Algae Monitoring Buoy Development

Earth Analytics Lab

ANALYTICAL MECHANICS ASSOCIATES

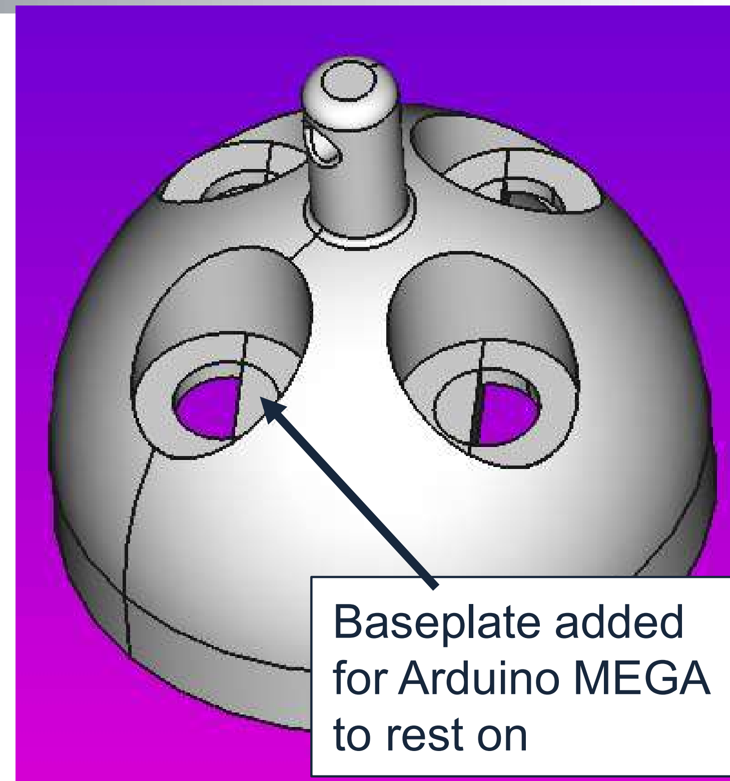
Table of Contents

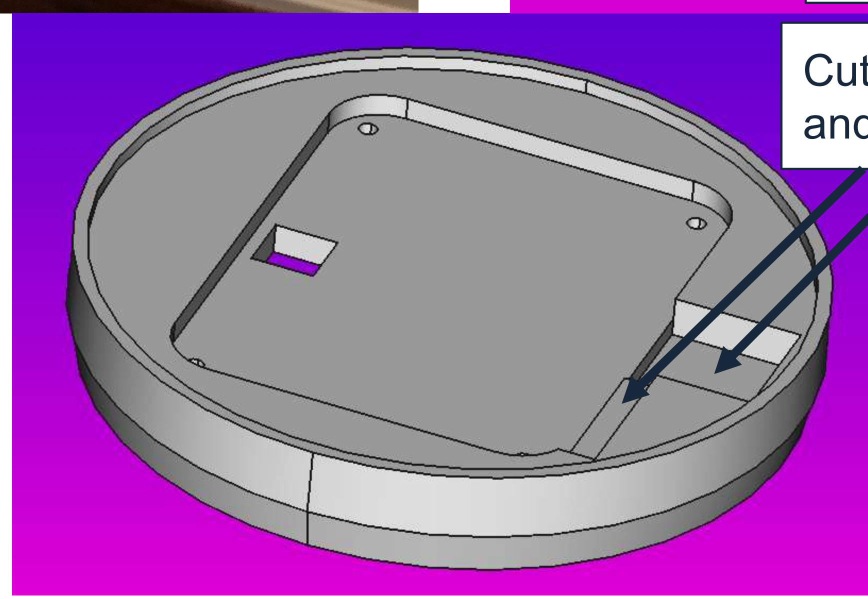
Click here to go to a live Jupyter notebook to visualize buoy data (beta)

Algae Monitoring Buoy Background

- In recent years, Harmful Algae Blooms (HABs) have become more prevalent in lakes, estuaries and coastal regions due to increased water temperatures and increased nitrogen-based nutrient runoff.
- Harmful algae blooms increase waterborne toxins which kill marine life and prevent swimming and other water activities.
- It is difficult to predict when and where an algae bloom may occur.
- To remedy this, a low-cost sensor was developed which measures several parameters indicative of a harmful algae bloom.

Pictures

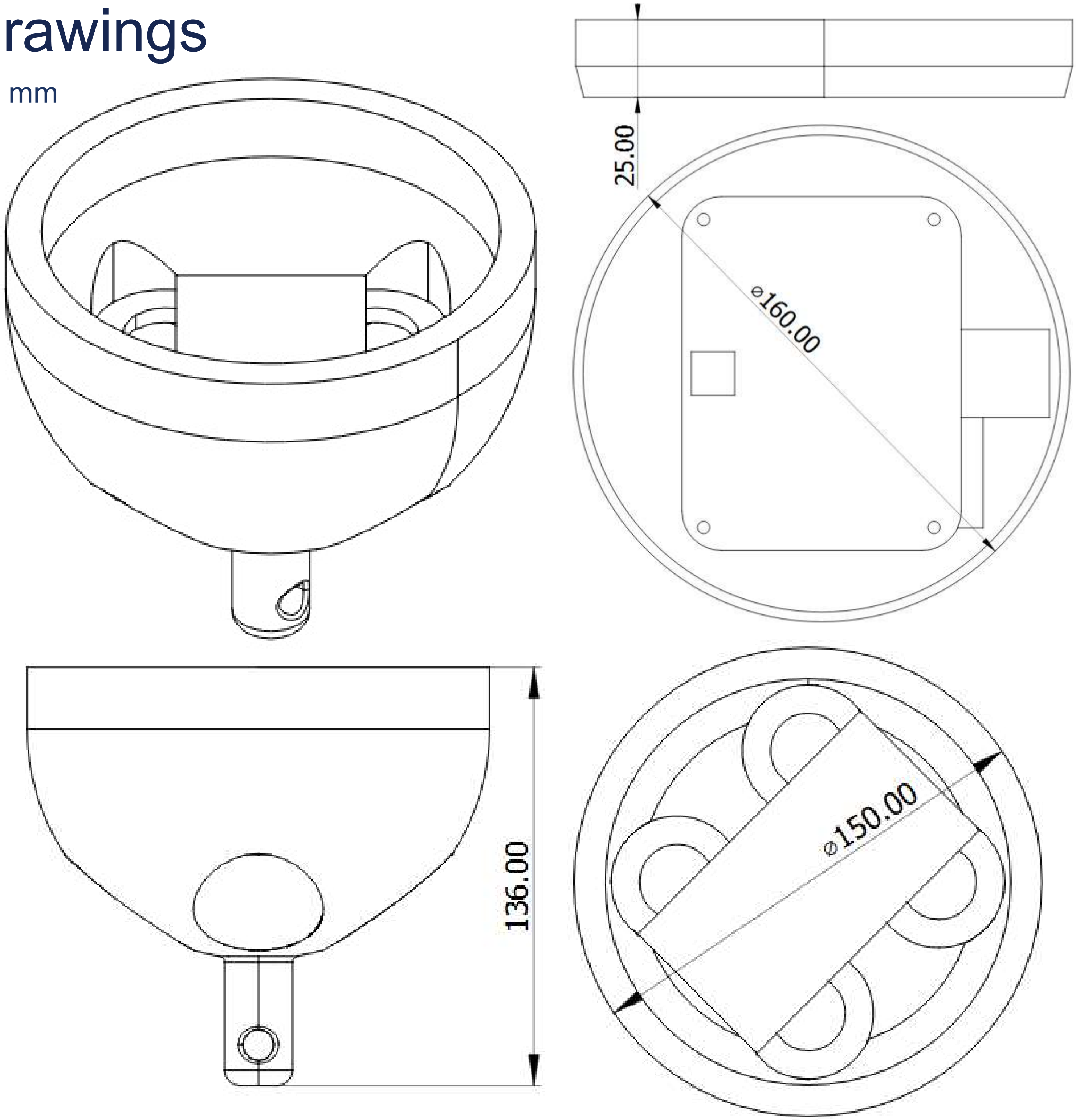

Baseplate added
for Arduino MEGA
to rest on


Cut-outs for GSM
and GPS antennas

Complete Buoy

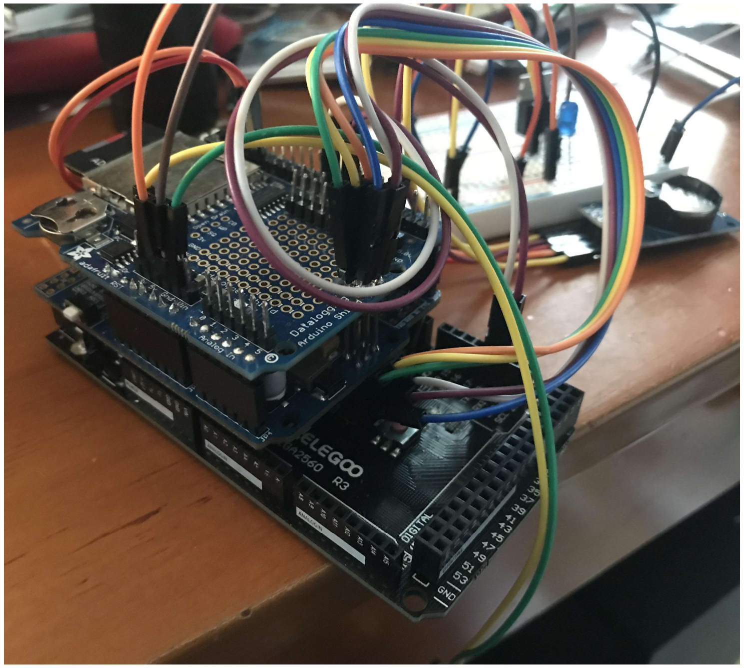
Buoy Drawings

* Dimensions in mm



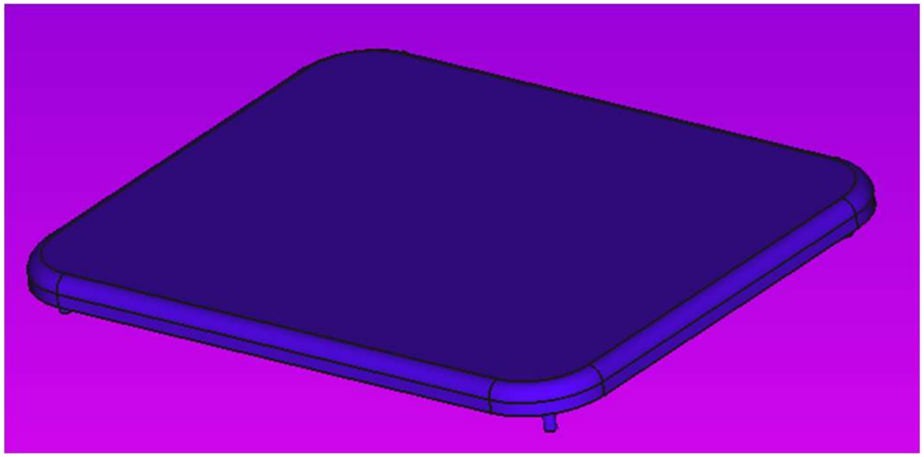
Microcontroller

- The algae monitoring buoy uses the ELEGOO MEGA for processing functions ($15.99)
- Low cost/easily accessible
- Many digital I/O pins
- 8 KB SRAM
- It has a higher power consumption rate than some boards but this can be mitigated



1 Watt, 6 Volt Solar Panel

- Designed with marine IoT applications in mind
- $20
- Will be mounted pointing directly vertical (zenith) for simplicity
- Waterproof



Power Management

[The Adafruit BQ24074 Solar Charger]() is used to charge the battery with energy from solar panel

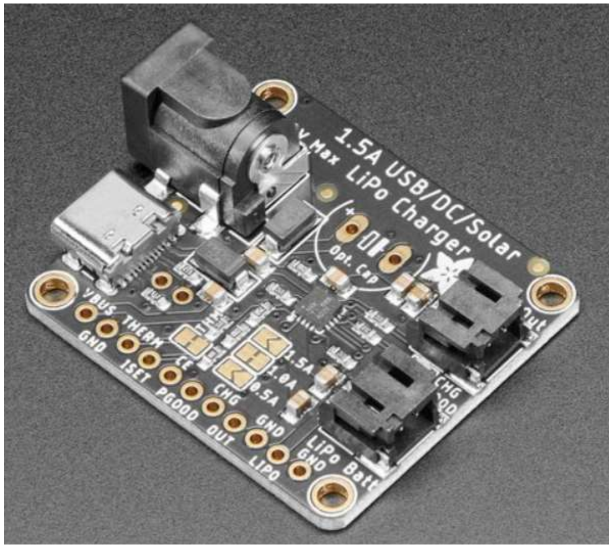
- Up to 1.5A charge and up to 10V input voltage, 28V protected
- Safe for 3.3V regulators or 5V boost converters

[Adafruit Miniboost 5V Boost Converter]()

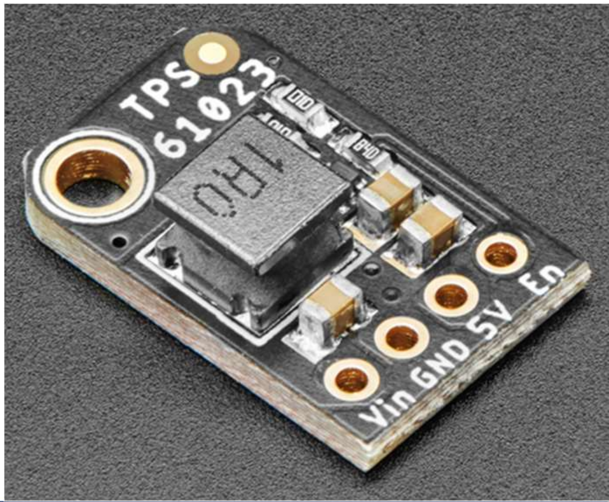
- Converts 0.5 – 5.5 V input from solar panel to 5 V
- Keeps power constant and adjusts input current according to

Power = Current x Voltage

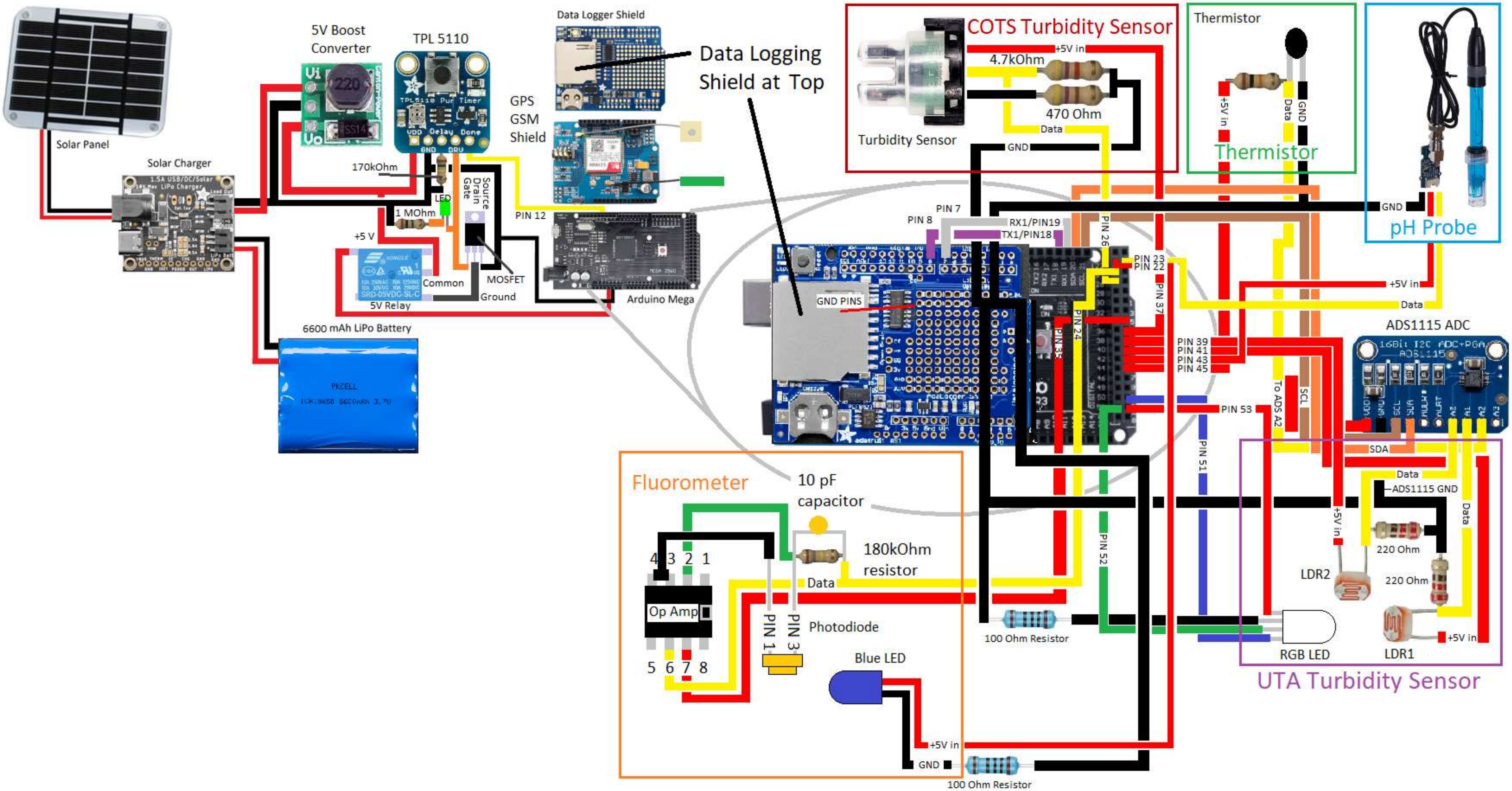
Solar charger



Boost converter

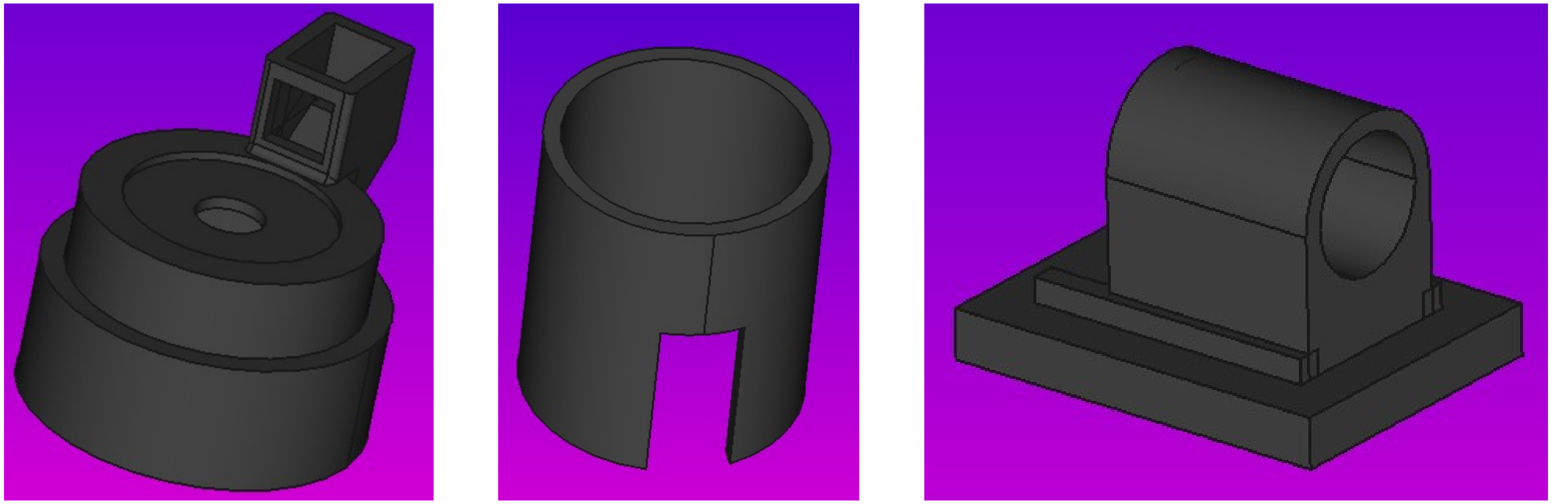


3D Printed Buoy Electrical Layout



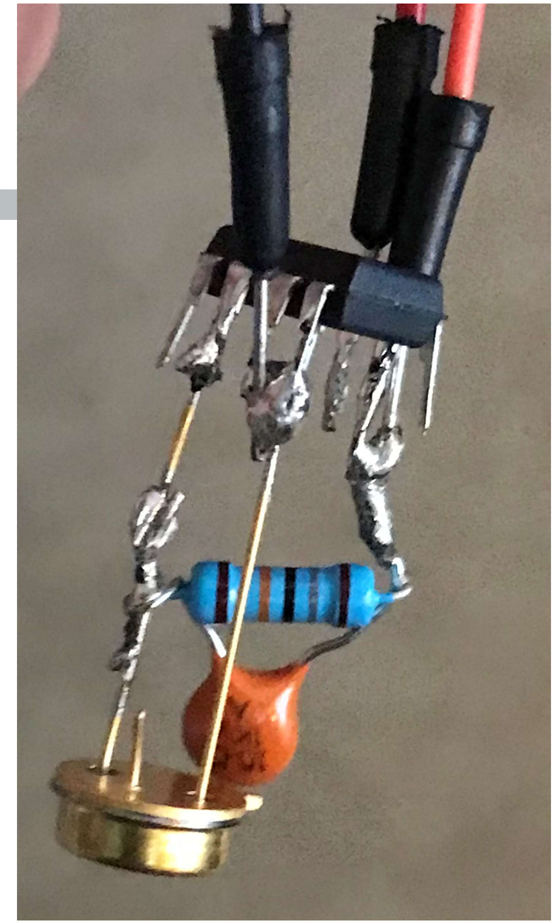
Fluorometer Development

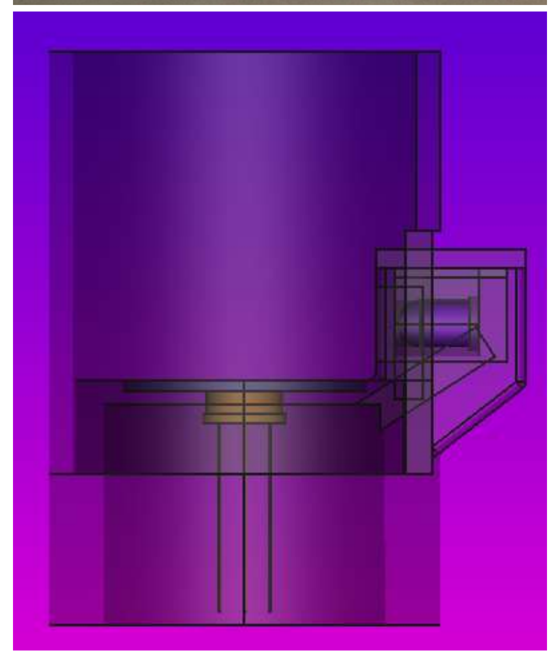
- Fluorometer
  - A fluorometer is a device that can be used to determine the fluorescence of a substance. This can be useful because chlorophyll concentration (and therefore algae concentration) can be determined based on how fluorescent the water is.
  - A low-cost fluorometer was developed based on *In-situ Measurements of Phytoplankton Fluorescence Using Low Cost Electronics*



Fluorometer Design

- Fluorometer
  - Light is transmitted from a 395 nm LED through the water and to the fluorescent chlorophyll, which will glow red.
  - The photodiode light sensor is mounted at 90 degrees to the blue LED so that only light from the fluorescing water will be detected.





Fluorometer with long-pass filter shown below

FDS 100 Photodiode

Specifications

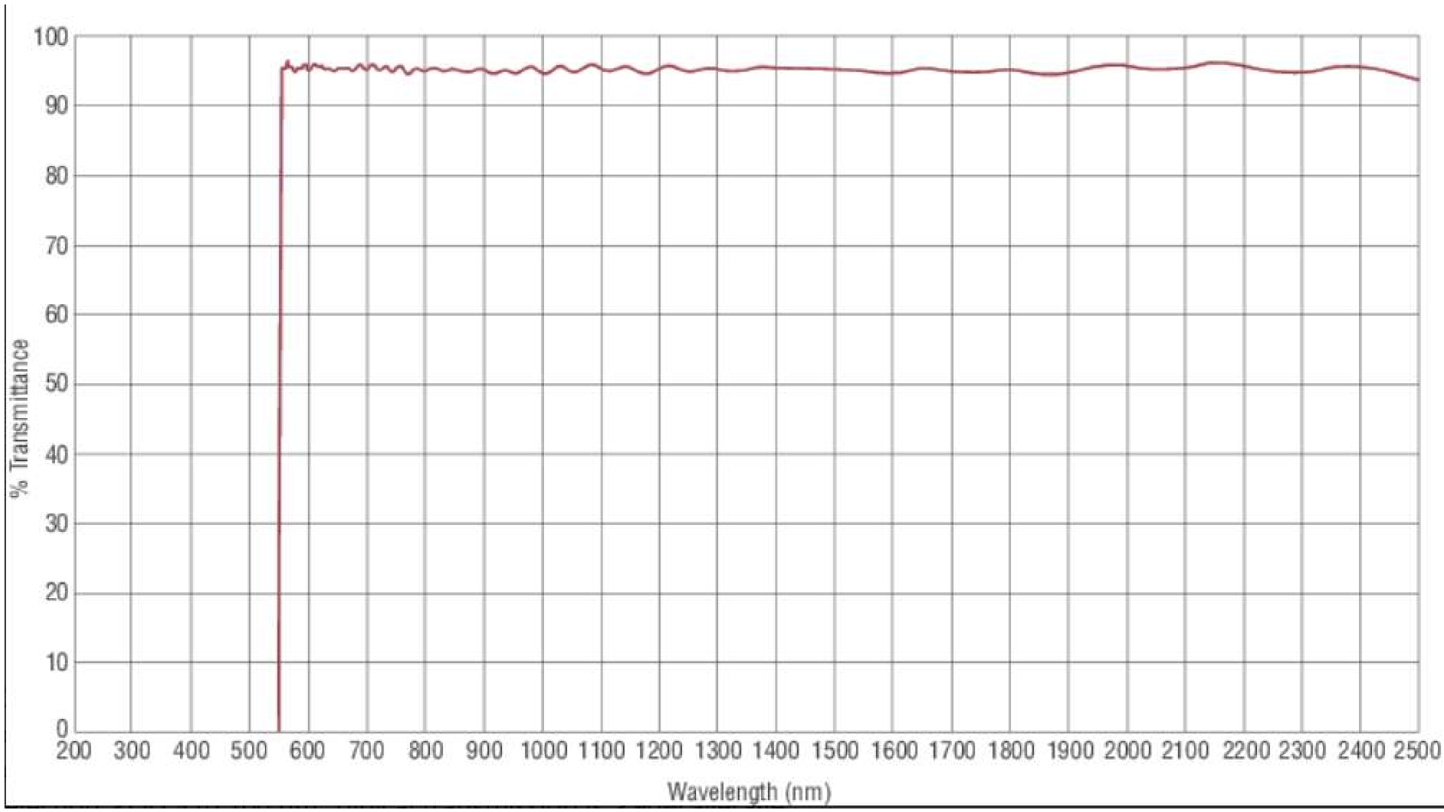
Specifications[a]		
Wavelength Range	λ	350 - 1100 nm
Peak Wavelength	λ_P	980 nm
Responsivity	$\Re(\lambda_p)$	0.65 A/W
Active Area		13 mm^2
Rise/Fall Time (632 nm, R_L=50 Ω, 20 V)	t_r/t_f	10 ns / 10 ns
NEP, Typical (900 nm, 20 V)	$W/\sqrt{Hz}$	1.2×10^{-14}
Dark Current (20V)	I_d	1.0 nA (Typ.) 20 nA (Max.)
Capacitance (20V)	C_j	24 pF (Typ.)
Package		TO-5
Sensor Material		Si

Maximum Rating	
Max Bias (Reverse) Voltage	25 V
Reverse Current	5 mA
Operating Temperature	-40 to 100 °C
Storage Temperature	-55 to 125 °C

FDS100

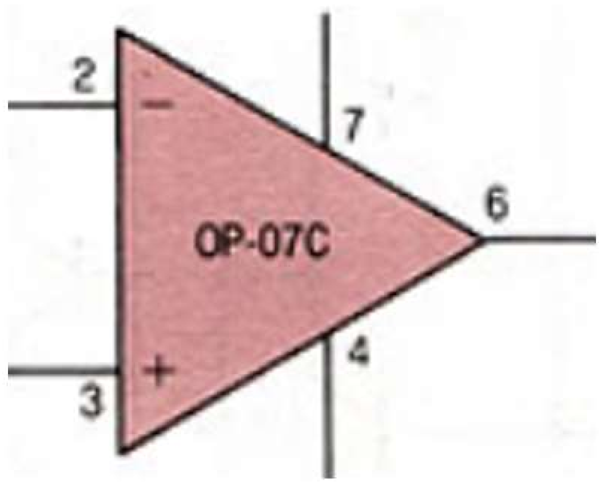
Newport Optics Longpass Filter

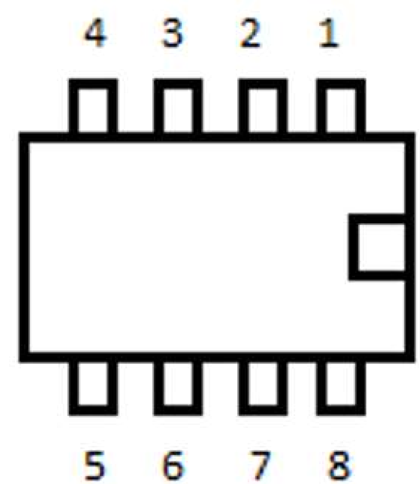
- Used to filter lower wavelengths emitted by the 395 nm LED so that fluorescence from the chlorophyll can be observed
- 550 nm cut-on wavelength
- https://www.newport.com/p/10CGA-550



OP07 Op Amp

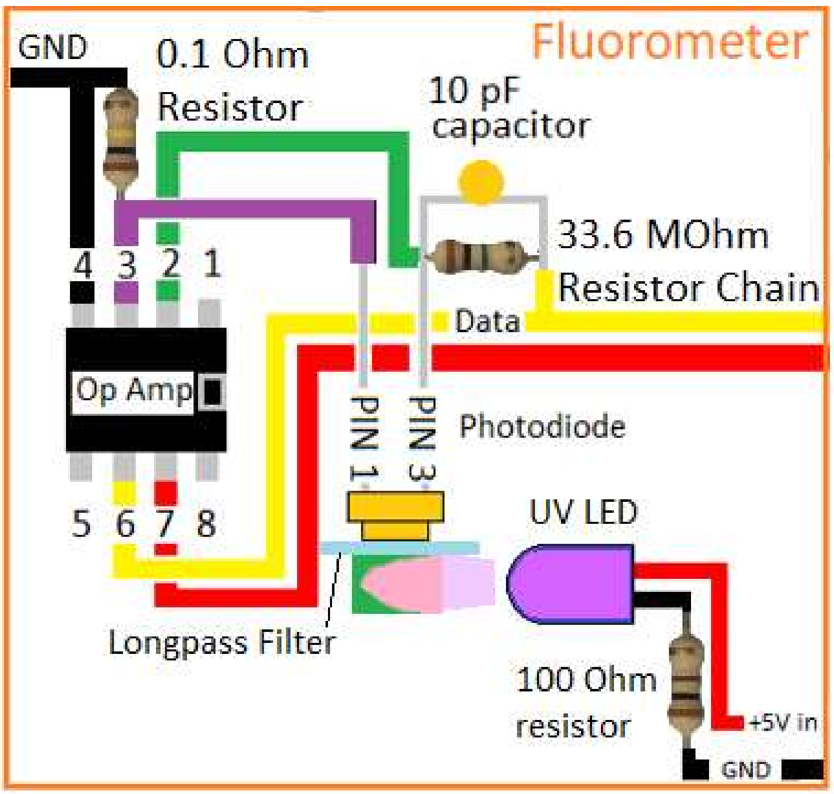
- *Guaranteed* 25μV *max.* Offset Voltage
- *Guaranteed* 0.6μV/°C *max.* Offset Voltage Drift with Temperature
- *Excellent* 1.0μV/Month *max.* Long Term Stability
- *Guaranteed* 0.6μV_{p-p} *max.* Noise
- *Guaranteed* 2.0nA *max.* Input Bias Current

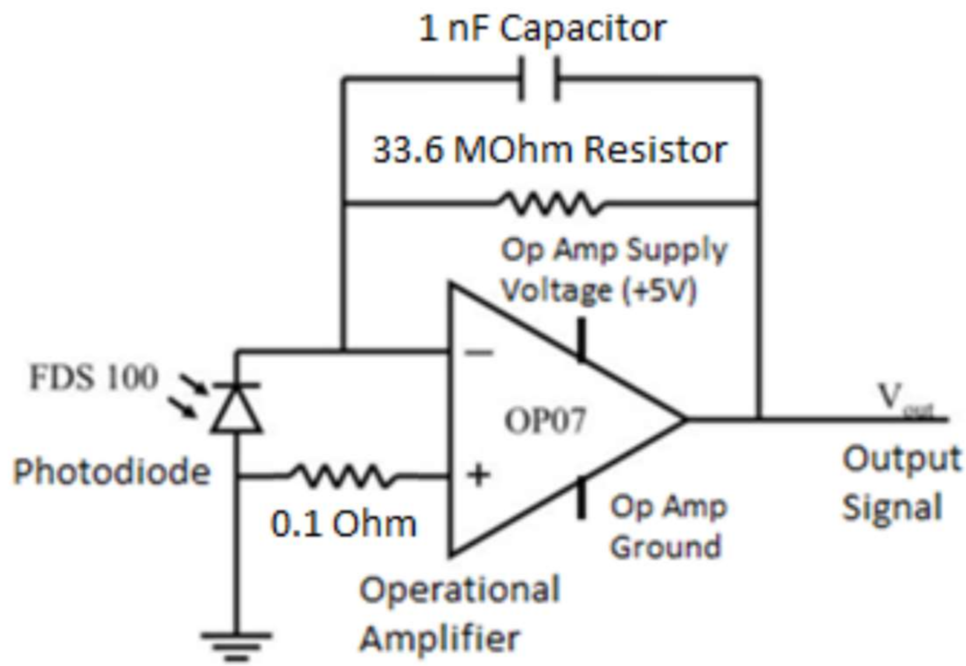


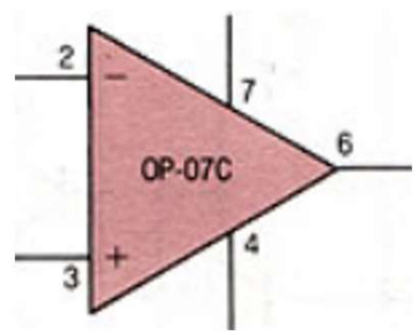


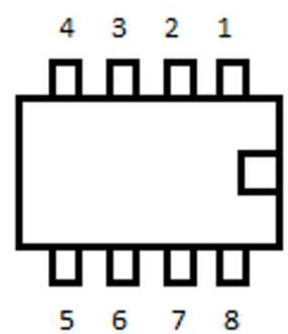
Fluorometer Circuit

- Uses a transimpedance amplifier to convert the current generated by the photodiode into a voltage readable by the ADS1115

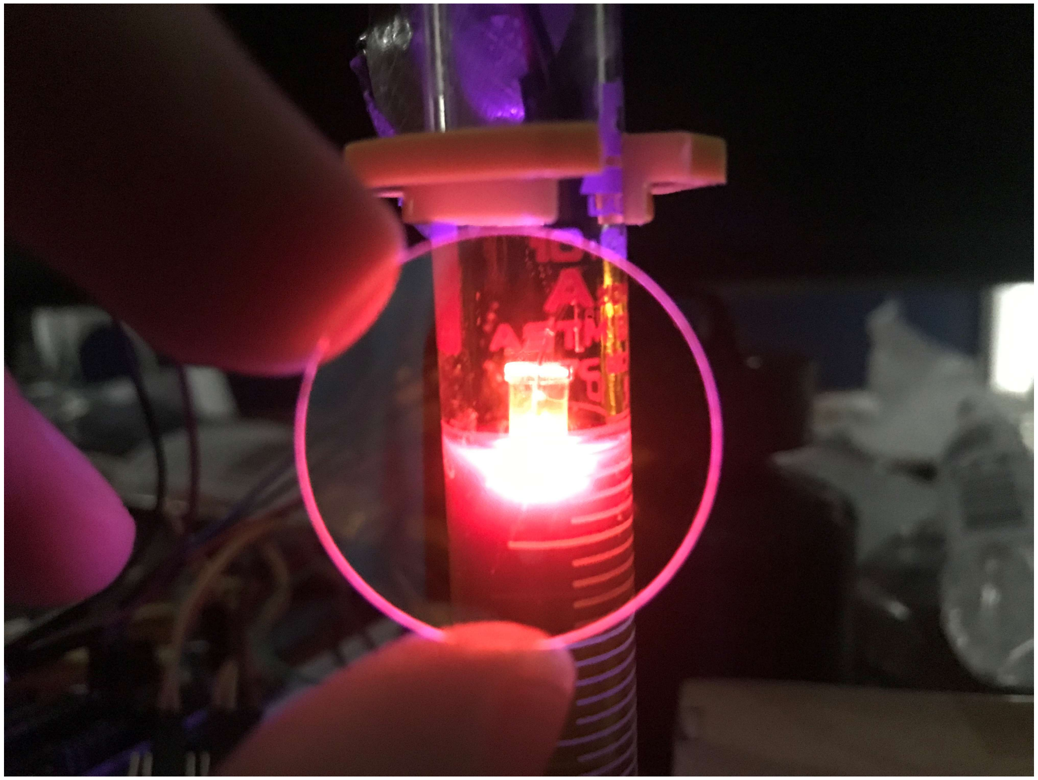






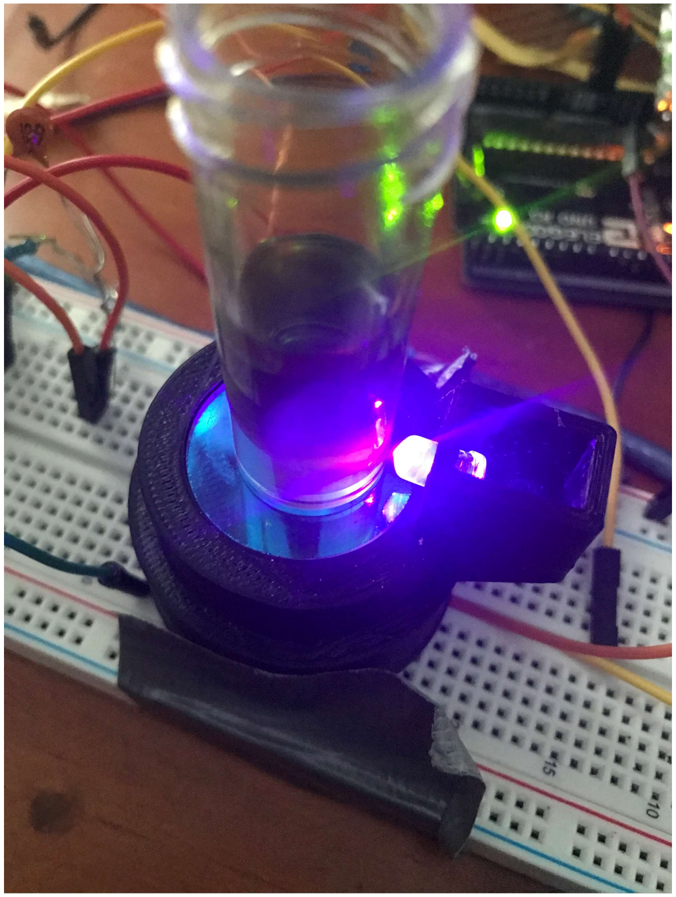


Testing and Setup

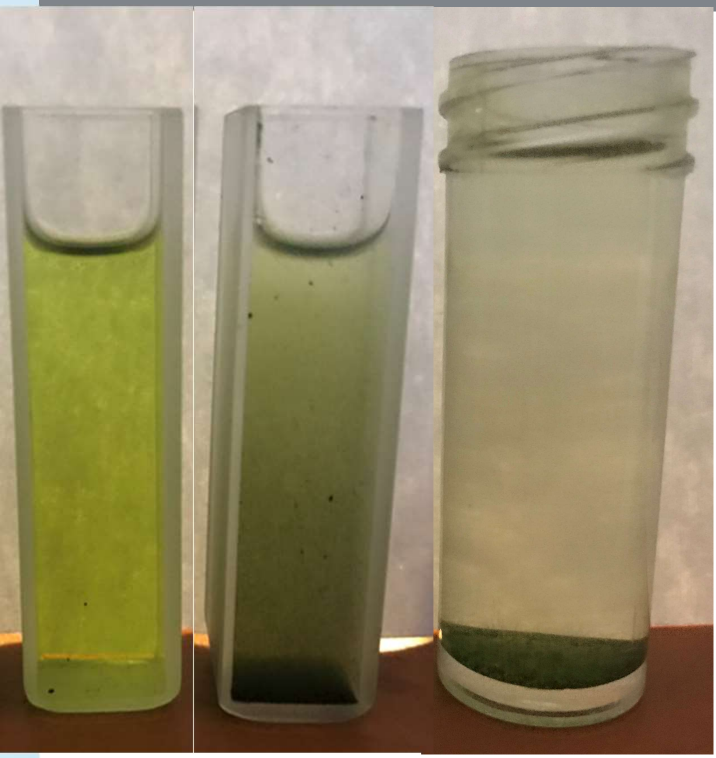


Chlorophyll Fluorescence as viewed through the High-pass Filter

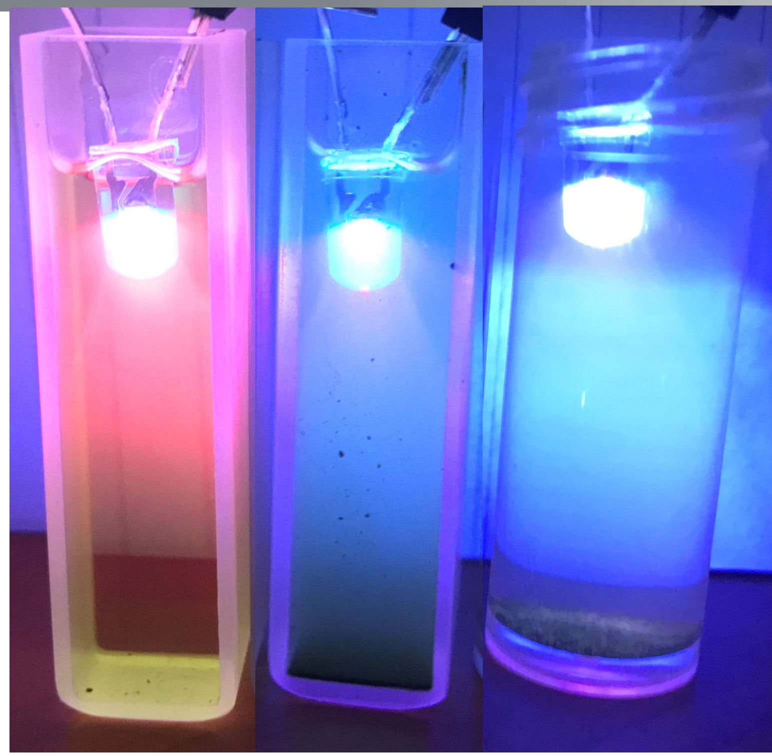
A test fluorometer was built with a UV LED



Samples Used



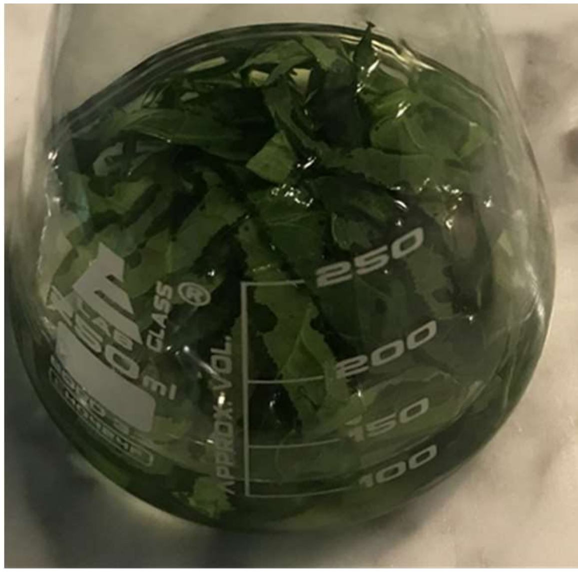
1. 2. 3.



1. 2. 3.

0.005 g/mL Chlorella Powder Mix (Well Mixed)

0.05 g/mL (Leaf mass/IPA volume) Chlorophyll Extract Creation



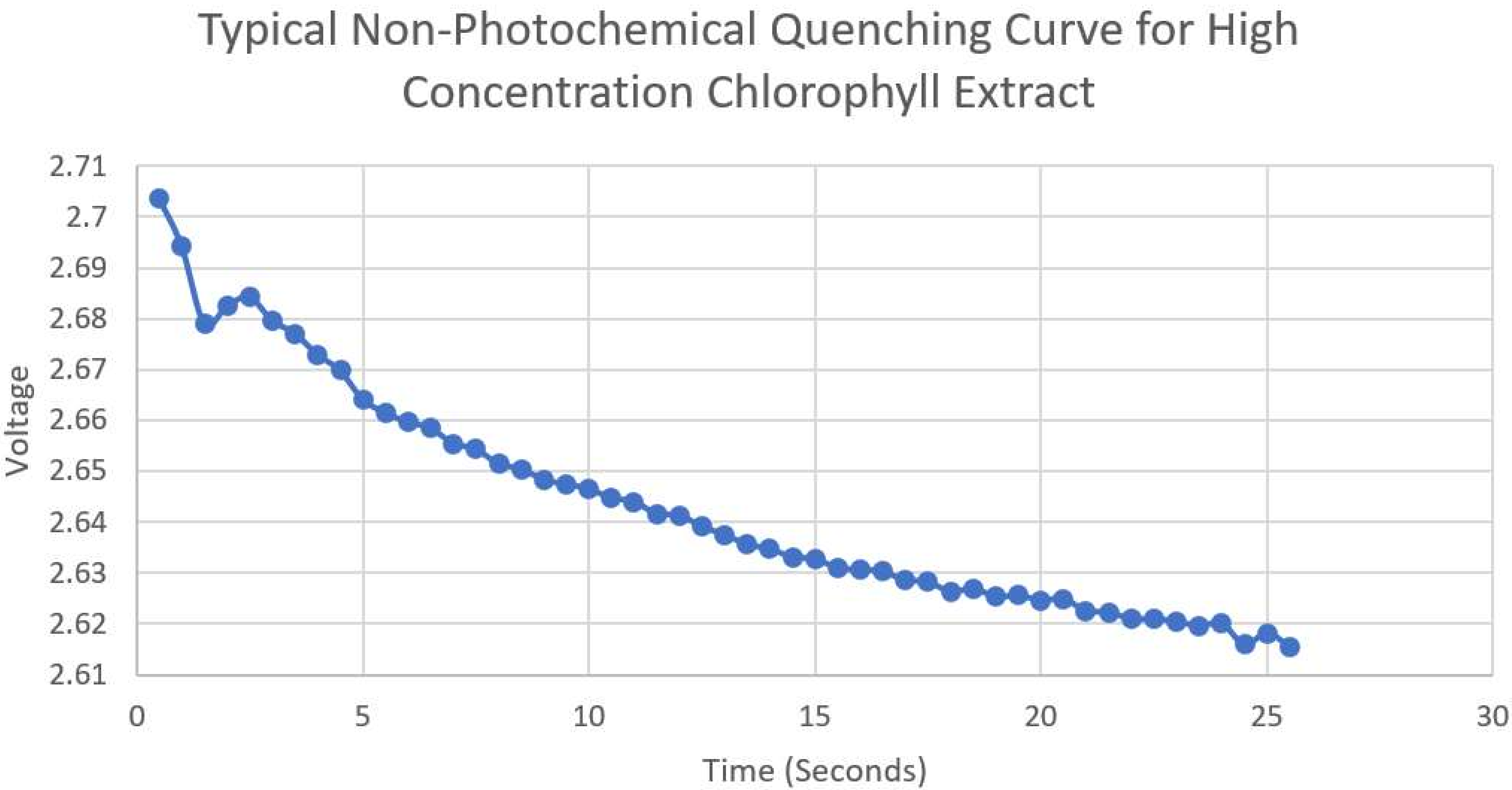
1. 0.05 g/mL chlorophyll extract
2. 0.005 g/mL unsettled chlorella mix
3. 0.005417 g/mL settled chlorella mix

Simple Fluorometer Test Script

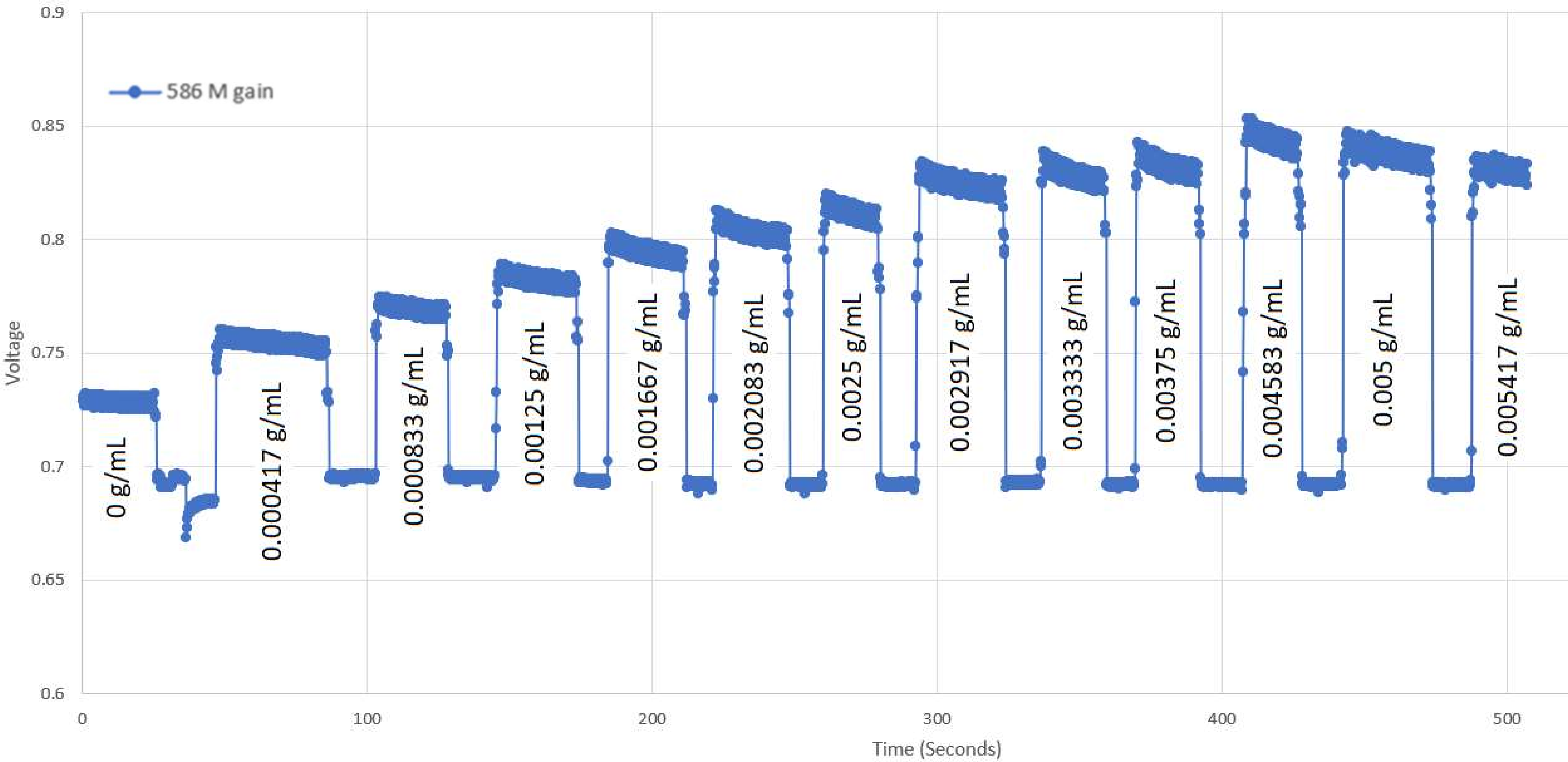
```
#include <Adafruit_ADS1X15.h>
Adafruit_ADS1115 ads;  /* Use this for the 16-bit version */
void setup() {
  ads.begin();
  Serial.begin(9600);
}

void loop() {
  Serial.println(ads.readADC_SingleEnded(2));
  delay(500);
}
```

Quenching

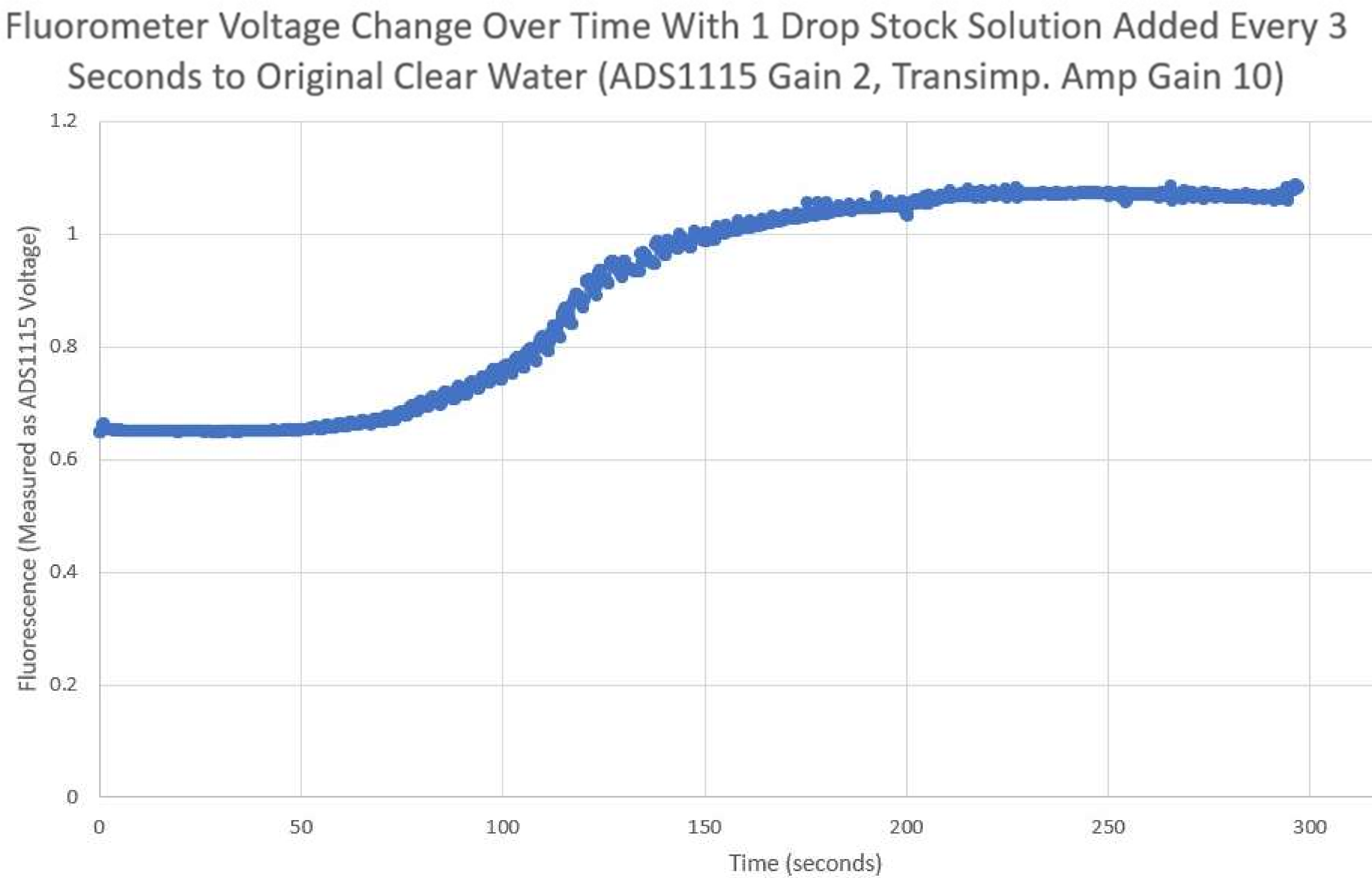

Typical Non-Photochemical Quenching Curve for High Concentration Chlorophyll Extract
Voltage
2.71
2.7
2.69
2.68
2.67
2.66
2.65
2.64
2.63
2.62
2.61
0
5
10
15
20
25
30
Time (Seconds)

Fluorometer Data (Each Step is an Addition of 5 Drops of 5g/L Chlorella/water solution added to 3 mL of water)



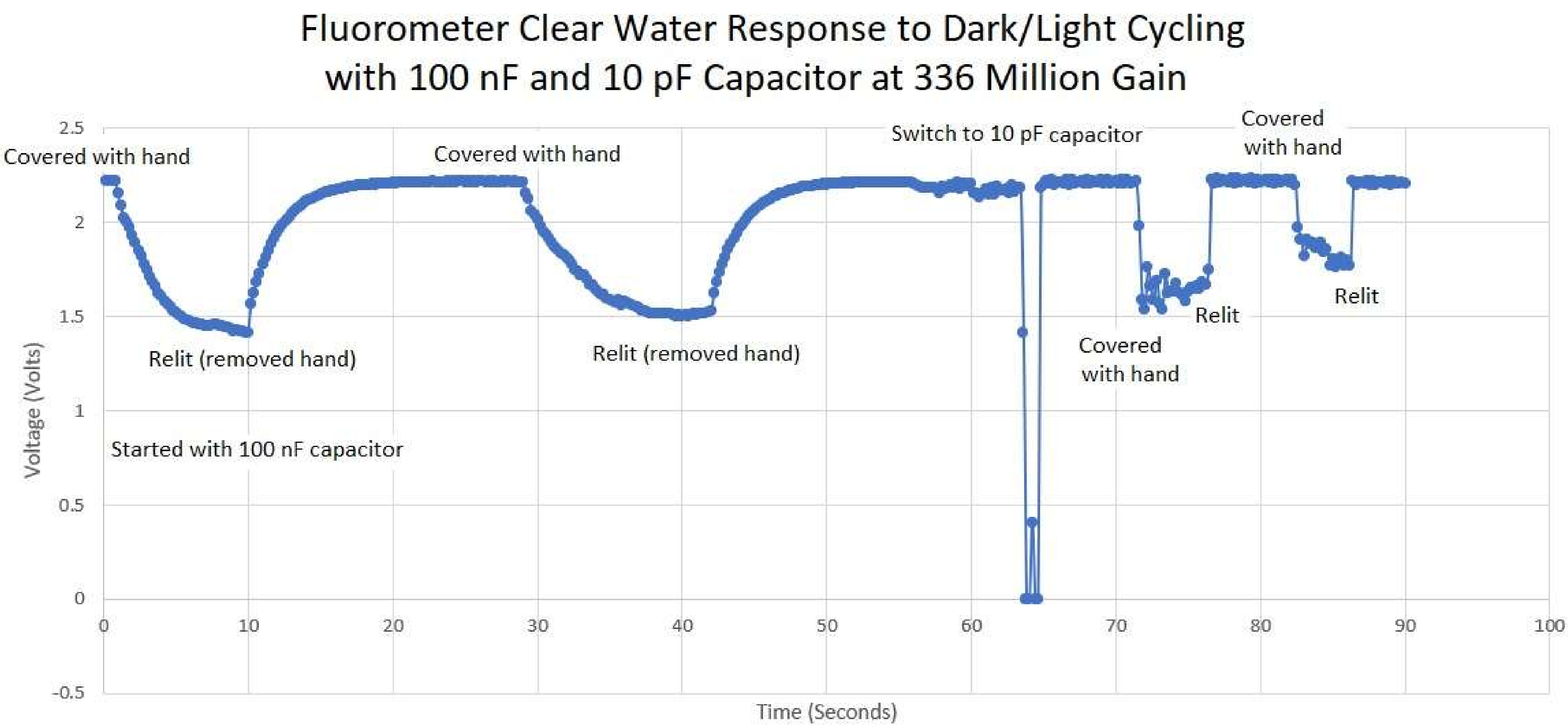
Slide 21

HAJ1 Horvath, Alexander J., 11/9/2021



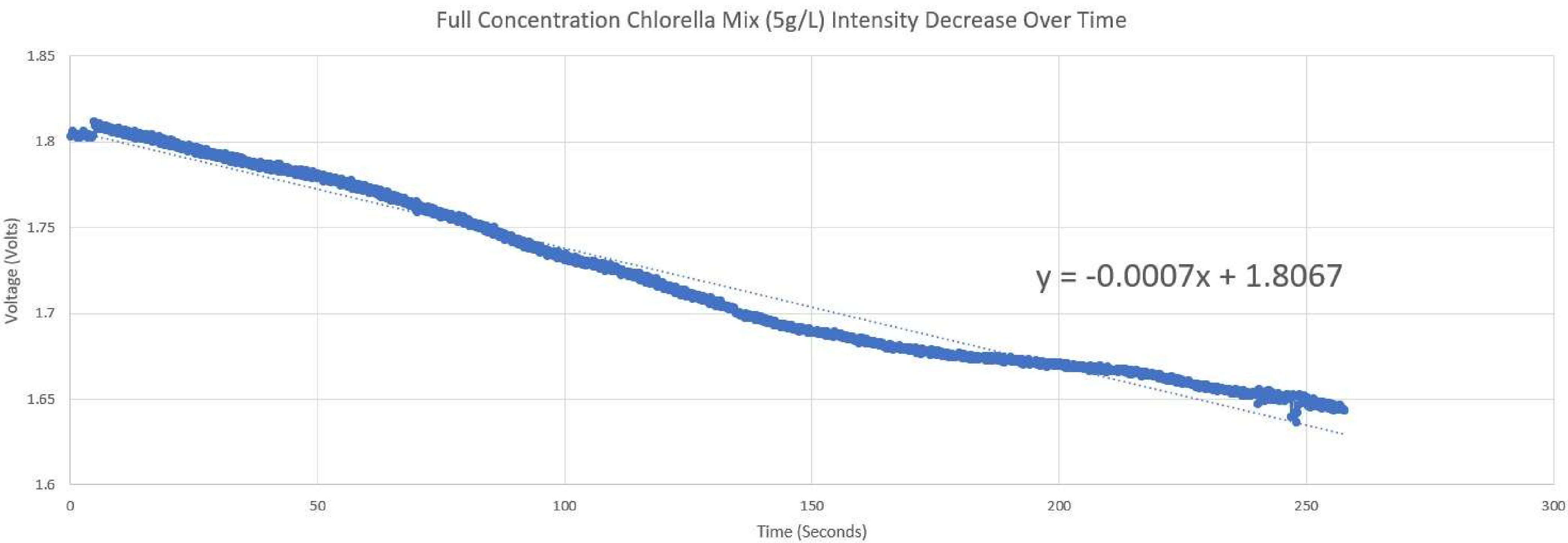
Fluorometer Voltage Change Over Time With 1 Drop Stock Solution Added Every 3 Seconds to Original Clear Water (ADS1115 Gain 2, Transimp. Amp Gain 10)
Fluorescence (Measured as ADS1115 Voltage)
Time (seconds)
0
0.2
0.4
0.6
0.8
1
1.2
0
50
100
150
200
250
300

Fluorometer Capacitance Data



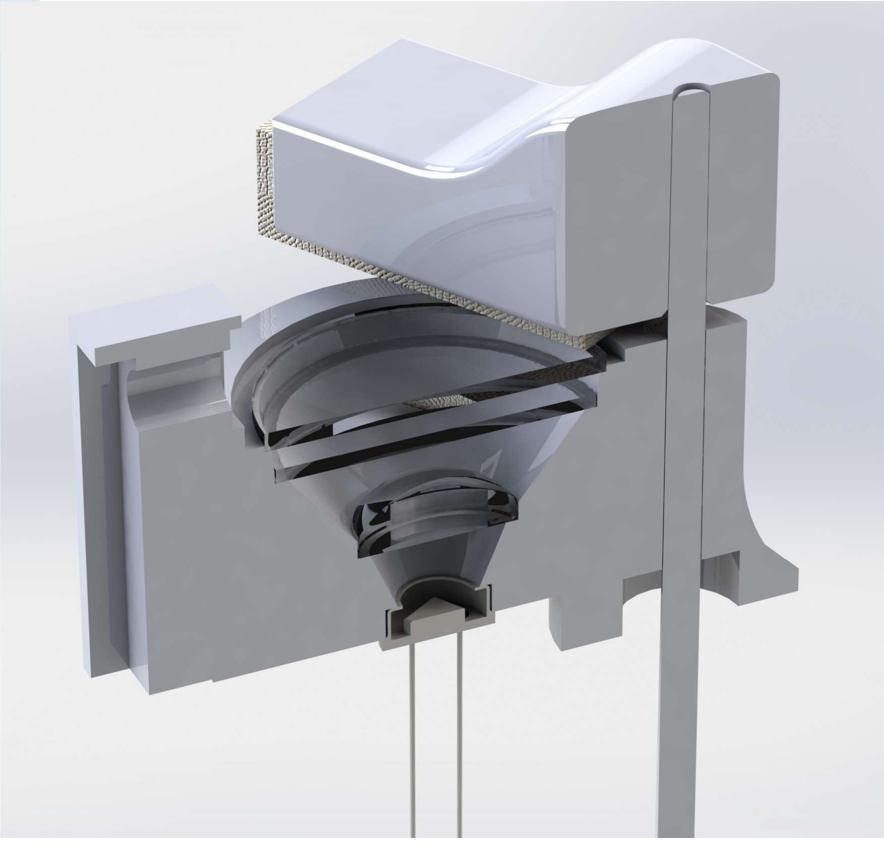
Fluorometer Data

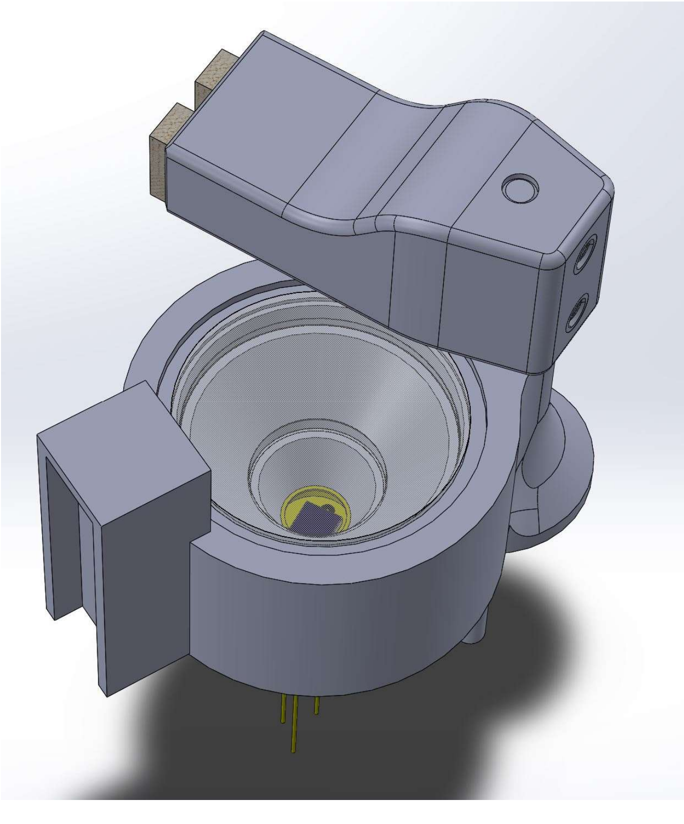
- Steady time-dependent decreases in fluorescence has been observed
  - Is this non-photochemical quenching or bleaching?



Fluorometer Future Developments

- Addition of fluorometer lens
- Addition of wiper mechanism
- Use of rhodamine-B for calibration
- Use of a lock-in amplifier to minimize the effects of ambient lighting



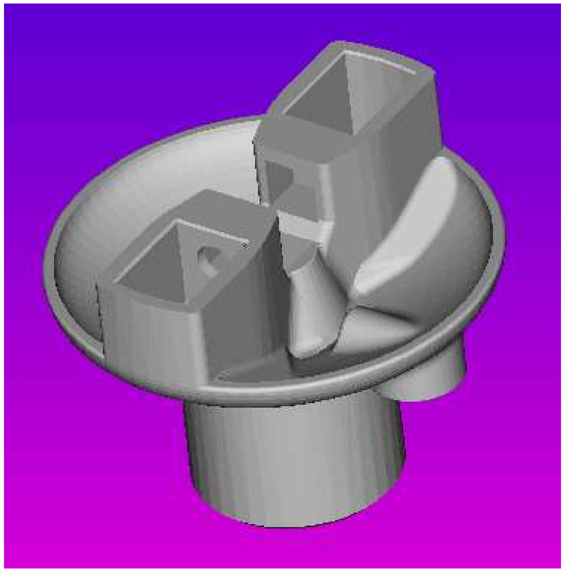


Turbidity Sensor Development

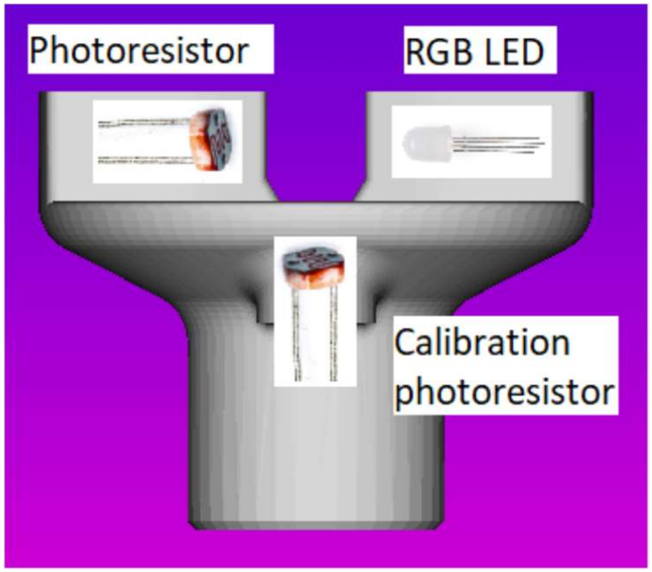
- Students at the University of Texas- Austin developed a turbidity sensor with help from AMA
    - The sensor uses an RGB LED and two photoresistors to determine the turbidity of the water.
    - The sensor has been field deployed in Hoffler Creek, VA

Revision 1 buoy with turbidity sensor

Turbidity sensor CAD drawing

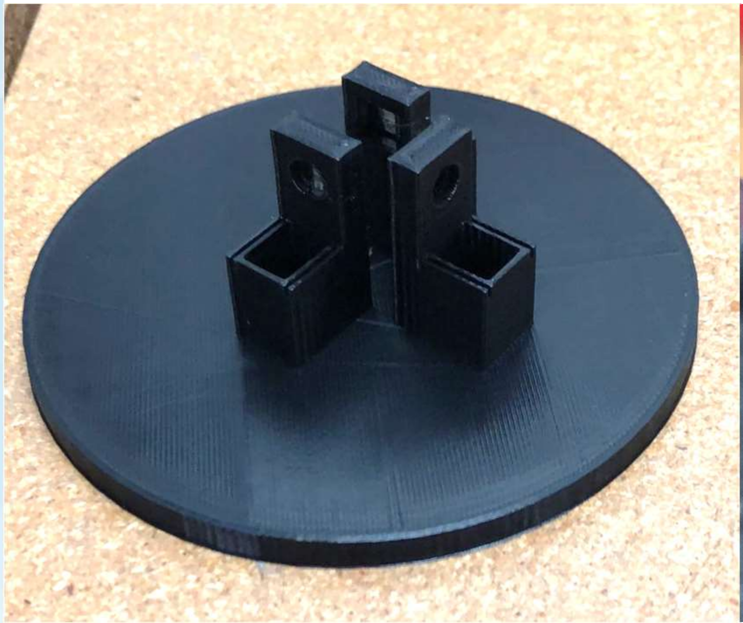


Sensor layout



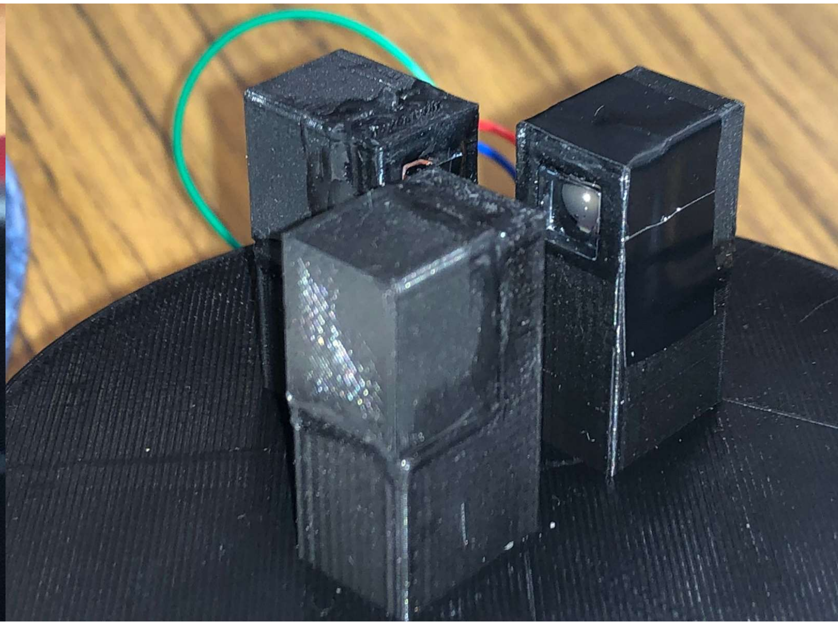
Transmission and Scattered Light Sensor Test Results

- Below show the initial student-built turbidity sensor prototype. It was redesigned to have a smaller form factor and for simplicity.
- The following slide shows serial dilution testing with the first turbidity sensor

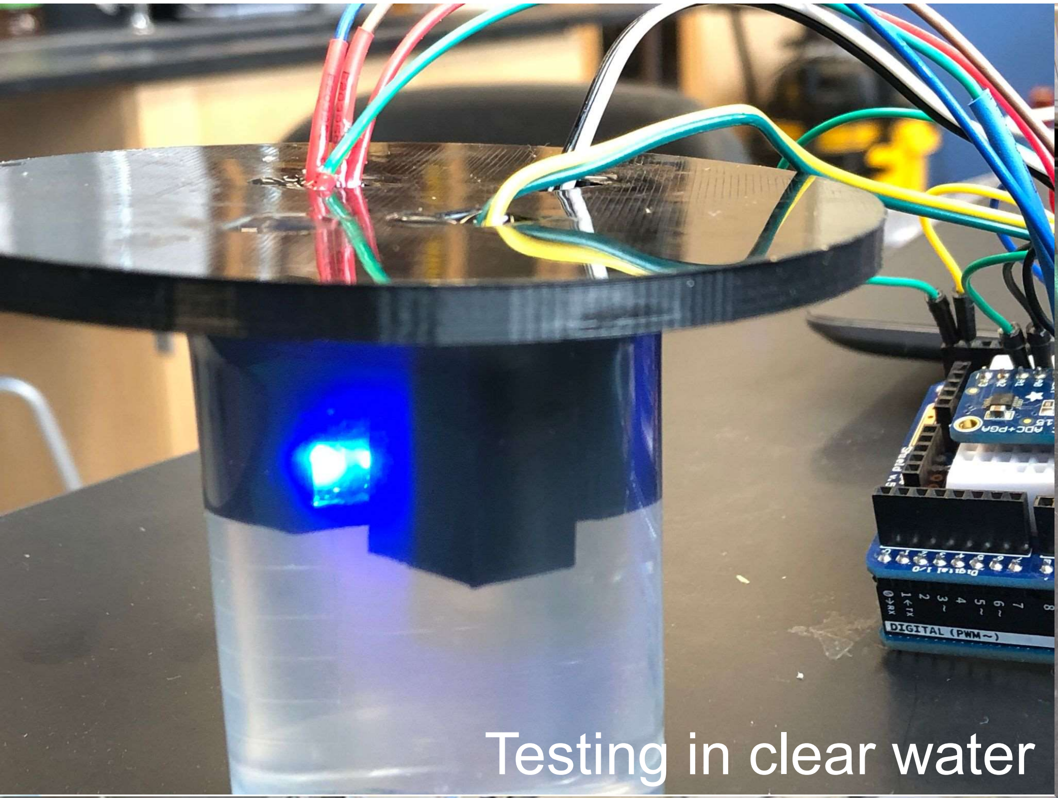


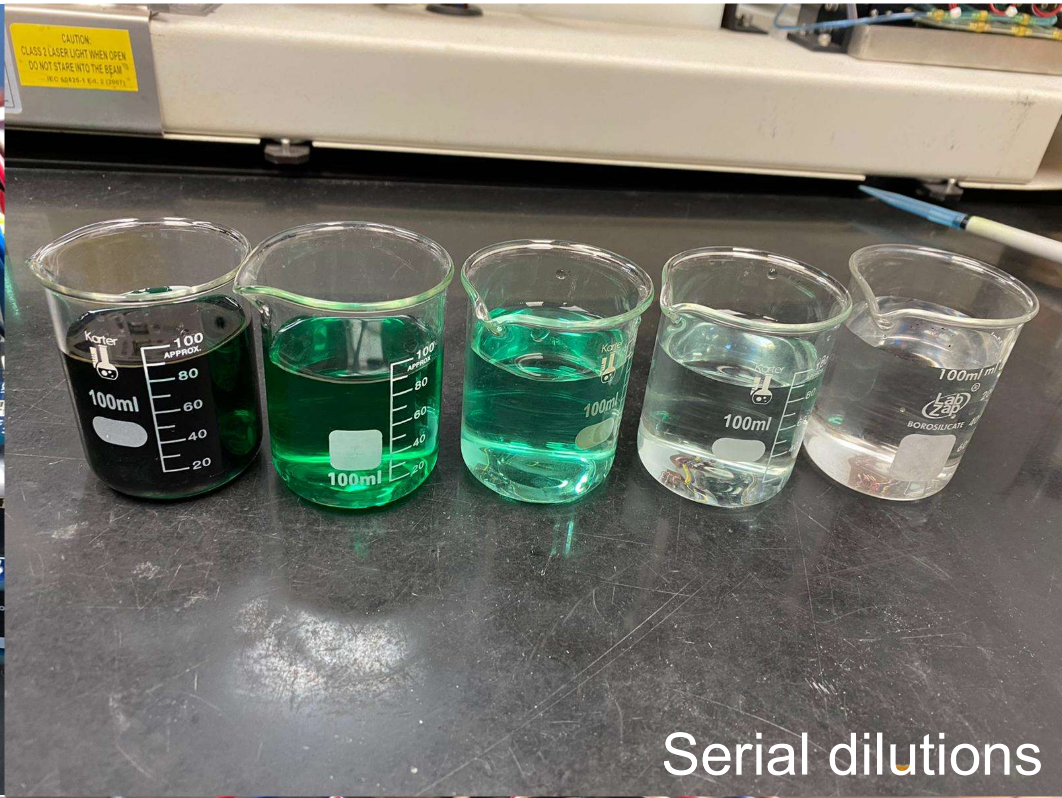
3D Printed Base

Photoresistor



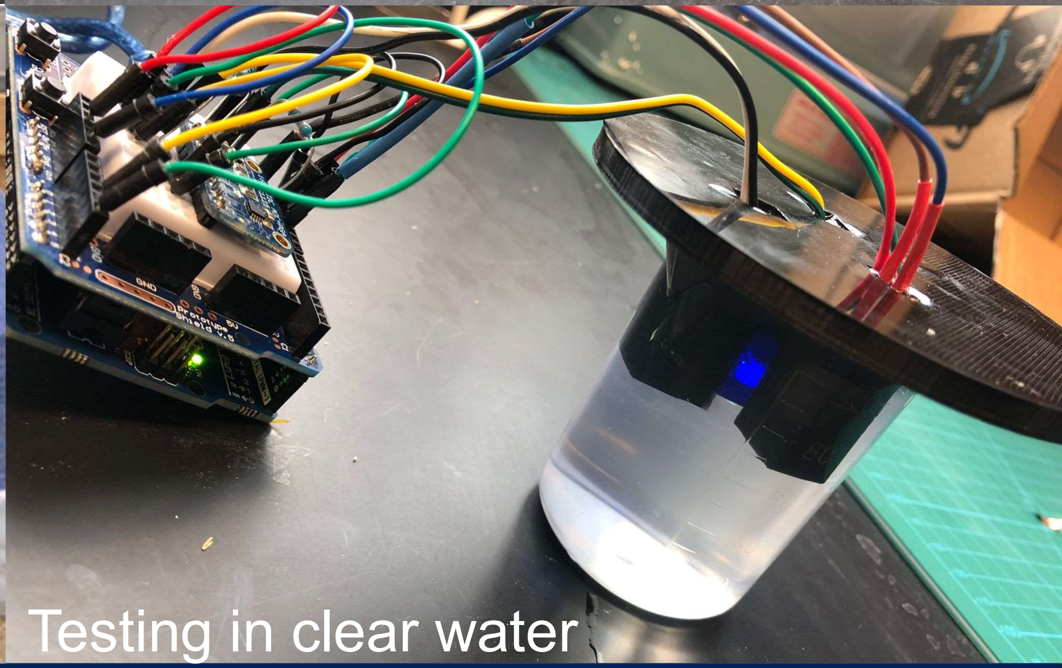
Sensor Housings


Testing in clear water

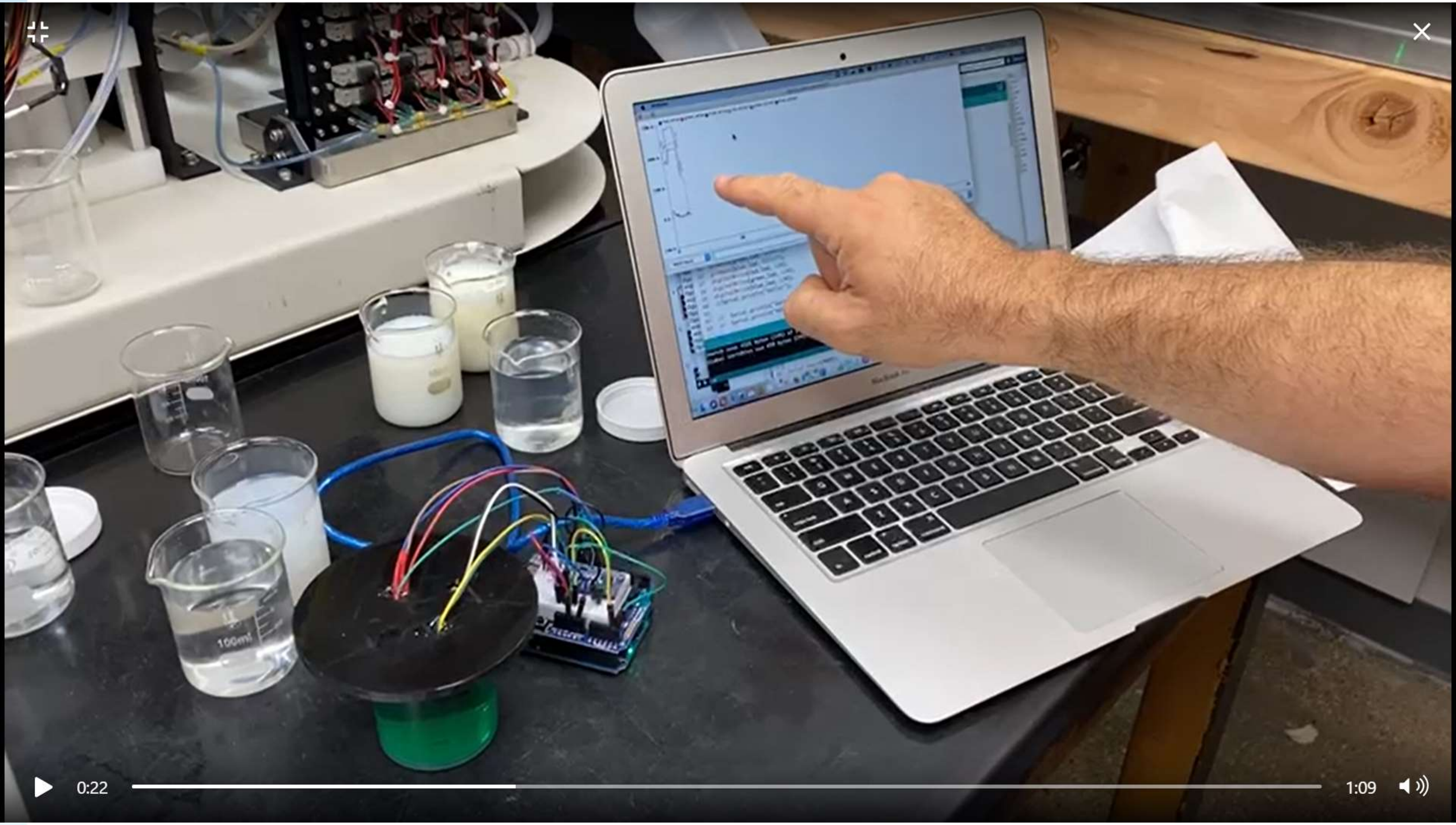


Serial dilutions

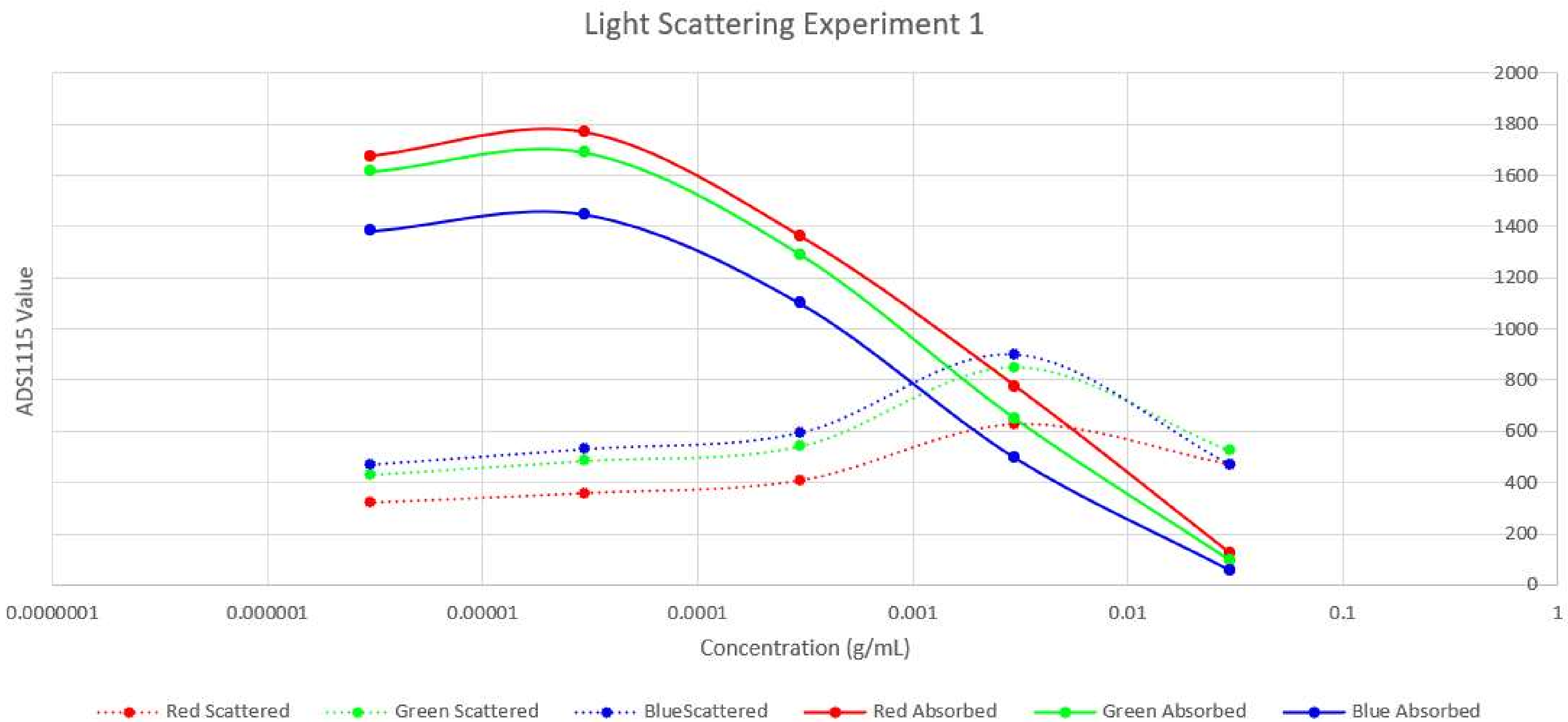
Creating serial dilutions


Testing in clear water

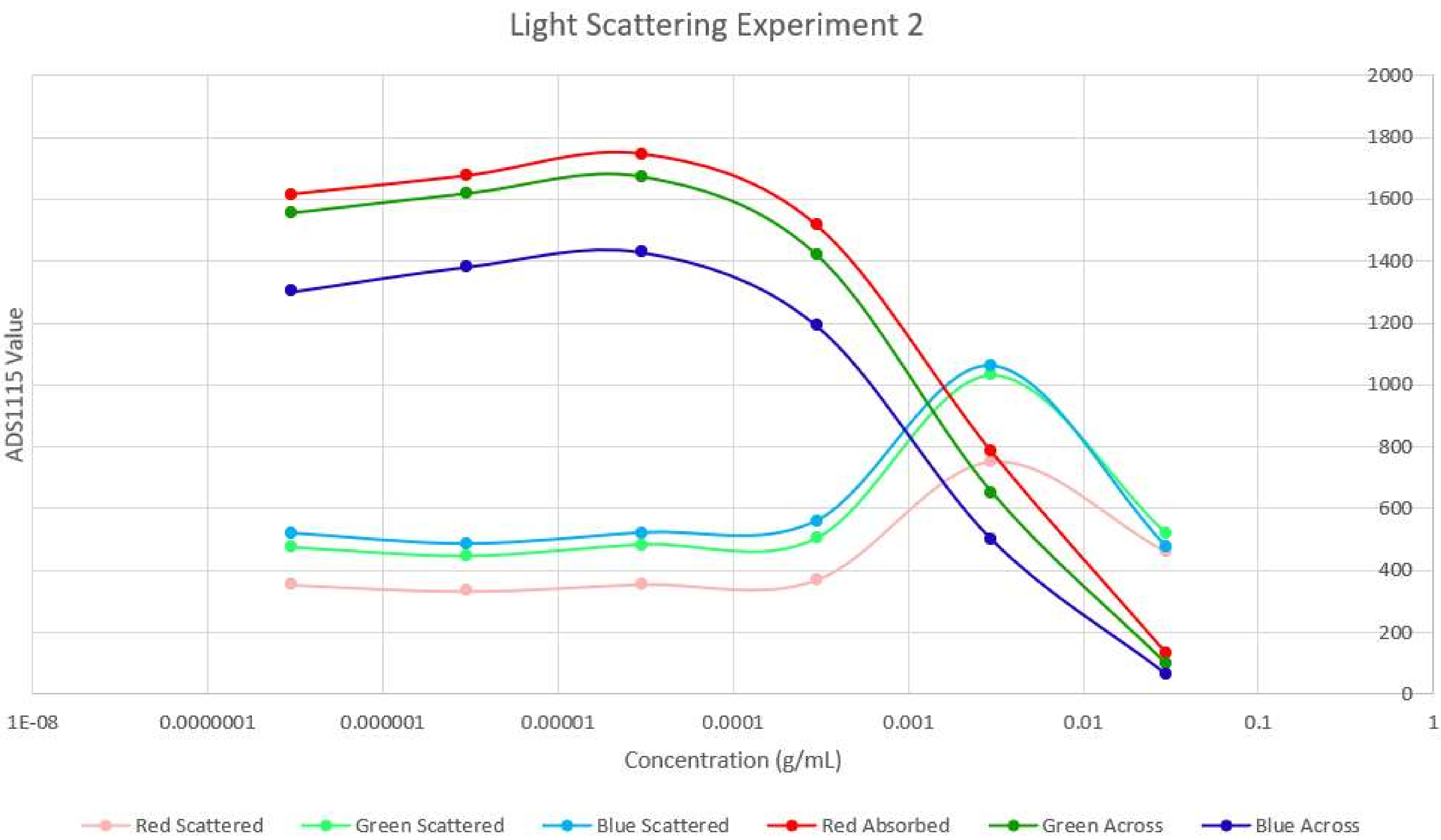
Transmission & Scattered Light Development Test



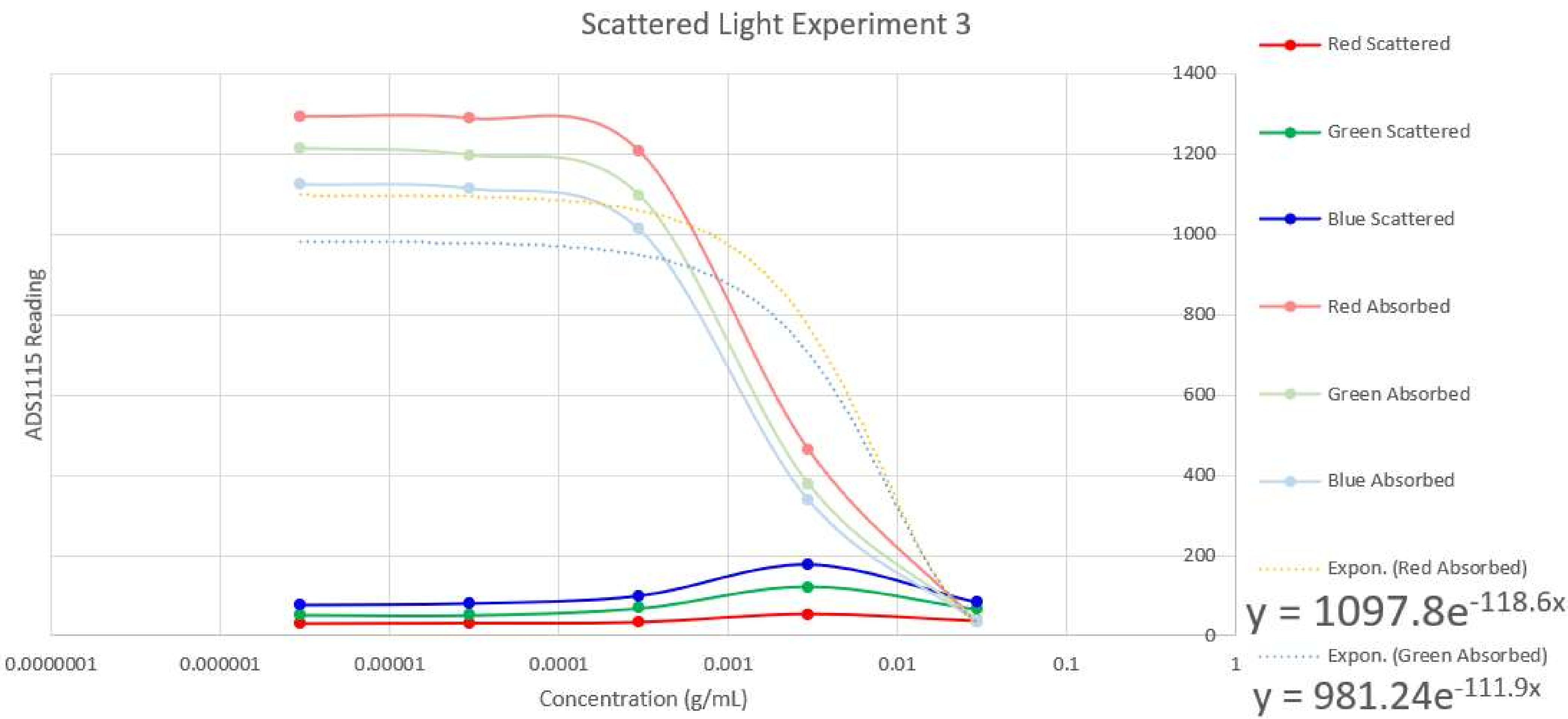
Turbidity Data



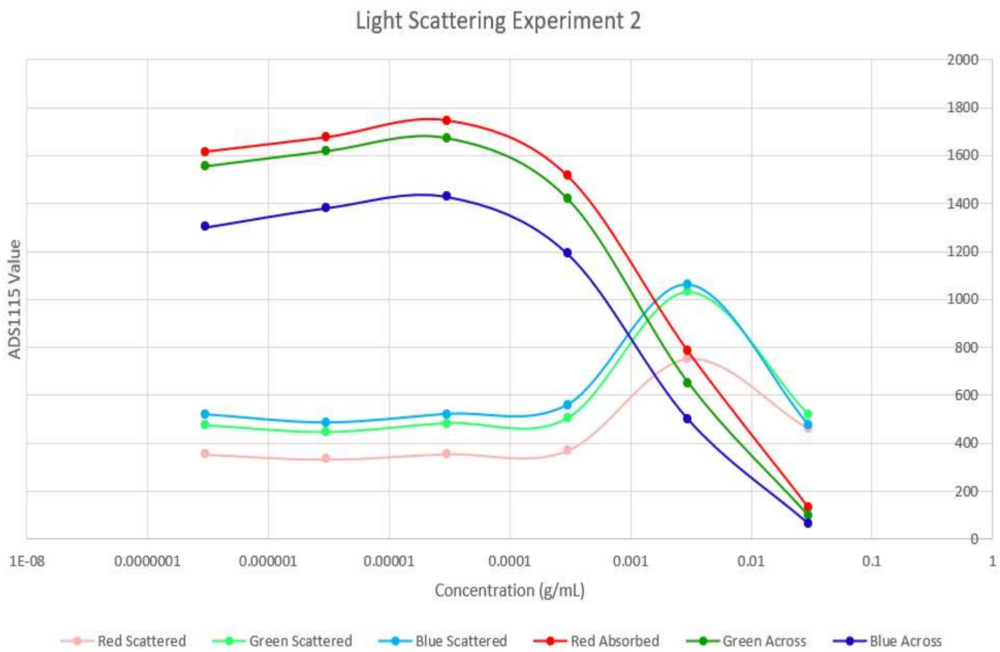
Turbidity Data

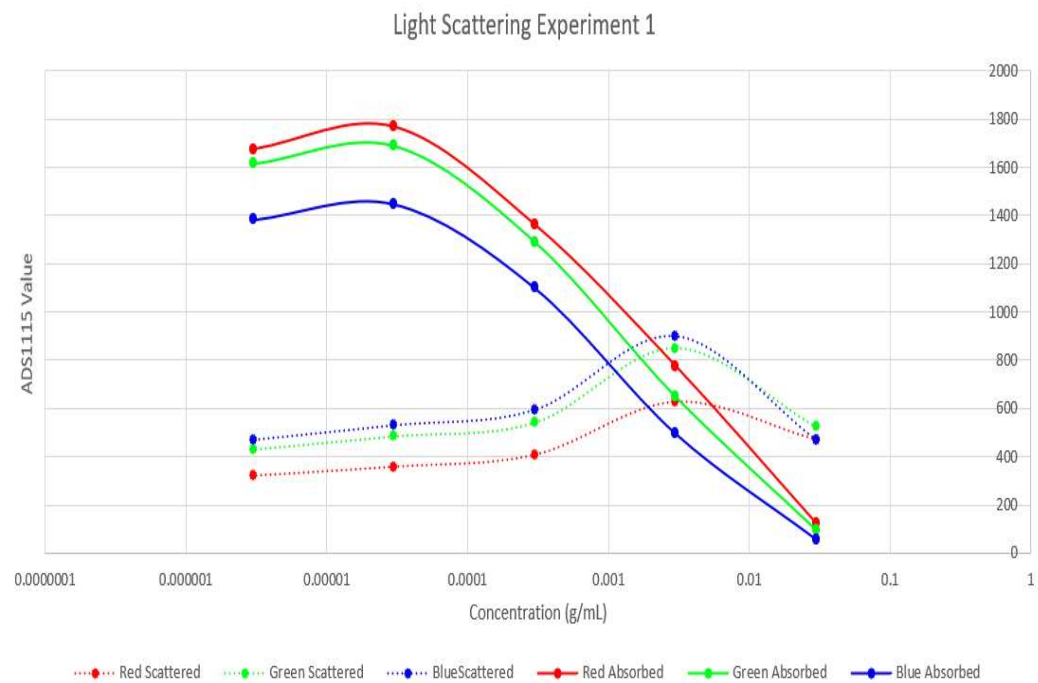


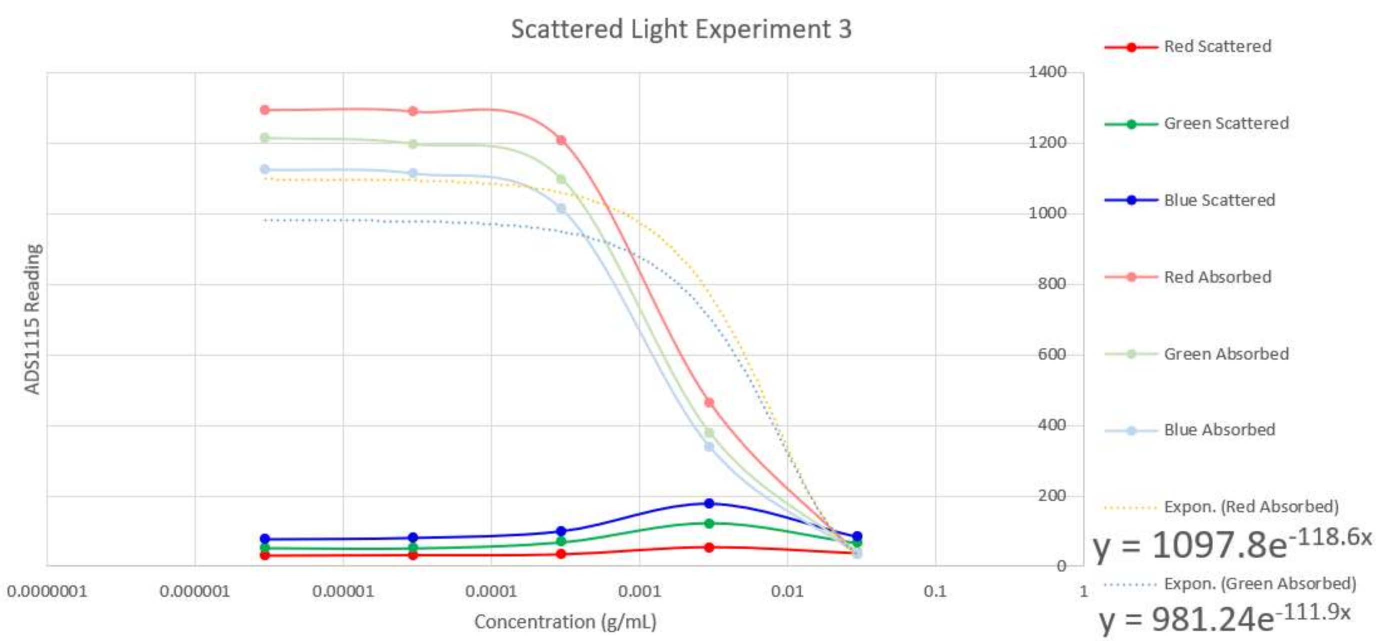
Turbidity Data



Turbidity Data

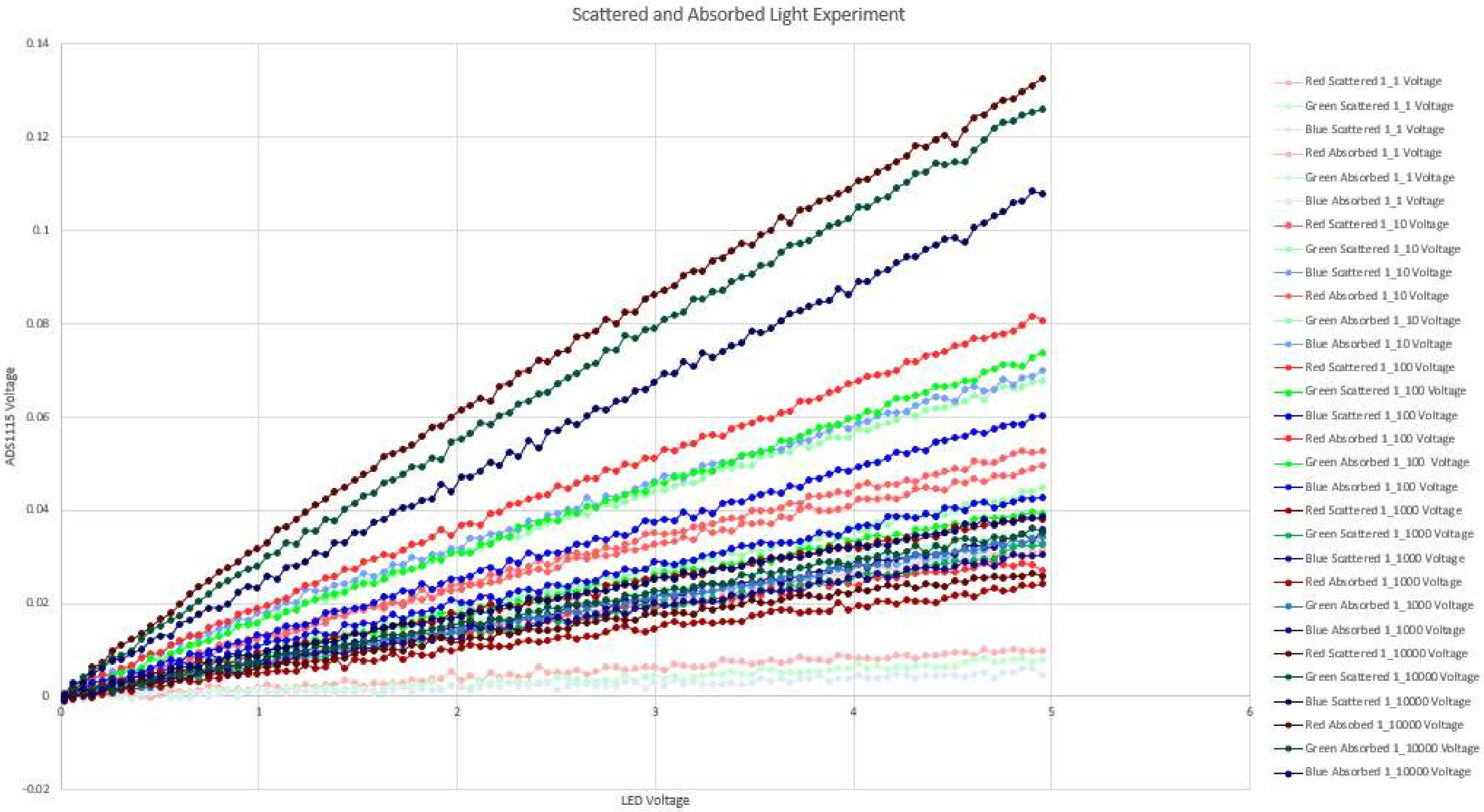






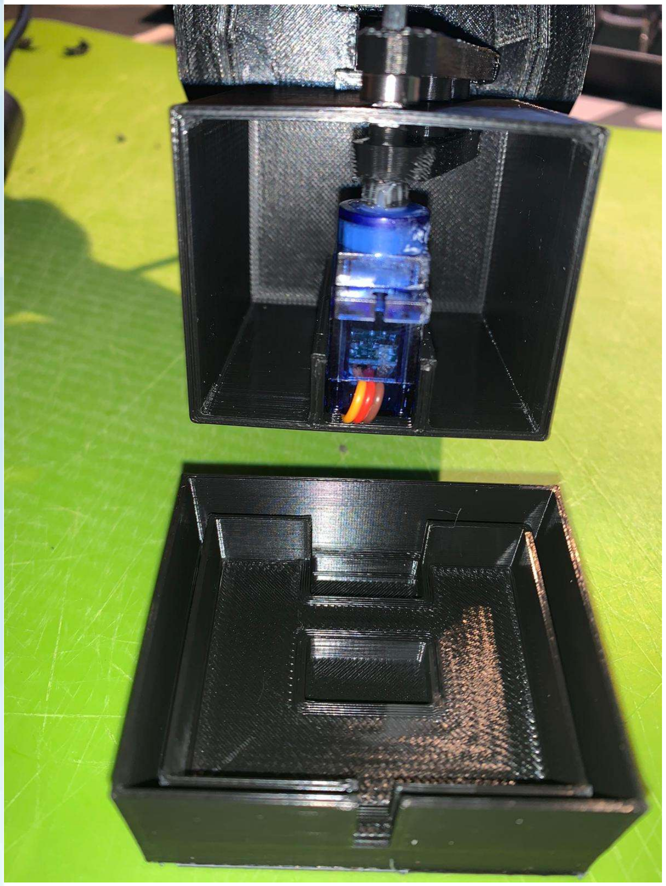
Turbidity Data

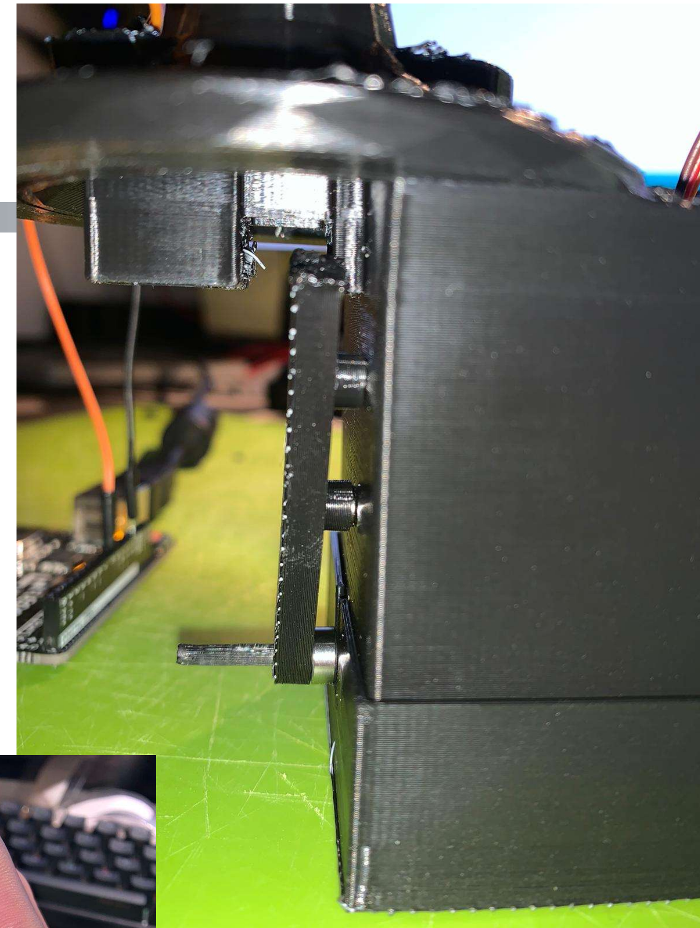
- Scattered and transmitted light scales linearly with LED intensity

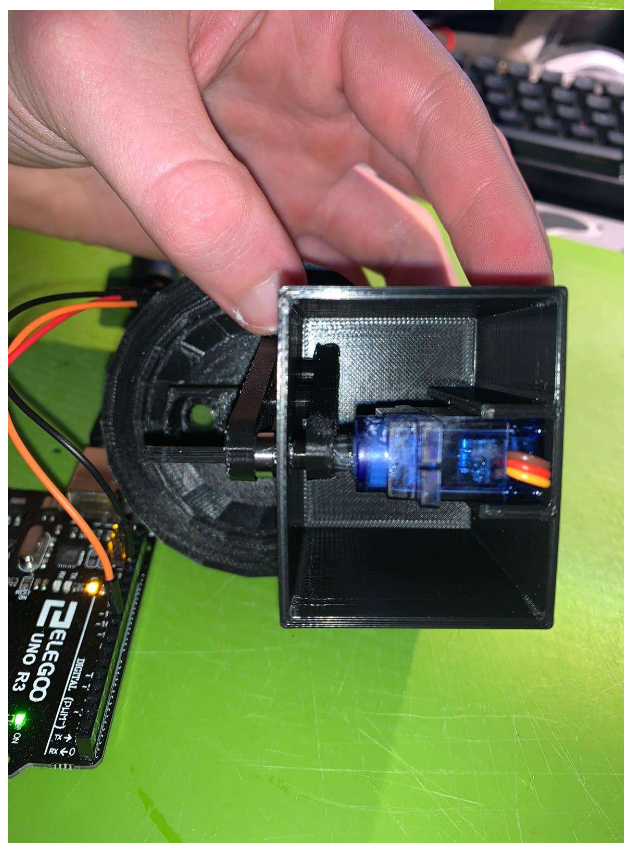


Future Turbidity Updates

- Additional magnetic wiper design
- Use of Formazine for calibration







Commercial Turbidity Sensor

* Nephelometric Turbidity Units (NTU)

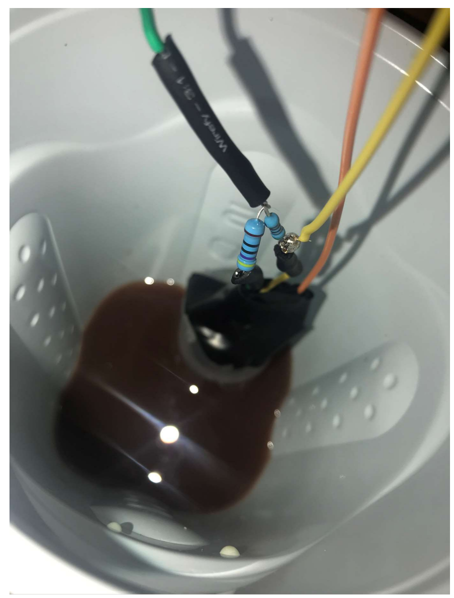
Substance	Voltage	NTU
Nominal	4.24	-147.651
Coffee Creamer	0.05	-4068.59
Old Orange Juice	2.02	2674.866
Pomegranate Juice	1.77	2300.87
Pickle Juice	4.73	-2258.42

- Turbidity is a measurement of how many suspended particles are in a fluid.
- High water turbidity often indicates low water quality with algae present.
  - A low cost sensor ($9.04) used for washing machines was selected

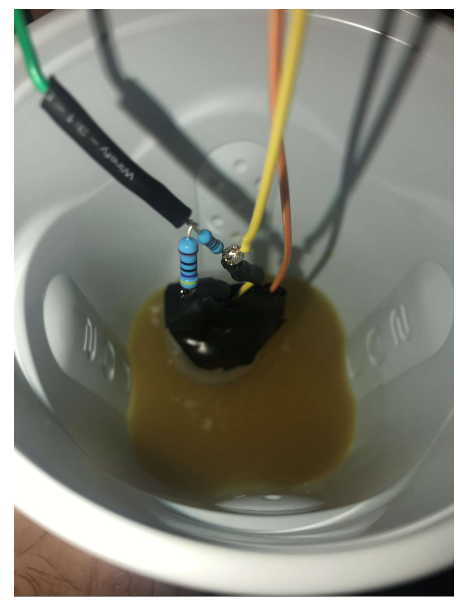
Turbidity Sensor (center)

Coffee Creamer

Pickle Juice



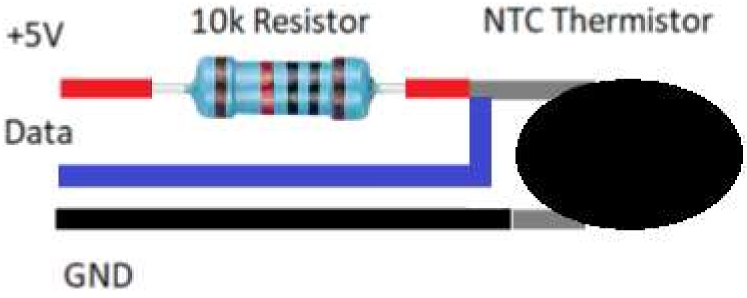
Pomegranate Juice



Old Orange Juice

Sensor Development

- Water temperature is an important metric in understanding algae bloom phenomena. Higher water temperatures allow algae to grow thicker and faster.
  - A low-cost thermistor with voltage divider was used and was mounted on the outside of the buoy as shown.



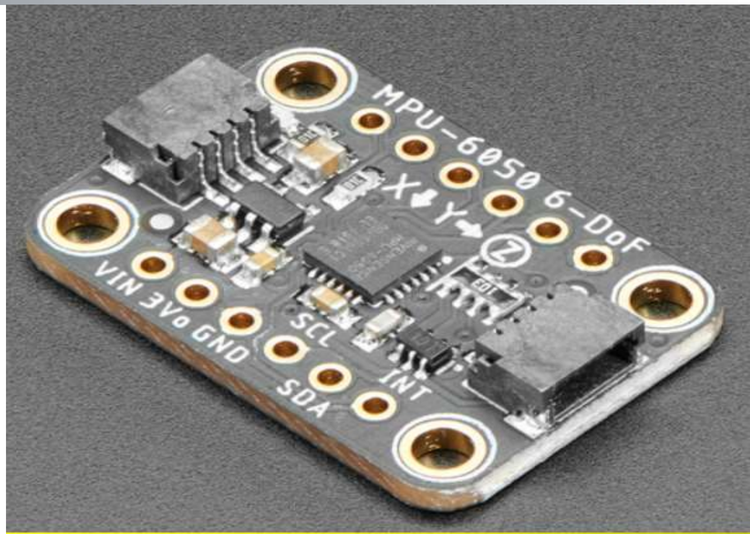
Sensor Development

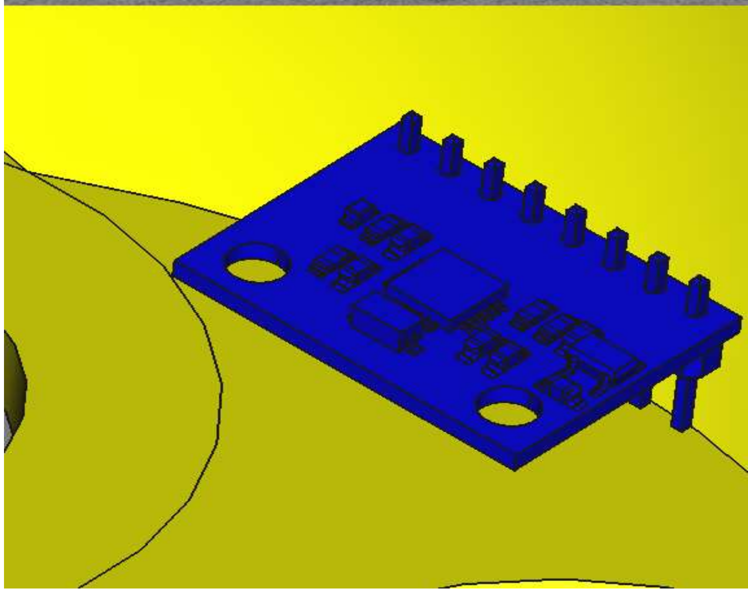
- Power of Hydrogen (pH) is a measurement that is used to determine how acidic or basic a solution is.
- Algae decay after an algae bloom can decrease water pH and increase acidity.
- Increasing CO2 levels in the atmosphere cause an increase in ocean acidity which can be harmful to marine ecosystems.
- The IoT buoy has 1 low-cost pH probe

Blue pH probe shown at right

MPU 6050 Inertial Measurement Unit

- Provides roll, pitch, yaw rates and linear acceleration
- Will determine buoy's orientation relative to straight down
- These can be used to determine wave height, wave energy, wave period and possibly even wave direction
- $6.95



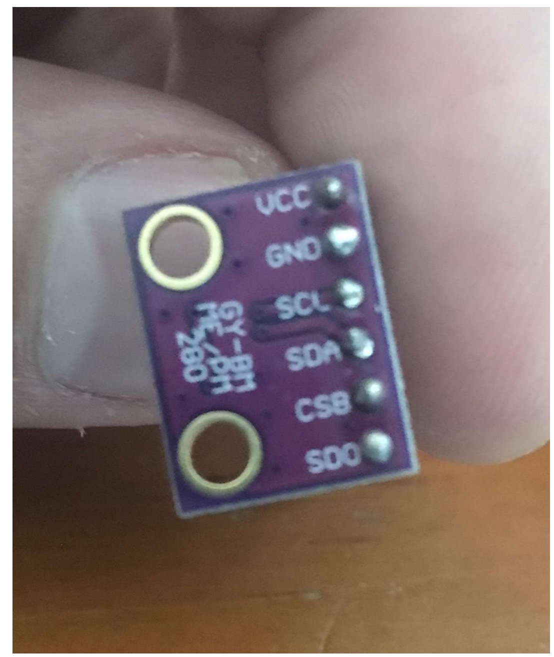


* Two separate versions of MPU-6050 shown

Sensor Development

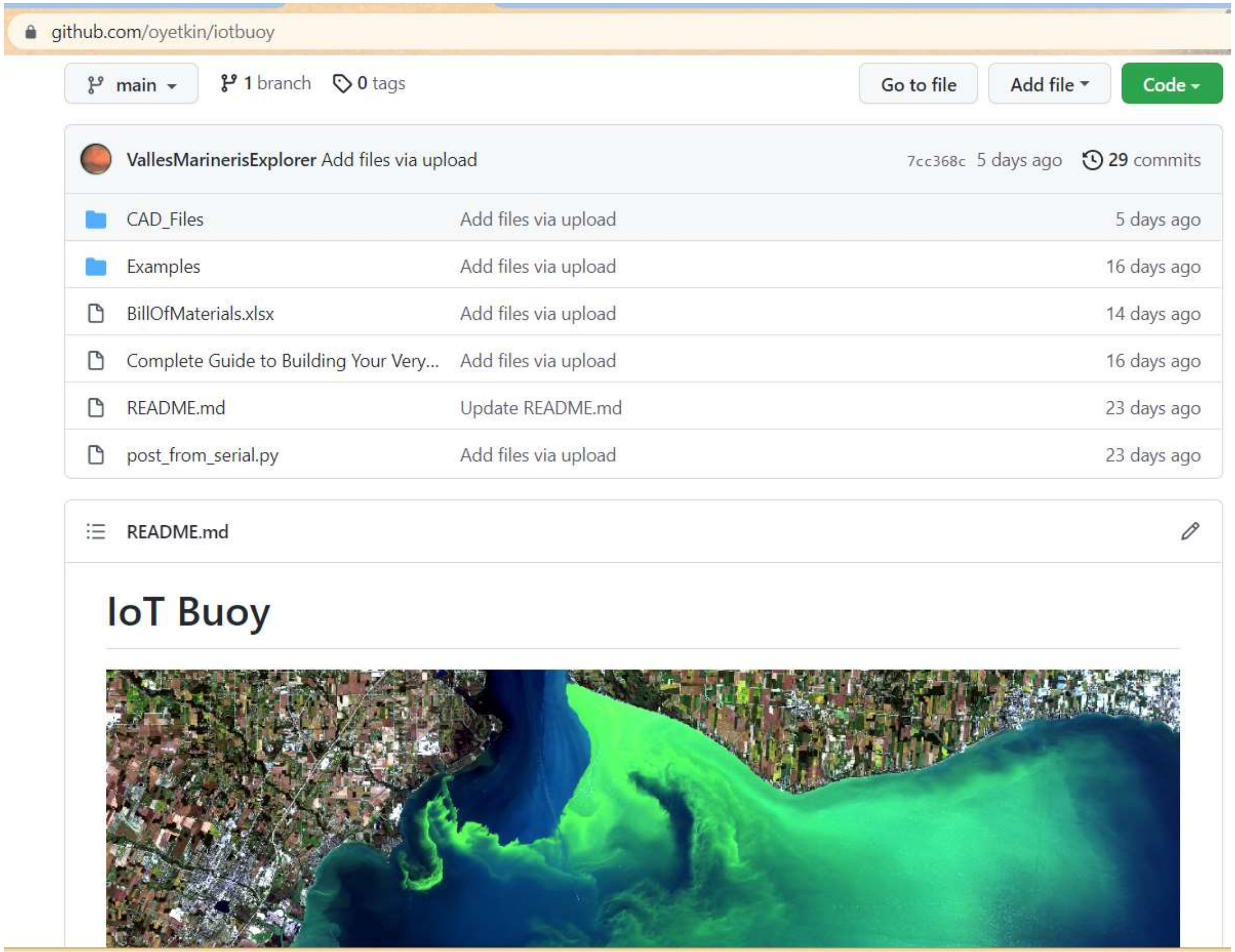
- A BME 280 is a low-cost sensor that can be used to monitor atmospheric pressure, temperature and the humidity of the buoy, which could be useful for machine learning models.
- Internal temperature is important in understanding the health of the buoy
- The BME 280 is frequently used in many IoT applications

BME 280 temperature, pressure and humidity sensor



Documentation

- Created a GitHub page
- Created a manual for building this algae monitoring buoy
- CAD files are available on the GitHub



Future Buoy Improvements

- Creation of some / no assembly required buoy kits
- Improvement of visualization tools
- Use of relays and timers for buoy power savings
- Create a Printed Circuit Board to minimize wiring headaches

Discussion

- What are the most important areas to focus on so that the buoy is usable by scientists?