC80080292014065LGN00



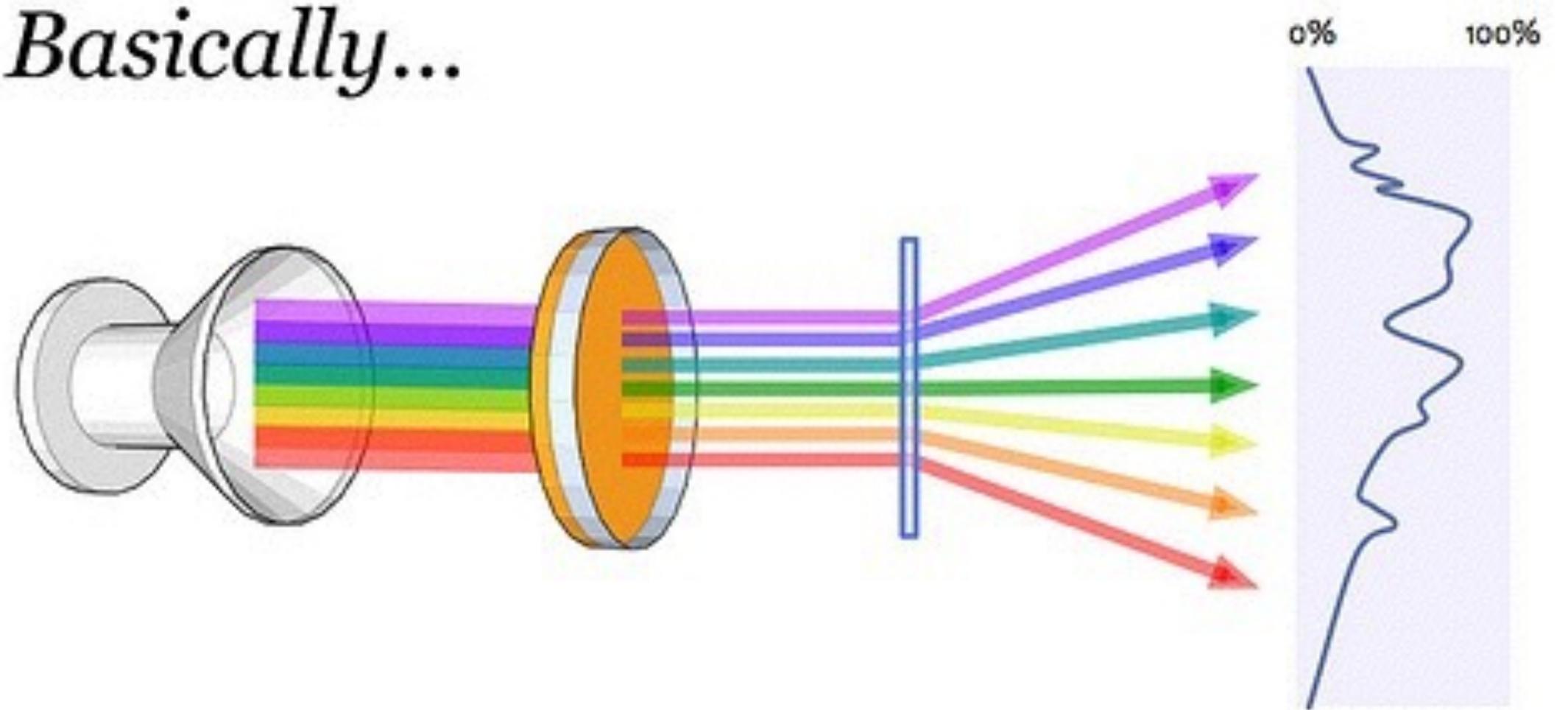
Part III - Hands on! Build and Calibrate

Spectrometer Workshop

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

What is spectrometry?

Basically...



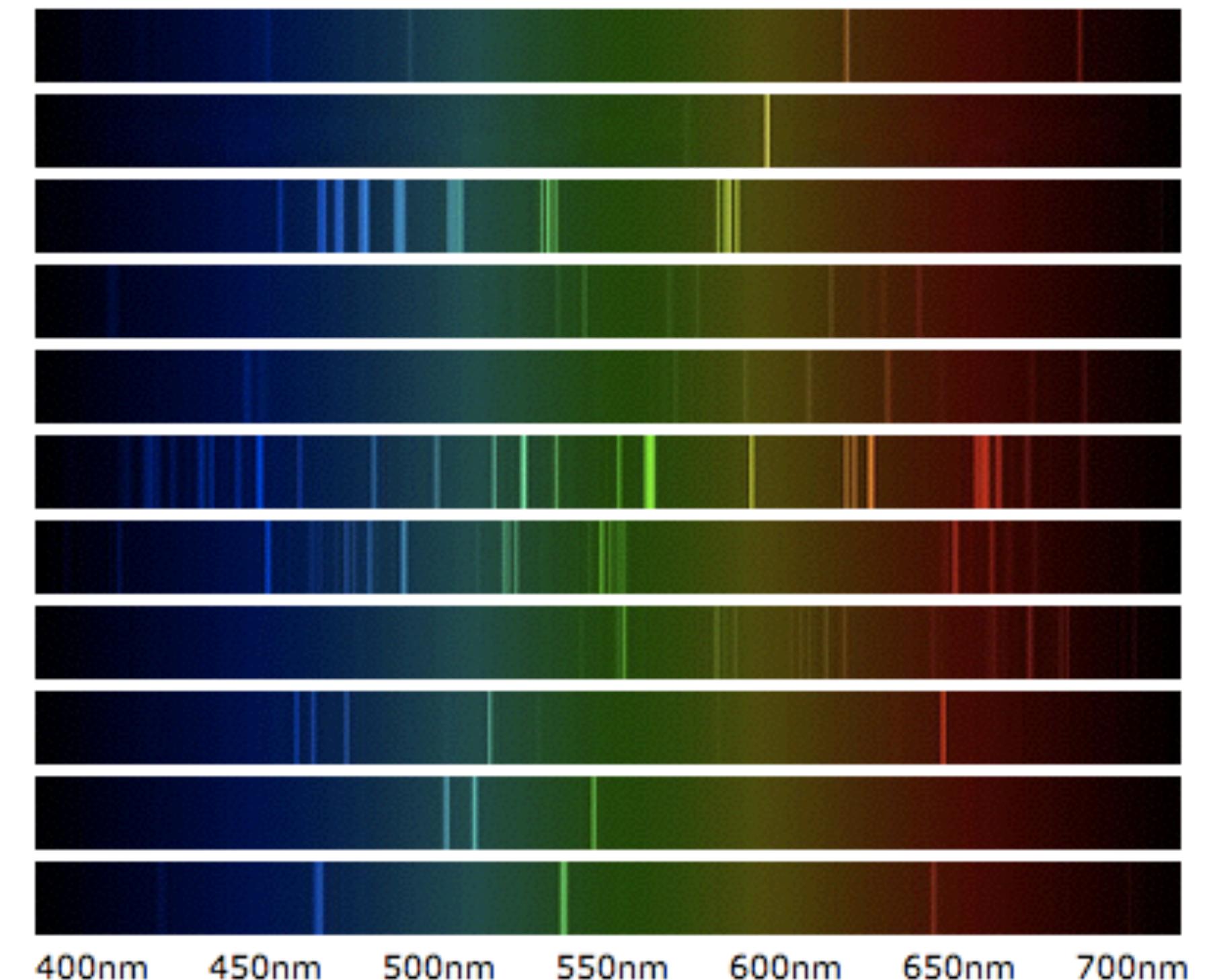
1. A broad-spectrum light (halogen, incandescent) is shone through a sample

2. Some colors are absorbed more than others depending on its composition

3. Diffraction grating splits light into colors so they can be measured separately

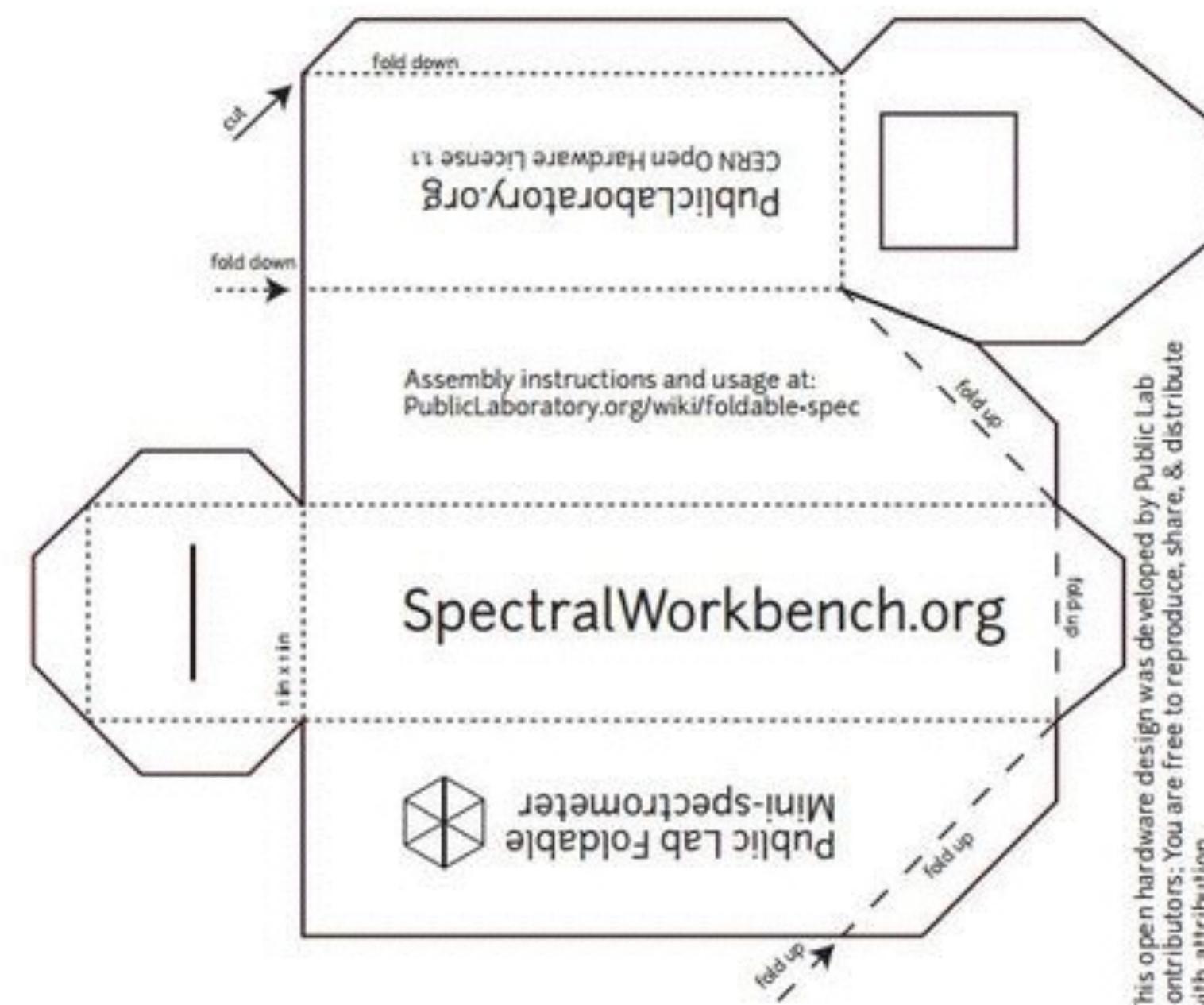
4. A webcam measures each color and graphs their intensities. This is compared to known samples.

lithium
sodium
potassium
rubidium
cesium
calcium
strontium
barium
zinc
arsenic
selenium
wavelength



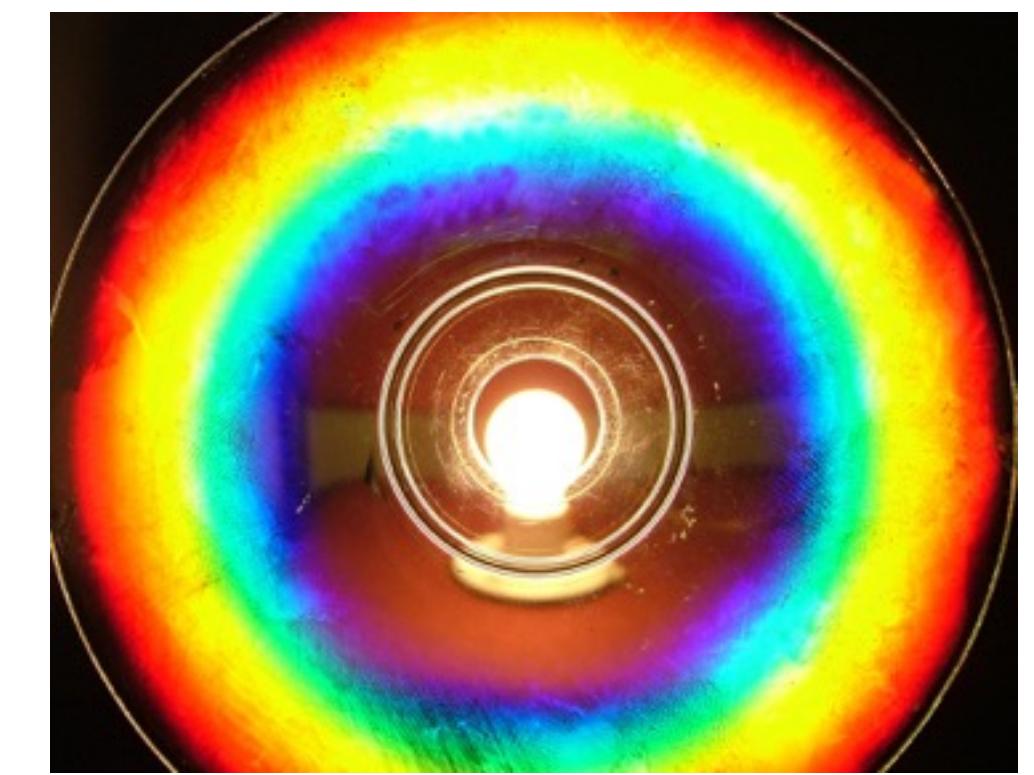
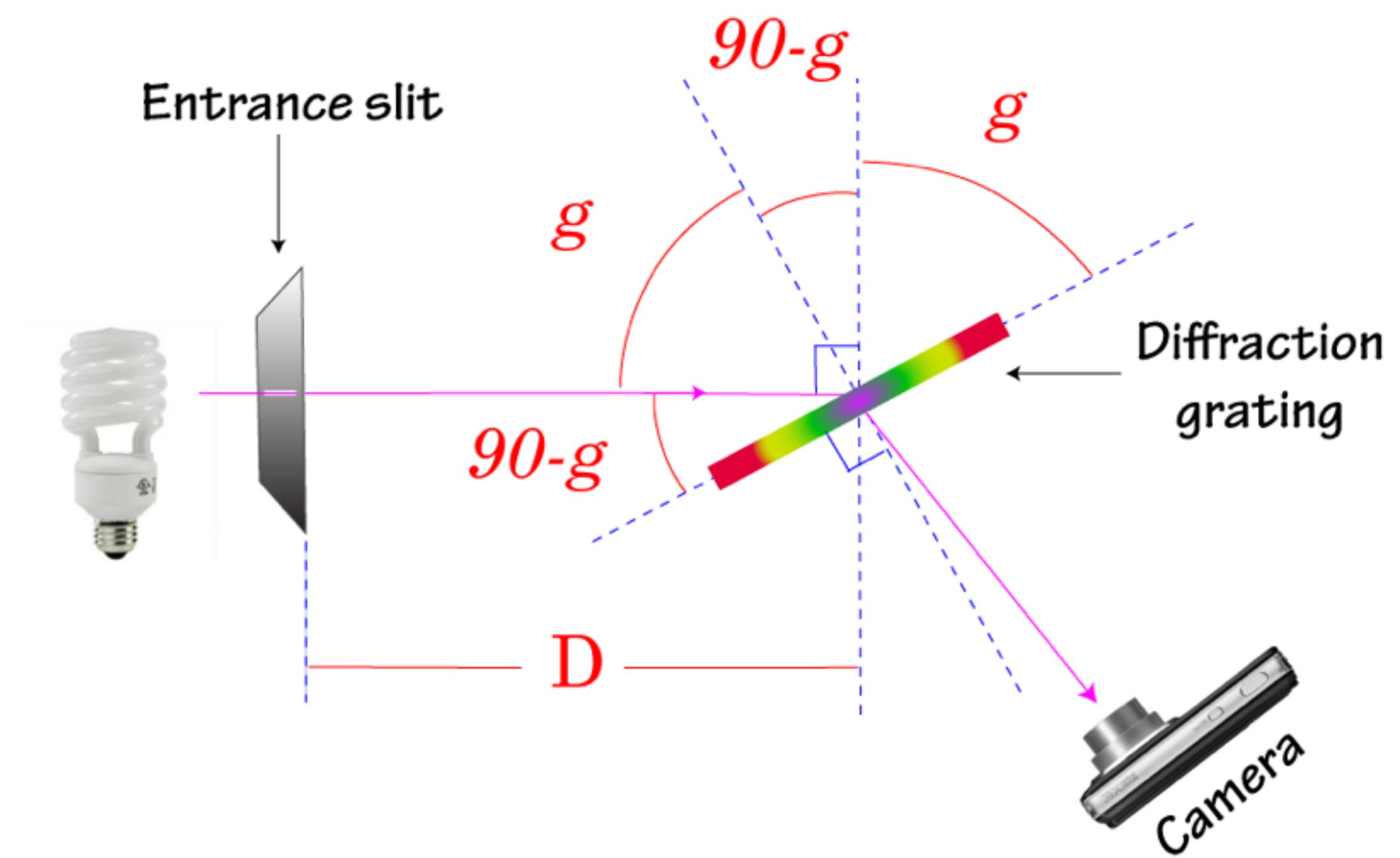
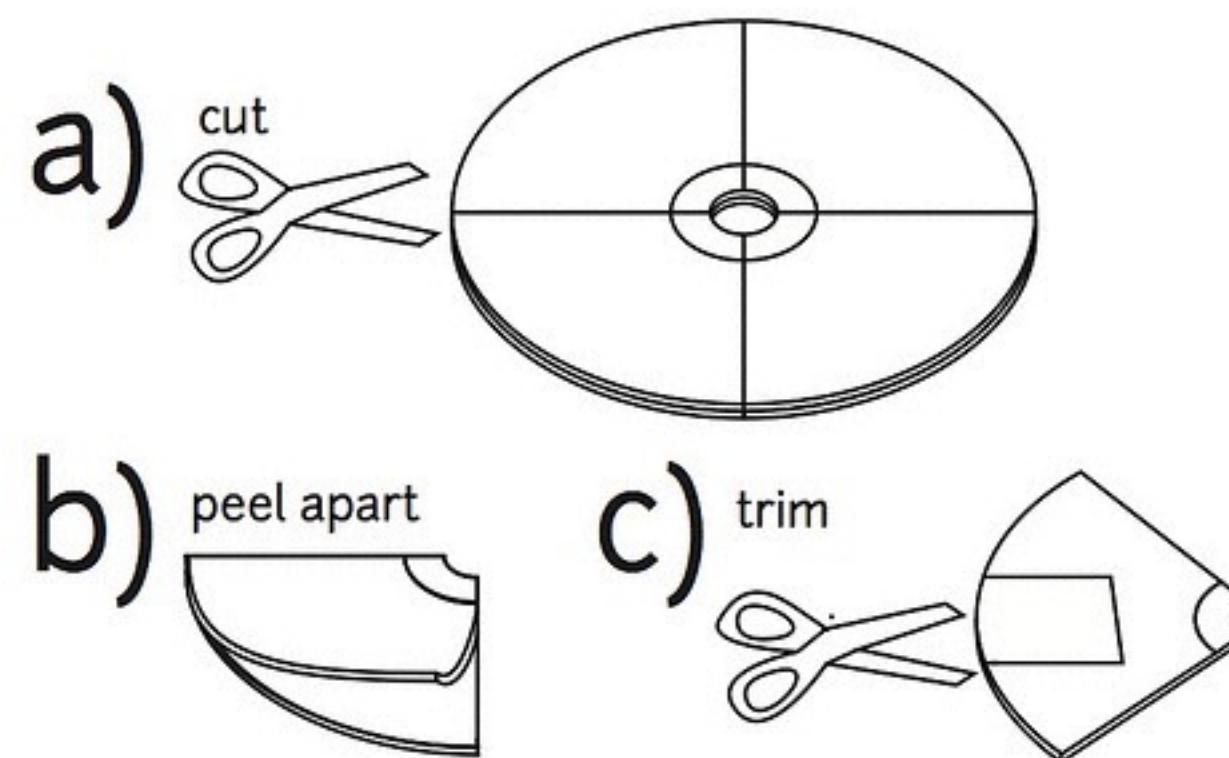
Build Chamber

- 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



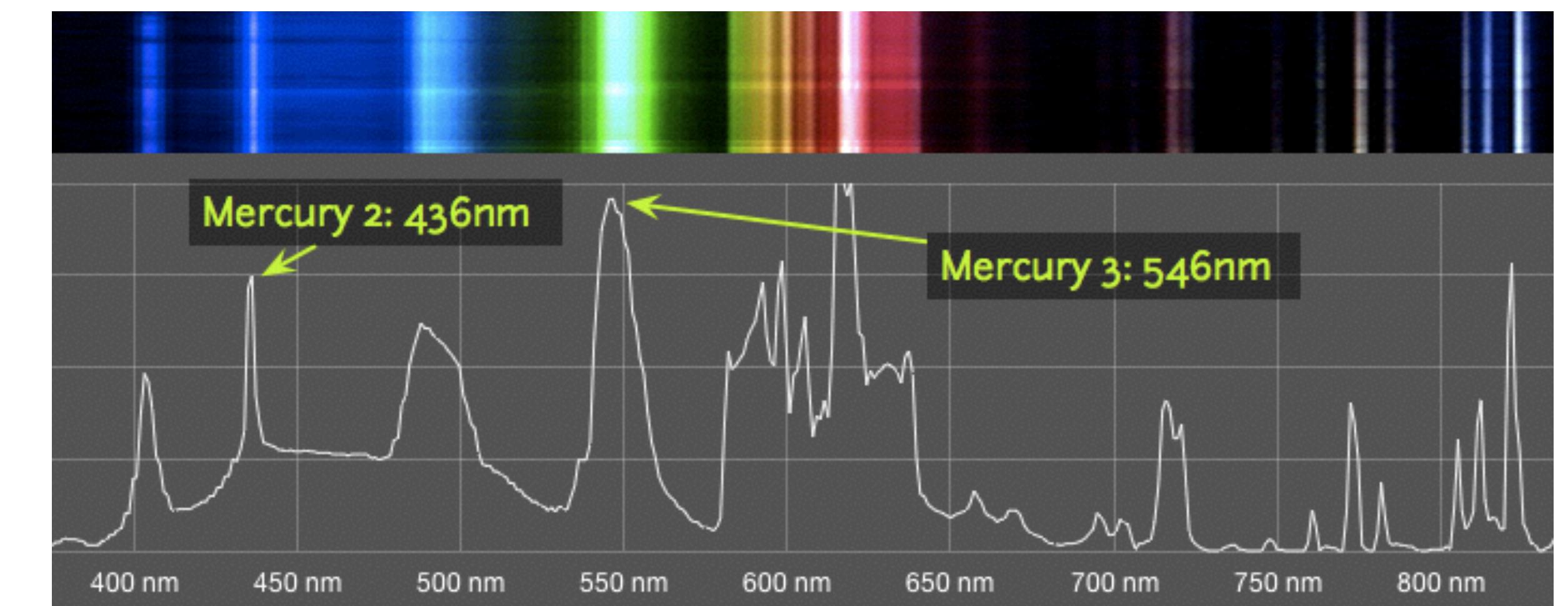
Prepare Diffraction Grating

- 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



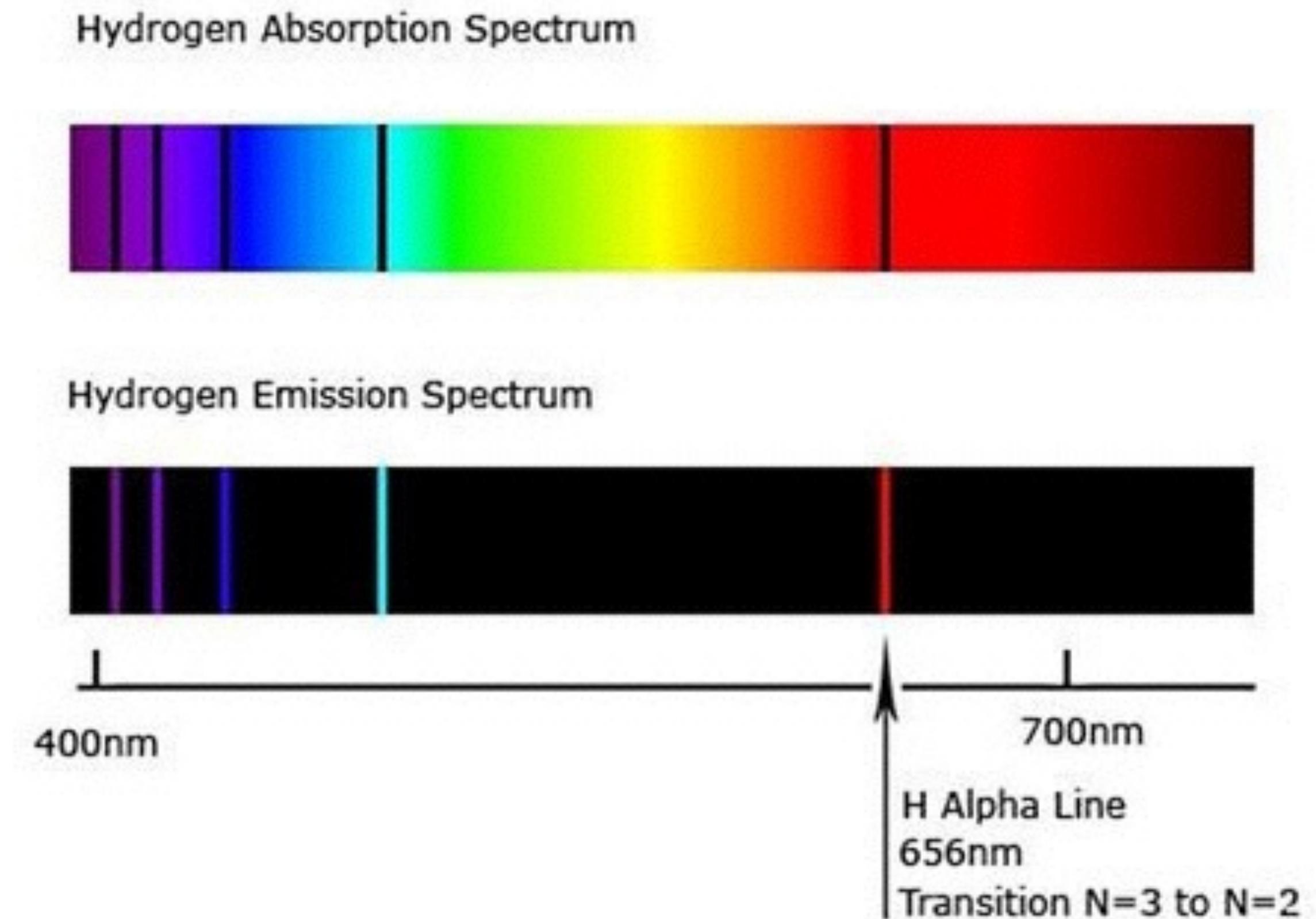
Calibration

- 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

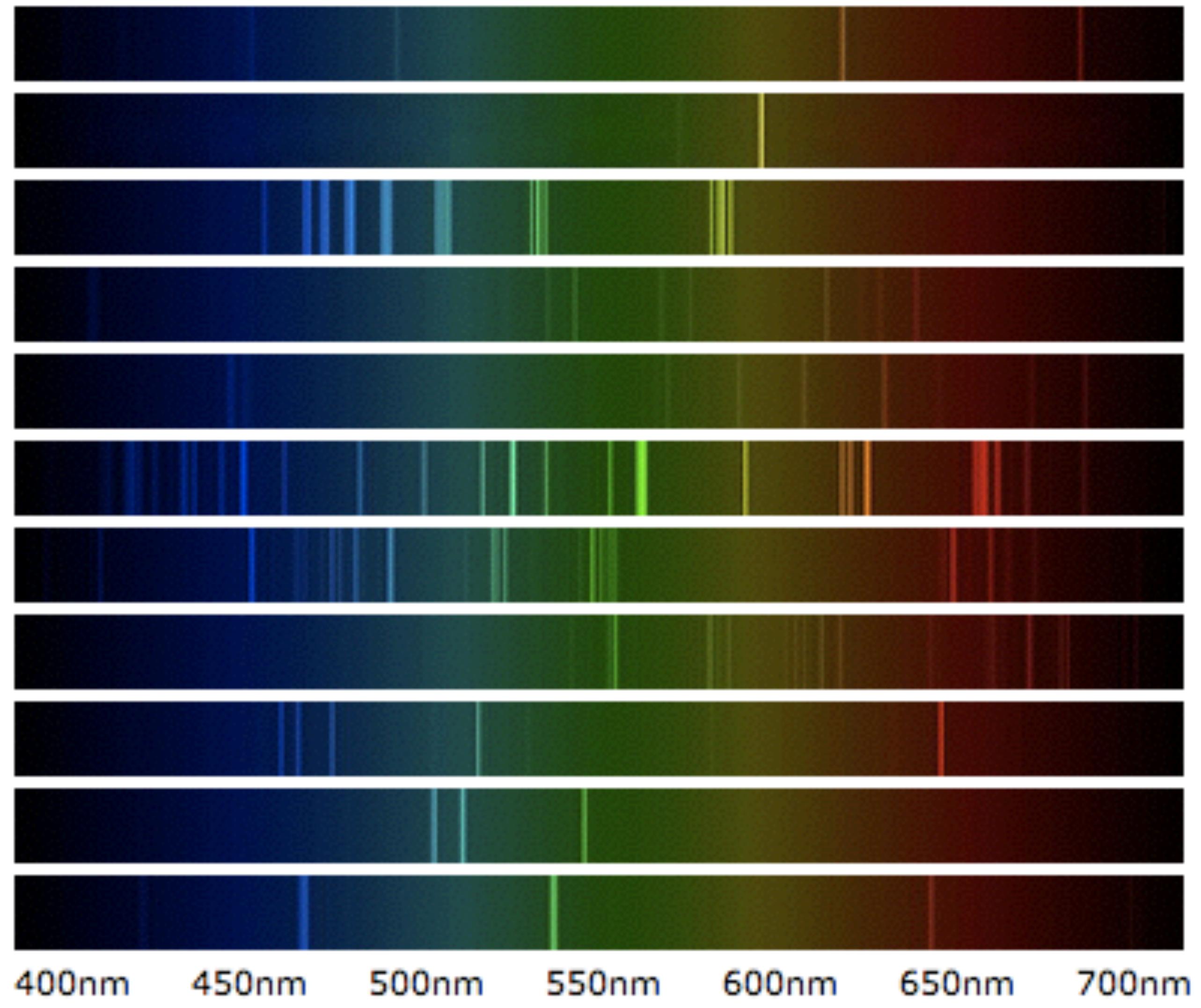
- Absorption spectroscopy
 - measure a reference spectrum using a full-spectrum white light source (and any container that will be used for the sample)
 - measure a second spectrum with sample
 - subtract the reference from the sample to determine absorption
- Emission spectroscopy
 - directly sample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



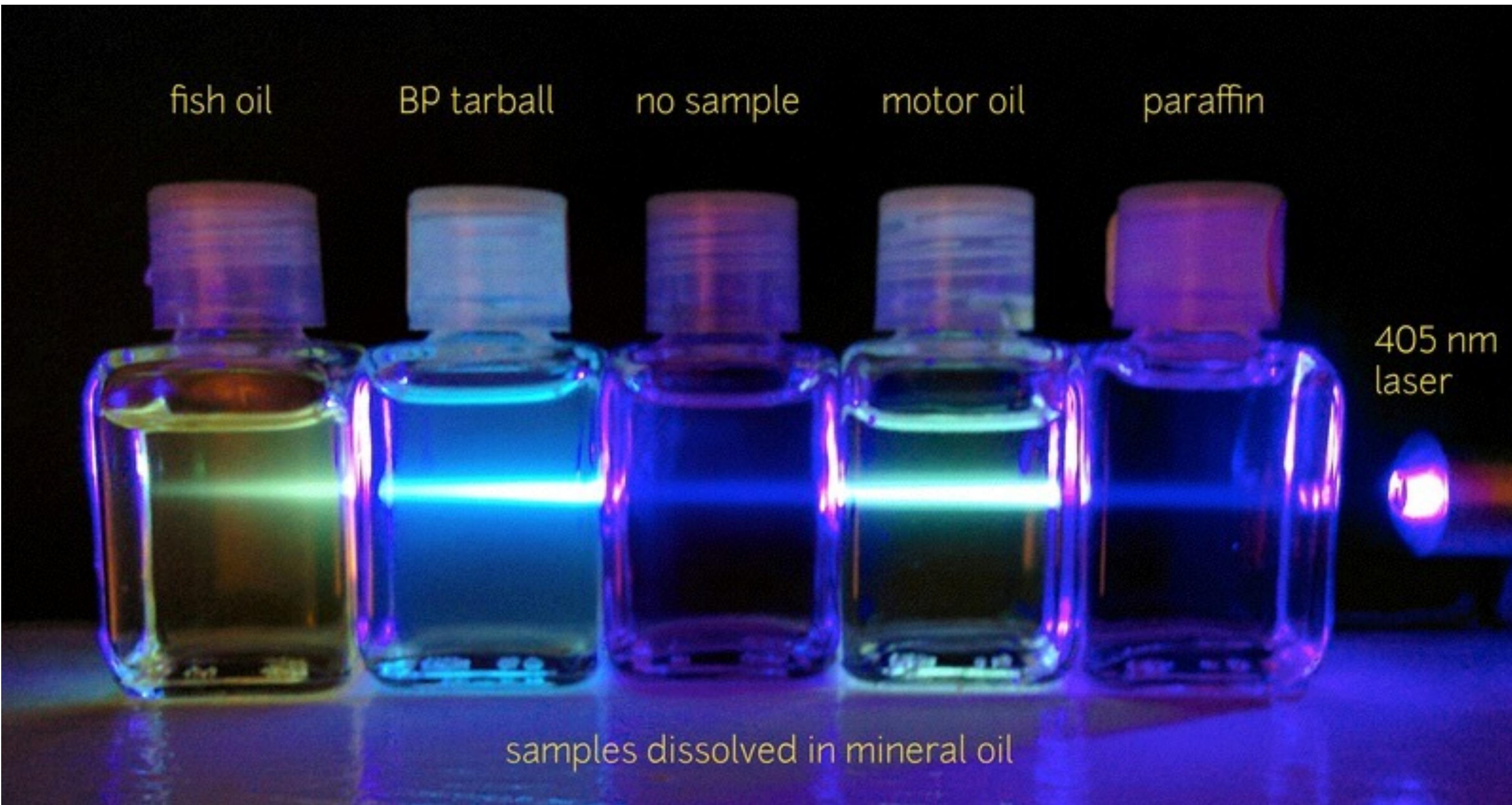
Flame Spectroscopy



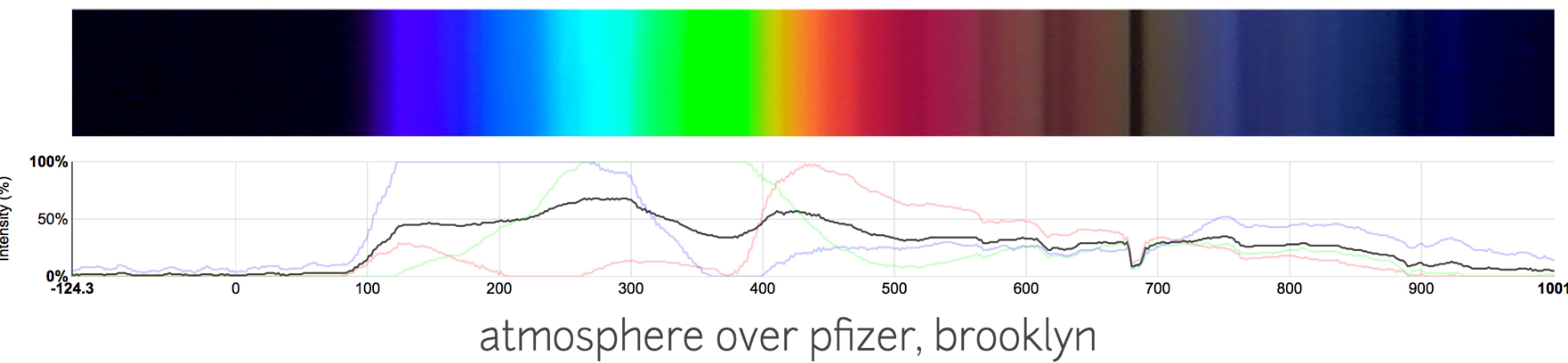
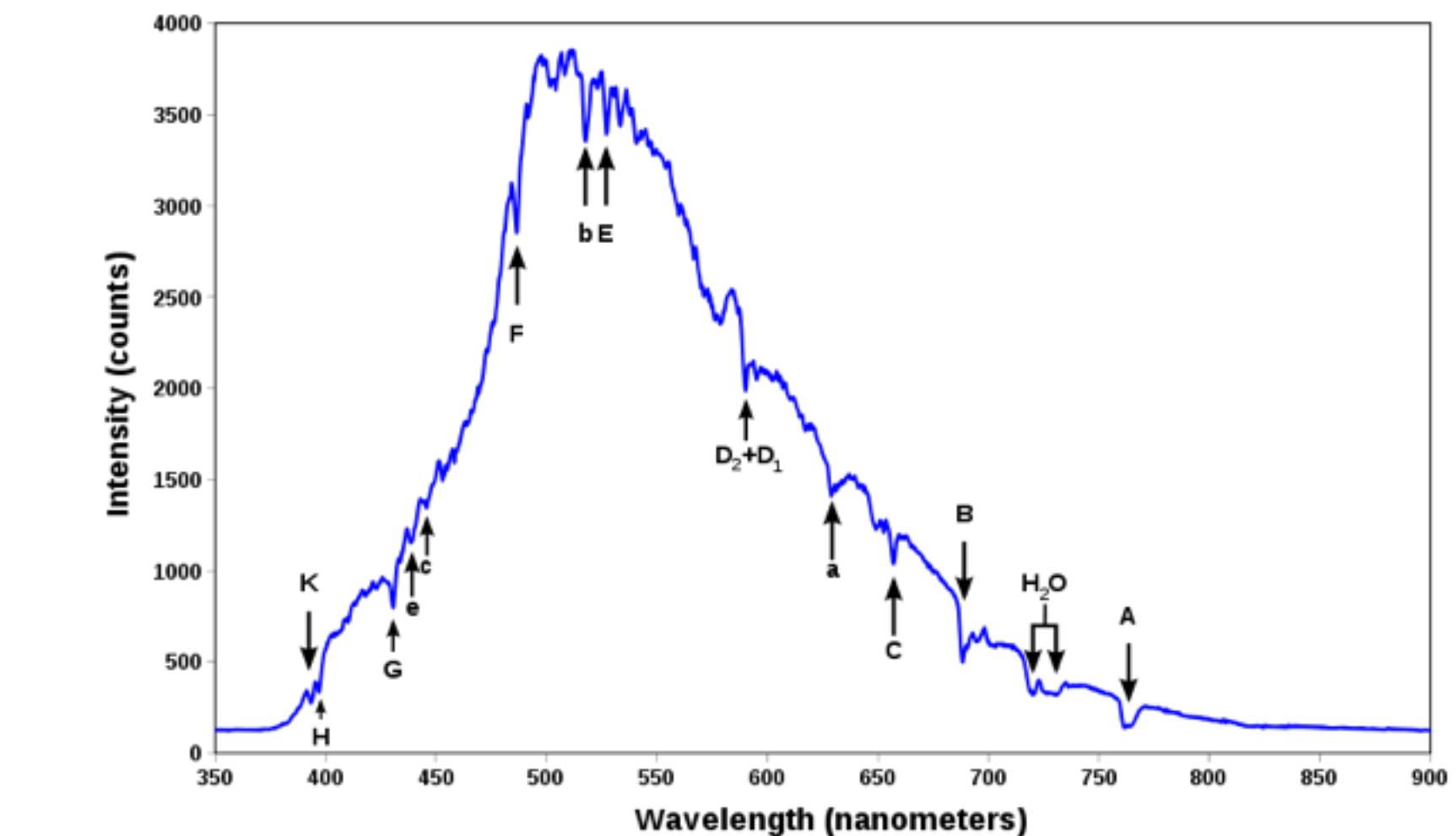
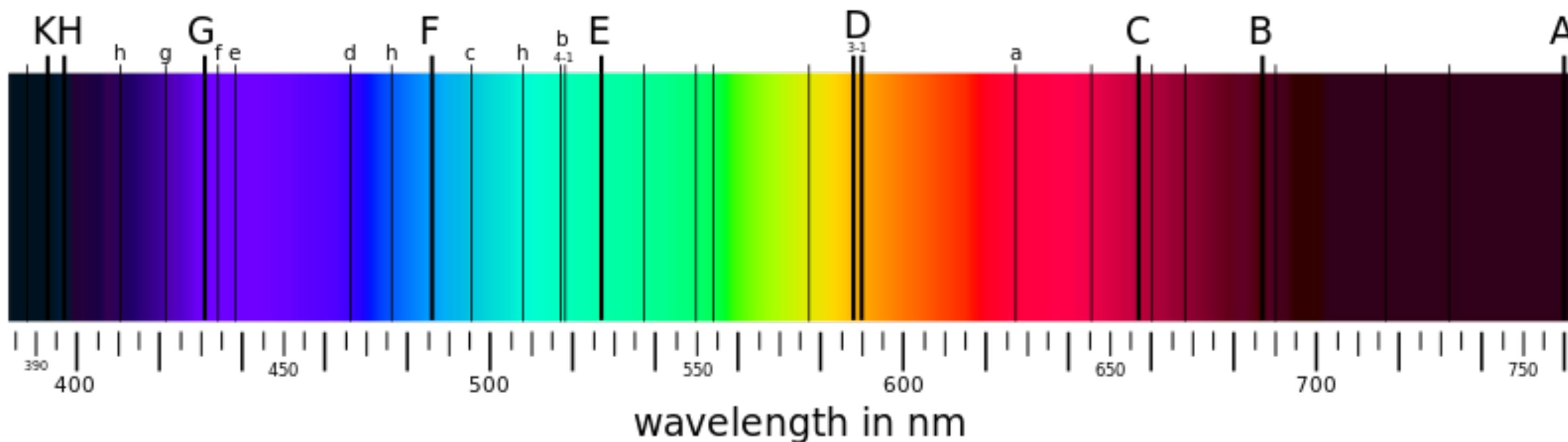
lithium
sodium
potassium
rubidium
cesium
calcium
strontium
barium
zinc
arsenic
selenium
wavelength



Oil Sampling



Fraunhofer Lines

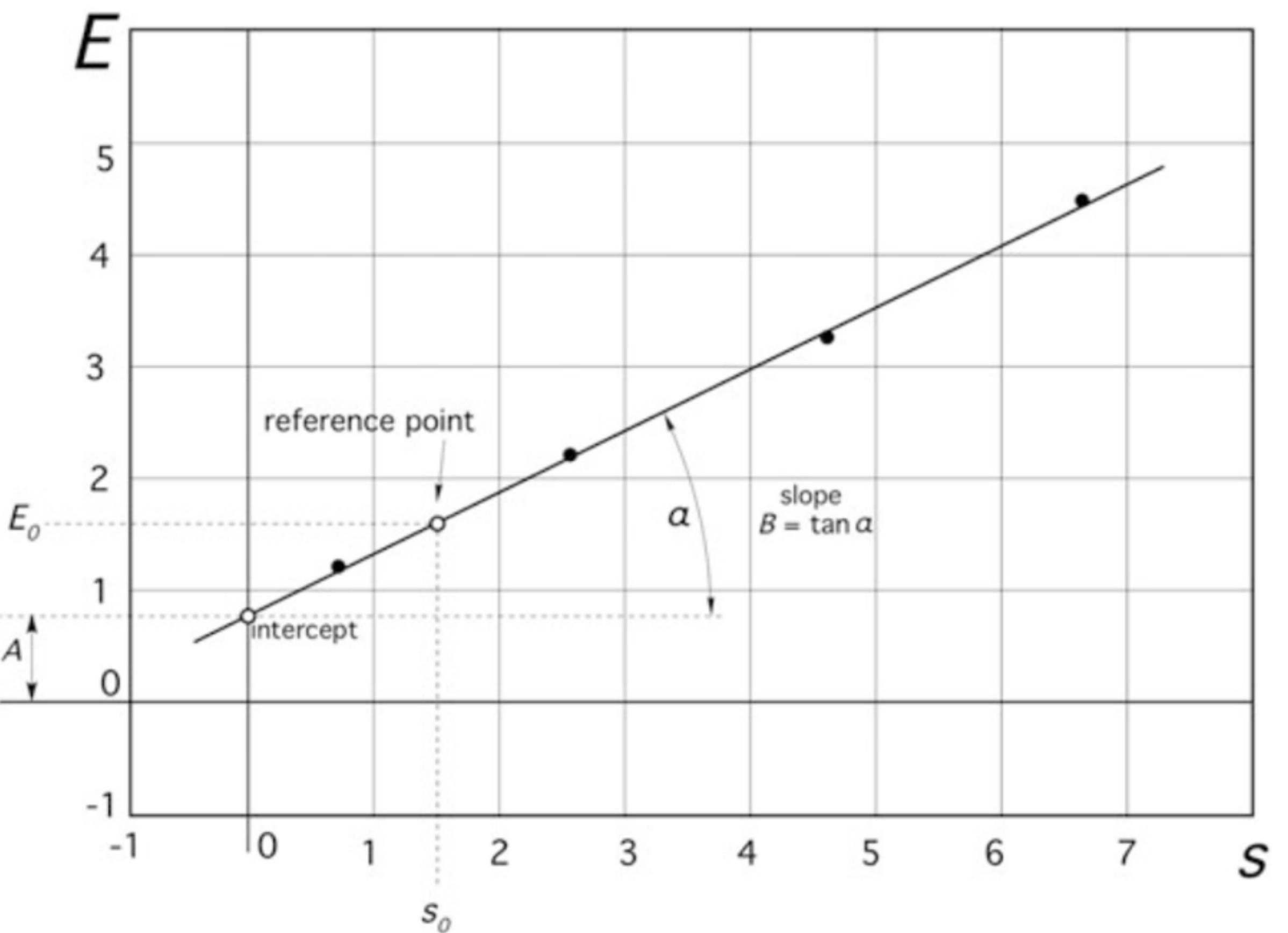


SENSOR CHARACTERISTICS

- 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

