Critical Design Review

ECOspec

Microplastic Detection via Raman Spectroscopy

ECO spec
RAMAN DETECTION

GROUP #6

MEMBERS

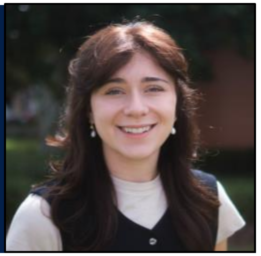
Sophia Adams (PSE)

Michael Rusinko (PSE/EE)

Logan Sullivan (CPE)

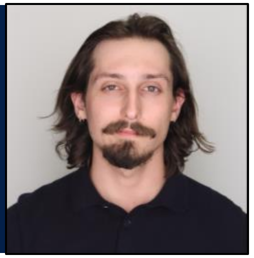
Landon Morjal (CPE)

PROBLEM, MOTIVATION, & PROJECT SOLUTION

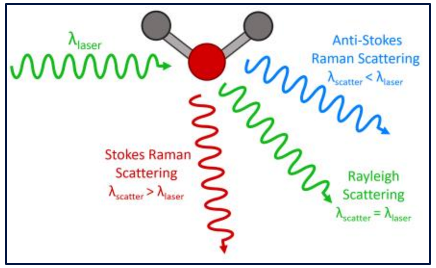


- **Environmental contamination from microplastics** poses a **global health issue**
  - Detecting and identifying contamination from microplastics is key for understanding their impact
- **Current solutions are limited**
  - Manual inspection slow, human error
  - Plastic identification burn methods destroys the sample
  - Lab grade micro-Raman systems are expensive $75,000 +
- **ECOspec is a compact Raman spectroscopy system** designed to detect and identify microplastics in water
  - Our project lays the groundwork for an electro-optical solution to improve environmental monitoring, water quality analysis, and research into microplastic pollution

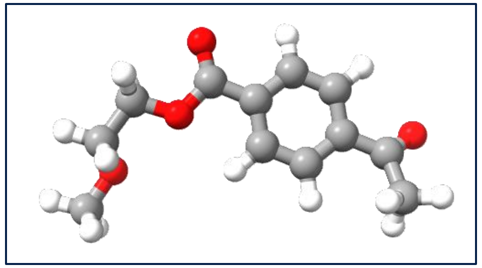
BACKGROUND



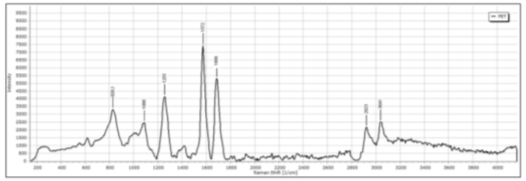
- **Scattering**
  - There are two main categories of scattering: elastic and inelastic
    - **Elastic**: Photon does **not** experience change in energy (common)
    - **Inelastic**: Photon experiences change in energy (uncommon)
  - **Raman Scattering** is **inelastic** and occurs ~$1/10^8$ interactions



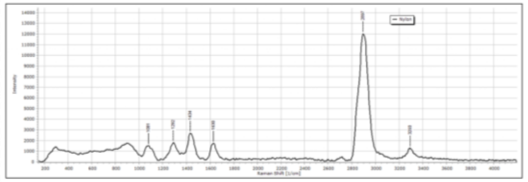
Scattering Diagram



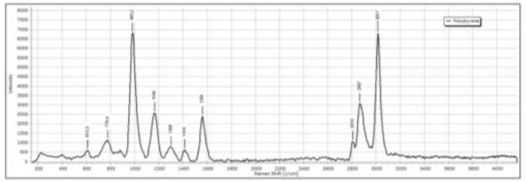
Model of PET from NIH



PET



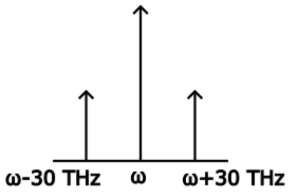
Nylon



Polystyrene

Spectra of Plastics

- **Different molecules have unique Raman spectra**
  - This comes from the ***unique electron clouds*** of the molecules caused by atomic bonds and structures
  - Laser light **polarizes** a molecules electron cloud, causing it to oscillate at optical frequencies (785 nm = 382 THz)
  - The molecule is also vibrating due to heat (@ 10s of THz)
  - ***The laser light oscillates the electron cloud while the molecule is vibrating***
  - The molecular vibration modulates the cloud’s “polarizability”



- **Sideband Generation**
  - Sum/difference frequencies are seen, where the molecules **vibrational modes** add/subtract energy to the incident photon.
  - These sum/diff frequencies correspond to the shifts in energy of Raman scattering
  - ***Each Raman peak is a different vibrational mode of the molecule***

GOALS AND OBJECTIVES

Goals
Collect Raman Spectra of specified polymers 1-5 mm^2 in maximum size
Detect presence of specified plastics using fingerprint spectra
Identify presence of microplastics in size in water
Collect, process, and identify samples in a timely manner
Ensure safety and design for ease of use by users

Objectives
Use a highspeed processor to collect and analyze data
Minimize incident spot size to <10 um in diameter
Expand and collimate beam to maximize use of microscope objective
Choose dichroic mirror to filter unwanted light to maximize signal
Use low loss components such as science grade lenses and gold mirrors
Enclose the system in a housing to remove ambient light and implement interlocks
Ensure safety system and analysis system are run by two different processors

ENGINEERING SPECIFICATIONS

Engineering Requirement	Specification	Unit
High spectral resolution so common polymer raman peaks can be resolved clearly with enough detail to distinguish one from the other for plastic identification purposes.	< 10	nm
The user needs to know the **smallest size of microplastic the system can detect.**	500	um
The device must perform collection and analysis in a reasonable **time frame**	<60	s
Wavelength range must fit the excitation laser wavelength and appropriate expected raman shift.	800 – 1020	nm
Dimensions of device needs to remain user friendly and reasonable.	< 50 x 100 x 100	cm x cm x cm

UCF-SD2-sp2026-G6-ECOspec

Hardware Block Diagram

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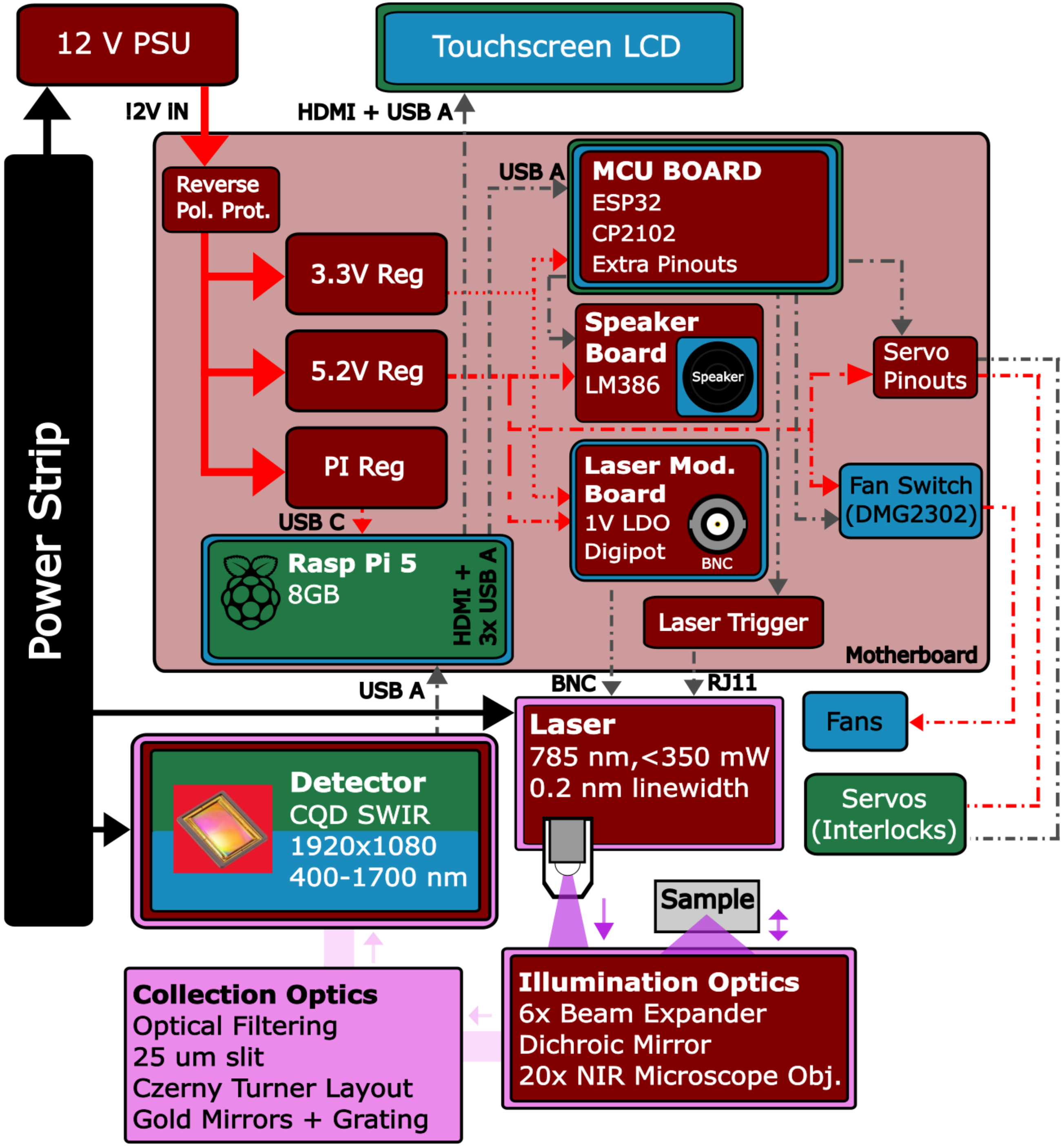
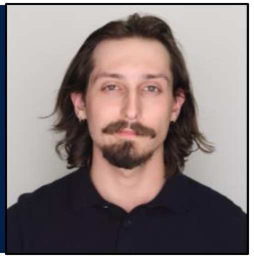
RAMAN DETECTION

Role
- Sophia (PSE)
- Michael (PSE/EE)
- Landon (CPE)
- Logan (CPE)

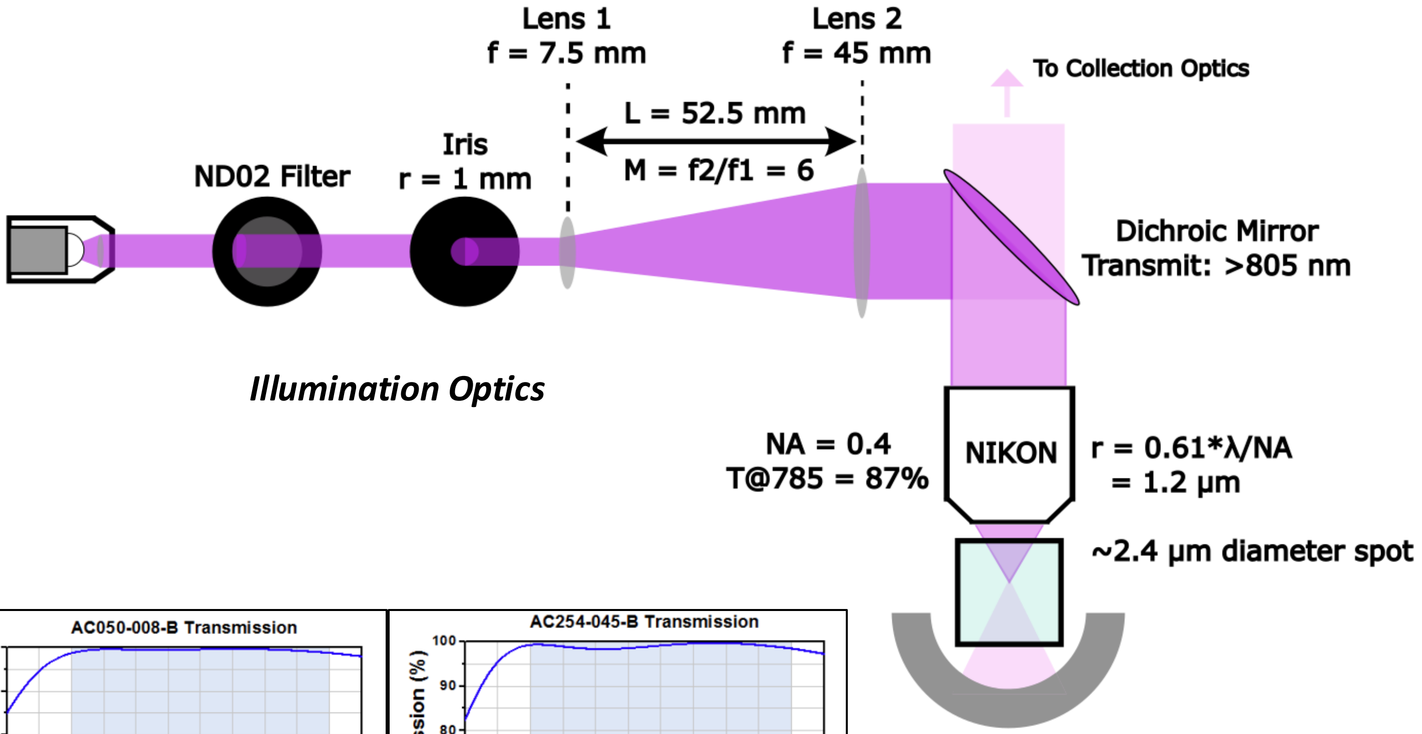
Connections
- 120 V AC
- 12 V DC
- 5.2 V DC
- 3.3 V DC
- DATA
- 785 nm Laser
- Raman Scattering



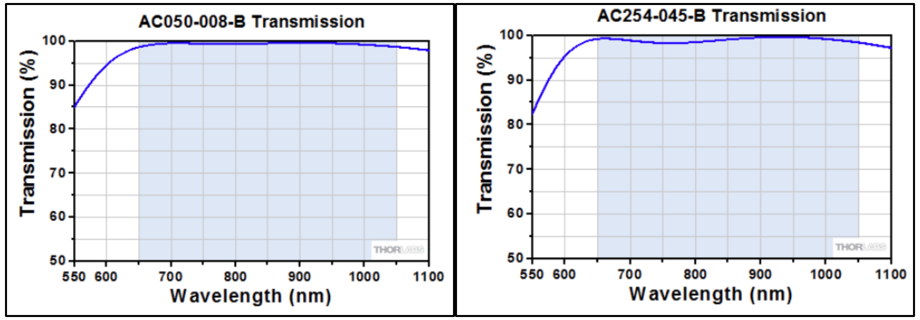


ILLUMINATION OPTICS

- **785 nm Laser**
  - Up to 350 mW output, 0.2 nm linewidth, SMA coupled Fiber output w/ 2.2 mm diam. spot
- **ND filter for retroreflection**
- **6x Mag. Beam Expander**
  - Lenses: AC050-008-B and AC254-045-B
    - B-coating optimal for NIR
- **Dichroic Mirror**
  - Transmits > 805 nm
- **20x Microscope Objective**
  - 0.4 NA, Infinity-corrected, 12 mm aperture
- **Quartz Cuvette to hold sample**

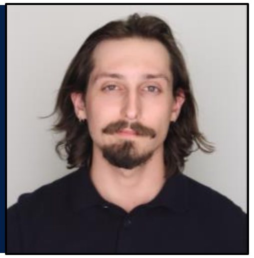


Illumination Optics



Transmission vs. Wavelength for Lenses 1 & 2

ILLUMINATION OPTICS



Power Calculations

P_{in} = 120 mW

Beam Radius = 1.1 mm

$A = \pi * r^2$

$A_{1mm} = \pi$

$A_{1.1mm} = \pi*(1.1)^2$

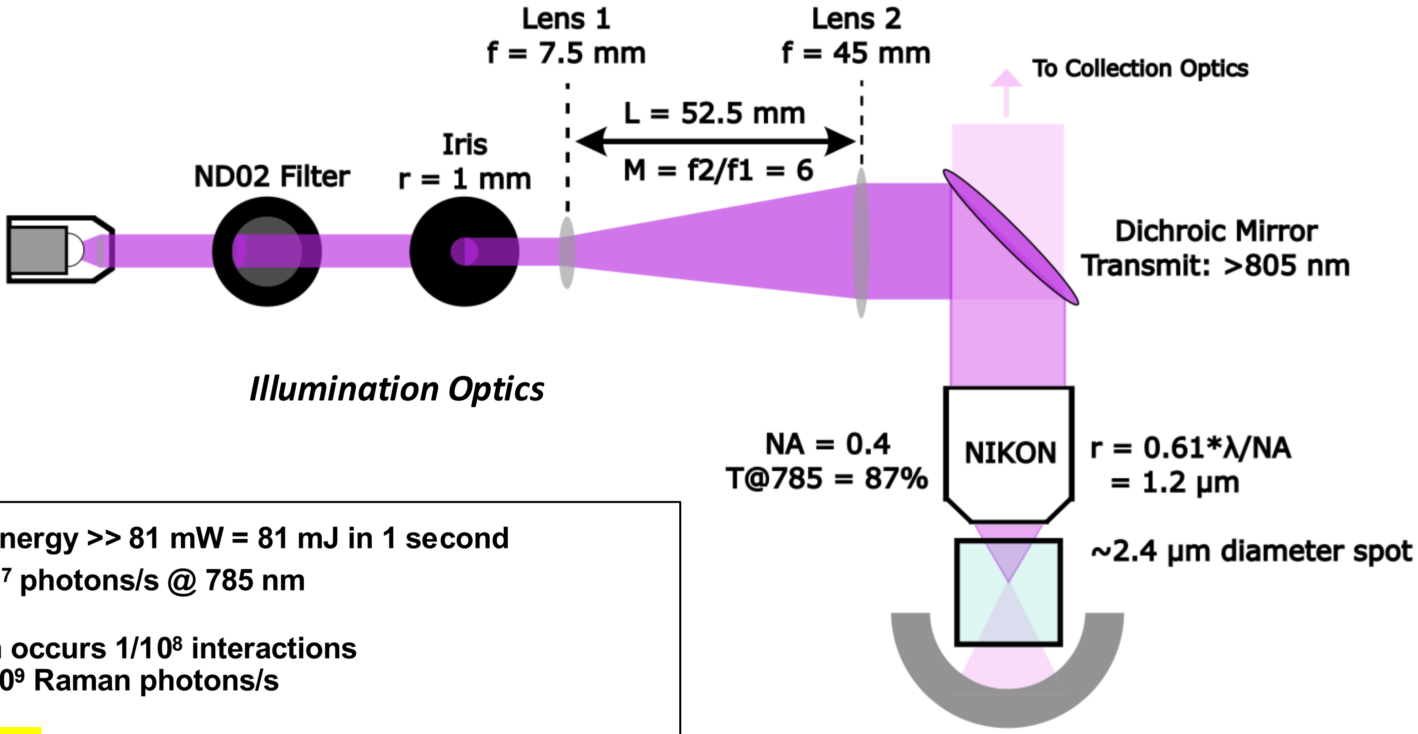
$T = A_{1mm} / A_{1.1mm} = 0.826$

P_{loss} = 120*(1-.826) = ~21 mW

Use ND Filter to reduce retroreflection and speckle if needed (ND02 = 63%Tx)

$P_{incident}$
= 120 mW * .8 * .99 * .99 * .99 * .87
= 81 mW incident on sample

Intensity
= $80*10^{-3}$ (W) / $2.4*10^{-6}$ (m)
= 33750 W/m^2



Illumination Optics

Total energy >> 81 mW = 81 mJ in 1 second
$3.2*10^{17}$ photons/s @ 785 nm

Raman occurs $1/10^8$ interactions
= $3.2*10^9$ Raman photons/s

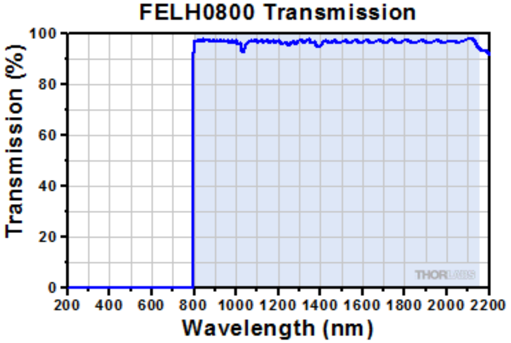
@ 935 nm
>> $2.126*10^{-19}$ J/photon
>> 0.680 nJ of Raman scattering per second

1 mW = 0 dBm
1 uW = -30 dBm
1 nW = -60 dBm
0.5 nW = -63 dBm >> 0.68 nW = -61.7 dBm Raman

COLLECTION OPTICS SELECTION

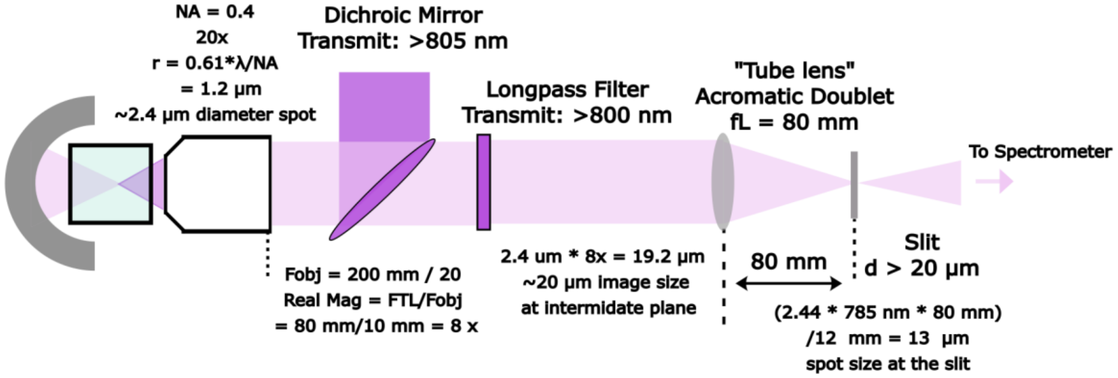
- **Finite vs infinity-corrected objective**
  - Finite microscope objective will introduce spherical aberrations with filters
  - Choice: infinity-corrected objective with a tube lens
    - AC254-080-B-ML, 650-1050 nm, acromatic doublet

- **Additional Laser Filtering**
  - Longpass vs Notch filter
  - Choice: Longpass filter



- **Slit size design choice**
  - 20 um
  - Smaller slit size improves resolution and reduces spherical aberrations, but also reduces optical power reaching detector
  - Optimize trade-off by matching real image size produced by objective to slit size

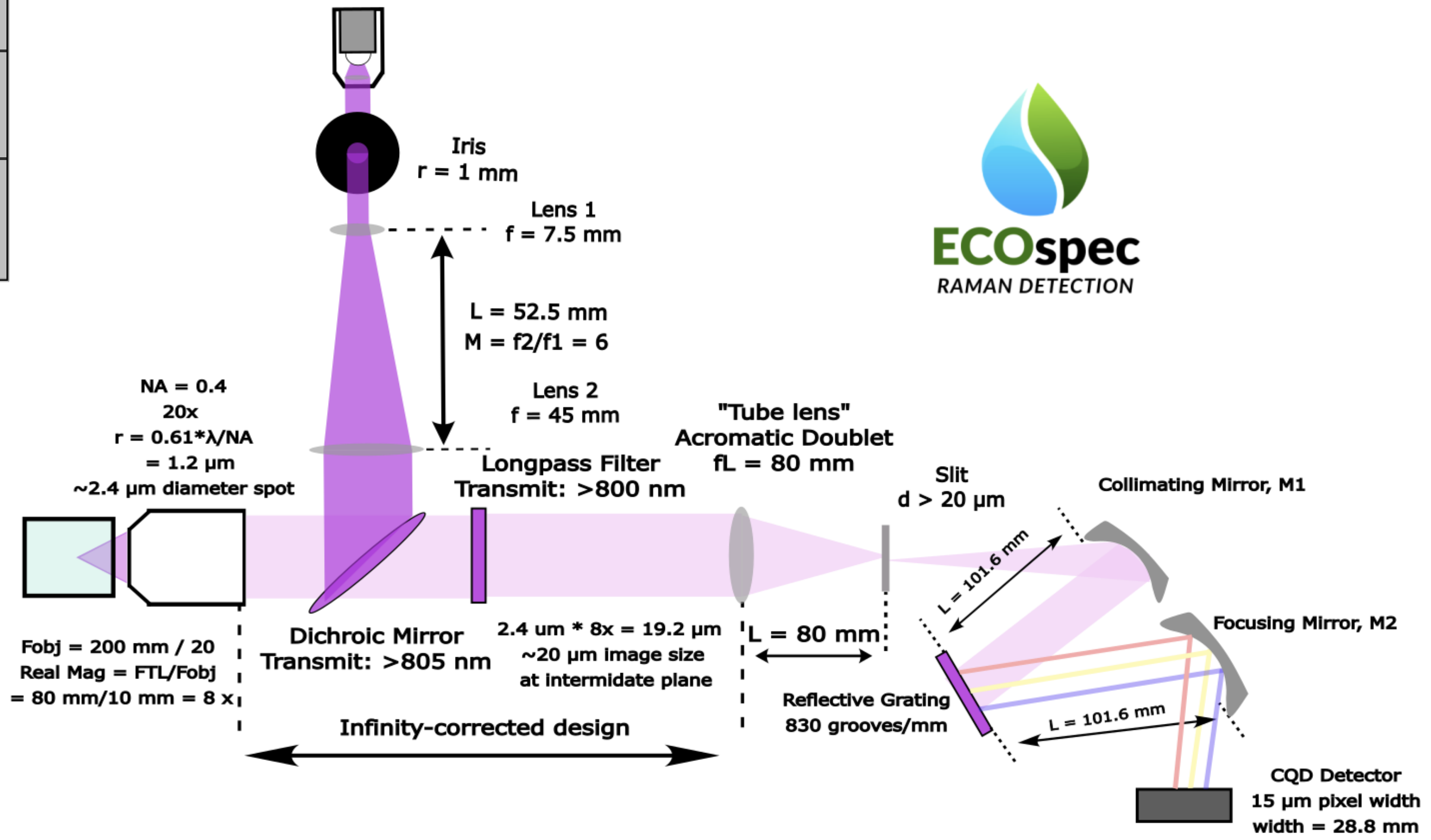
	800 nm Longpass Filter	785 Notch Filter
Vendor	Thorlabs, FELH0880	Thorlabs, NF785-33
Transmission Range	823-2510 nm	590-760 and 820-1040 nm
Rejection Range	200-785 nm	N/A
Cost	$169.26	$635.55



SPECTROMETER DESIGN & HARDWARE SELECTION

	Spectrometer Specification
Raman Shift Range	0 – 3200 cm^{-1}
Wavelength Range, Center	780 – 1050 nm, 915 nm
FHWM @ 785 nm	0.7 nm, 10 cm^{-1}

- **Spectrometer type:** Czerny-turner spectrometer
- **Collimating/focusing mirror selection**
  - Spherical, gold coated
  - reflectance > 94%, gold coated
  - Focal length 101.6 mm
- **Ruled Diffraction grating selection**
  - Groove density: 830 groves/mm
  - Blaze wavelength: 800 nm



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RAMAN DETECTION

SPECTROMETER DESIGN CALCULATIONS

- **Spectral resolution assuming we illuminate entire slit:** 0.2345 nm
  - Goal: 0.7 nm FWHM

- **Minimum detector length** for our wavelength range (270 nm) and pixel size (15 microns) = 16.875 mm
  - **Selected detector length:** 28.8 mm

- **Maximum grating groove density** for our wavelength range to ensure longest wavelength (1050 nm) does not exceed the diffraction limit at 90 degrees: 952.3 lines/mm
  - **Selected grating groove density:** 830 lines/mm

$$\omega_{slit} = \frac{G\,\Delta\lambda\,L_c}{cos(\alpha)}$$

$$20\ um = \frac{830\ g/mm\ \ \Delta\lambda\ \ 101.6\ mm}{cos(7.7607)}$$

$\Delta\lambda$ = 0.234 nm = 4 - 15 cm^{-1} (wavelength dependent)

$$L_{d,min} = \frac{2.5{*}w{*}(\lambda range)}{\Delta\lambda}$$

$$L_{d,min} = \frac{2.5{*}15\ um{*}(270\ nm}{0.6\ nm} = 16.875\ mm$$

$$G_{max} = \frac{1}{\lambda max{*}10^{-6}}$$

$$G_{max} = \frac{1}{1050\ nm\ {*}10^{-6}} = 952.381\ \text{lines/mm}$$

PROCESSING COMPUTER COMPARISON

- **Onboard processing:** A Raspberry Pi 5 handles camera communication and spectral data processing.
- **Linux compatibility:** Runs Linux and supports the camera SDK, enabling onboard analysis without an external computer.
- **Avoids Windows dependency:** OEM imaging software is Windows only, using the SDK allows full camera control on Linux without virtual machines.
- **Simplified integration:** SDK supports custom Linux GUIs and UART commands for camera control (TEC temperature, integration time, pixel data).

Specs	Raspberry Pi 5	NVIDIA Jetson	External PC
Processor	Broadcom BCM2712 Arm Cortex-A76	ARM Cortex-A57	N/A
Clock Rate	2.4 GHz	1.43 GHz	2.4+ GHz
RAM	8 GB	4 GB	8 GB+
Storage	Custom with microSD	Custom with microSD	Custom with SSD/HDD
Operating Voltage	5 V	5 V	N/A
Max Current	5 A	2 A	N/A
Max Power Draw	25 W	10 W	N/A

MCU COMPARISON

- **MCU-based control:** An MCU is sufficient for control and safety, an FPGA is unnecessarily complex.
- **Independent safety system:** The MCU operates separately from the Raspberry Pi to ensure reliability.
- **ESP32 functionality:** A dual-core ESP32 manages safety interlocks, laser power, and status indicators.
- **Fail-safe shutdown:** The laser turns off if interlocks fail, doors open, or runtime limits are exceeded.

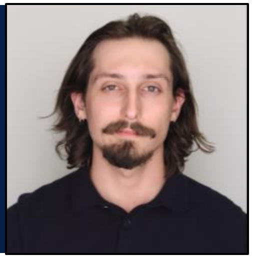
	ESP32	Teensy 4.1	STM32
Max Clock Rate	240 MHz	600 MHz	168 – 250 MHz
Dual Core	Optional	Optional	Optional
Flash Memory	4 MB	8 MB	16 – 128 KB
I/O Ports	36	40	40
Operating Voltage	3.3 V	3.3 V	3.3 V
Max Current Draw	500 mA	~150 mA	~150 mA

LCD COMPARISON

- **Standalone system design:** A Raspberry Pi enables us to operate without an external PC.
- **Integrated display choice:** An onboard LCD simplifies user interaction and avoids complex external communication setups.
- **Improved data visibility:** Larger screen size and higher resolution make Raman spectra easier to view and interpret.

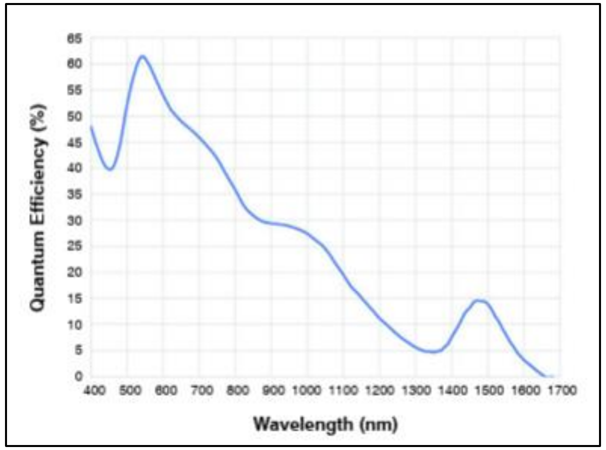
Specs	Geeekpi 10.1” Touchscreen	Waveshare 7” LCD	Raspberry Pi Official 7” Touchscreen
Screen Size	10.1 inches	7 inches	7 inches
Resolution	1024 x 600	1024 x 600	800 x 480
Touch Capability	Capacitive Touchscreen	Not Touchscreen	Capacitive Touchscreen
Interface	HDMI	HDMI	DSI (Ribbon)
View Angle	178 degrees	170 degrees	170 degrees
Power Supply	5 V DC	5 V DC	5 V DC (GPIO)
Raspberry Pi Compatible	Yes	Yes	Yes
Dimensions	9.25" W x 5.59" H	6.5" W x 4.5" H	6.5" W x 4.25" H
Cost	$60	$45	$80

ELECTRICAL - DETECTOR



- **onSEMI ACUROS 2MP CQD SWIR**
  - 400-1700 nm
  - Integrated TEC
  - USB interfacing
  - Normalized Uniformity Correction (NUC) Table
  - ePleora SDK compatible with Linux
  - GenICAM

Dynamic Range: 70 dBm = 20log(FWC/noise)
Read Noise: 80 e- /pix
\>> Full Well Capacity: 252982 e- /pix
Max integration time = 30 ms = 33 FPS



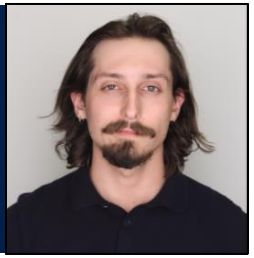
Q.E. vs. Wavelength (nm)

81 mW incident > **0.68 nW = -61 dBm Raman signal**
= 0.68 nJ * 0.03 = .0204 nJ in 1 frame
\>> 95*10^6 Raman Photons/frame
Spread over 200 pixels = ~ 475K photons/pix/frame
\>> 475K * 27% Q.E. = ~128K converted photons

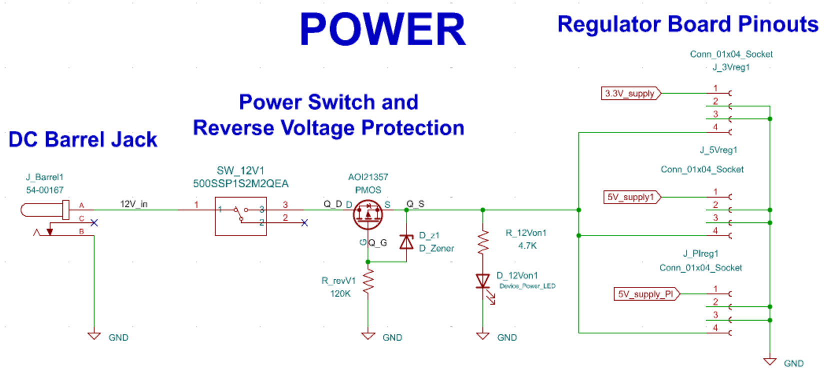
128K photons is greater than 80 e-
\>> **127.9K available photons/pixel above noise @ 120 mW output**

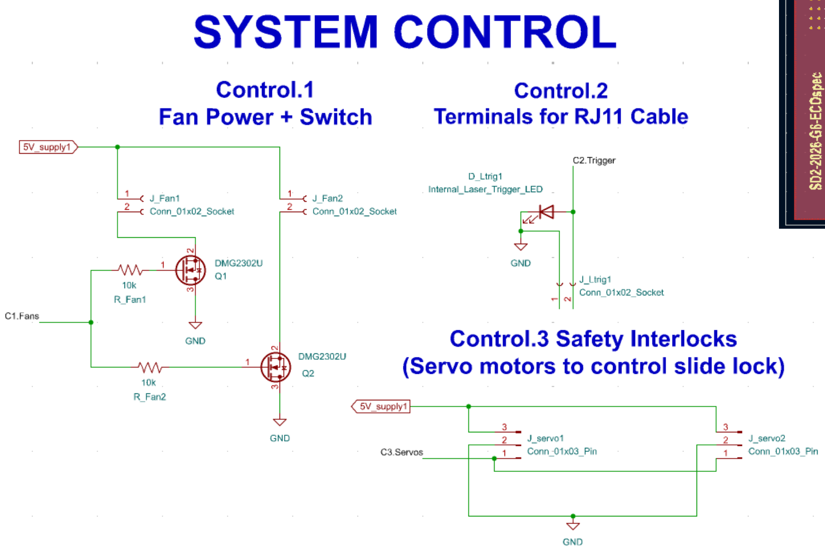
Laser	Detector	Range	QE at laser	QE at Δ+200nm	Pro	Con	Expense
785	ACUROS **CQD SWIR** (2.2 MP)	700-1400	50%	25%	Has SDK USB Interface Integrated Stage 1 TEC for +10 C	Very big Difficult interfacing	Borrow
785	**CCD** | Hamamatsu S10141 (2000 x 500)	200-1100	75%	20%	High sensitivity in NIR Stage 2 Integrated TEC for –14 C	Would need to design…, TEC control, signal amplification	Borrow
785	**CMOS** | Sony STARVIS IMX327 (2 MP)	VIS-NIR	70% relative	12% relative	Easier than CCD	Not cooled, typically has IR filter,	$180
785	**CMOS** | OSRAM OS05A20 (5 MP)	VIS-NIR	N/A	N/A	Easier than CCD	Not cooled	$80
532	**CCD** | Toshiba TCD1304DG	VIS	100% relative	10% relative	More resilient to noise than 785	Would need to design… Not sensitive enough	$13
532	**CMOS** | BlackFly FLIR Sony IMX265 (3.2 MP)	VIS	68.5%	40%	Shown to work with OpenRaman project SDK CMOS are easier to interface	Not cooled	$1000 New, $250 used
532	**CMOS** | Raspberry Pi Cam (8 MP)	VIS	95% relative	40% relative	Easier than CCD Not cooled High resolution	Not cooled, has IR filter	$50

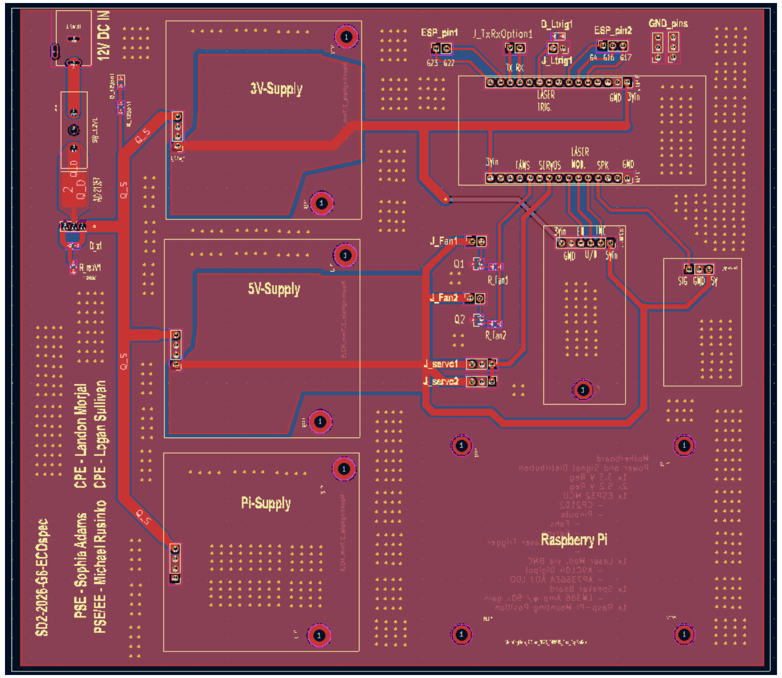
ELECTRICAL - MOTHERBOARD

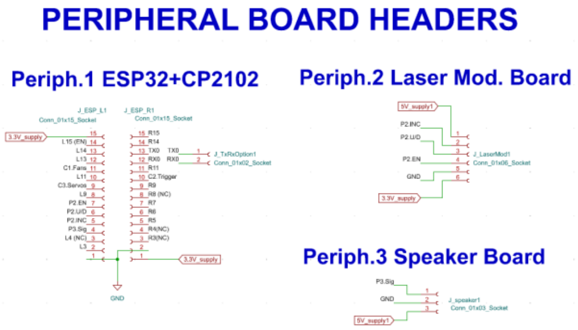


- Power Supply and Signal Distribution Boards
  - Takes in 12 V DC
  - Reverse polarity protection implemented with PMOS
  - Holds headers for MCU board, peripheral boards, fans, servos, and laser trigger

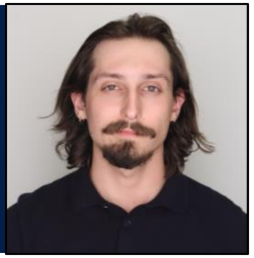


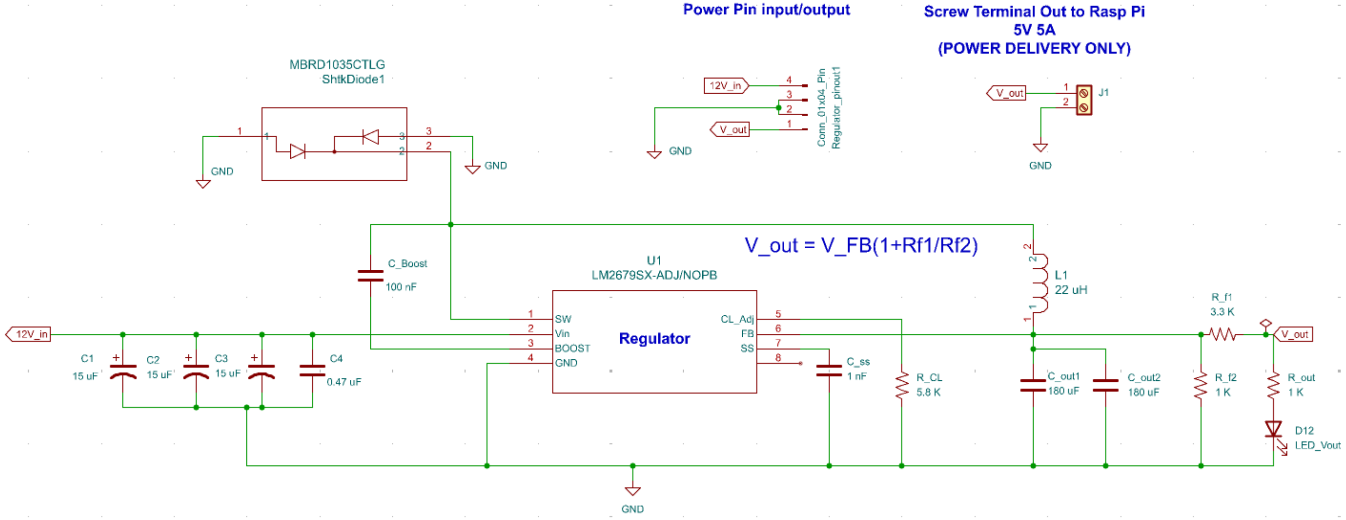


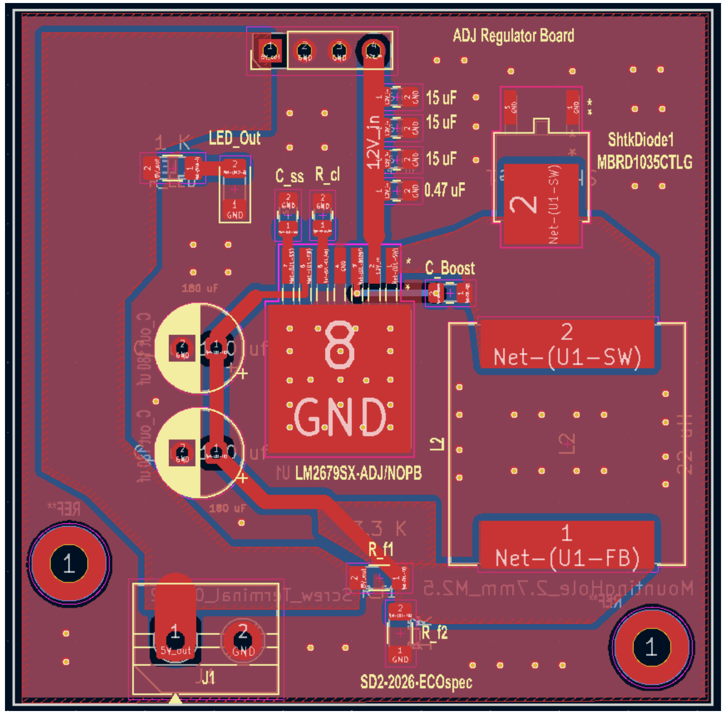




ELECTRICAL - REGULATOR

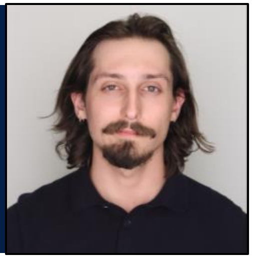




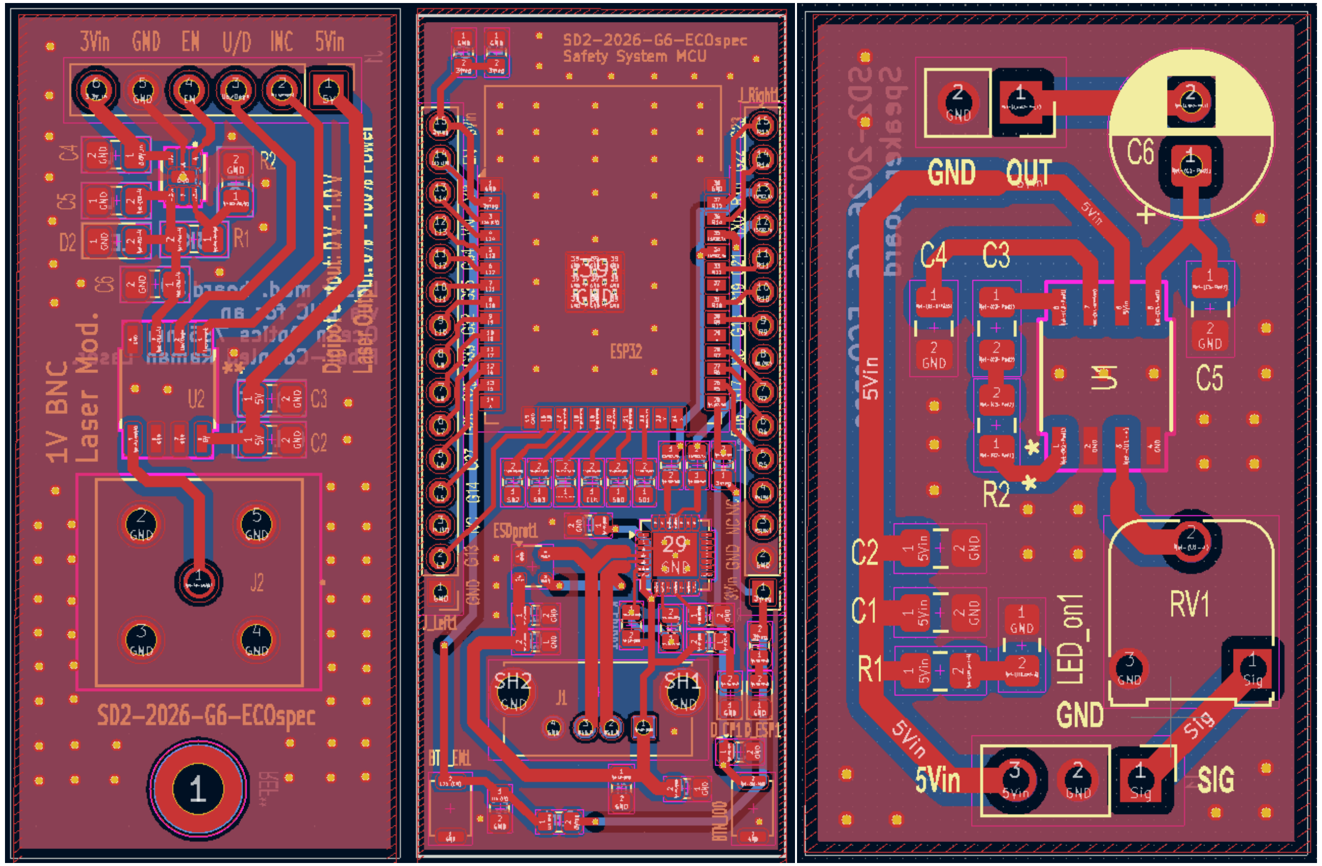


- LM2679SX ADJ Voltage Regulators
  - Modular board for 3.3 V and 5.2 V
  - Screw terminals for access to additional power and for USB-C to Rasp-Pi
  - Up to 5 A of output current, set by R_{CL}

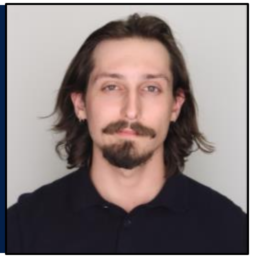
ELECTRICAL – MCU + PERIPHERALS

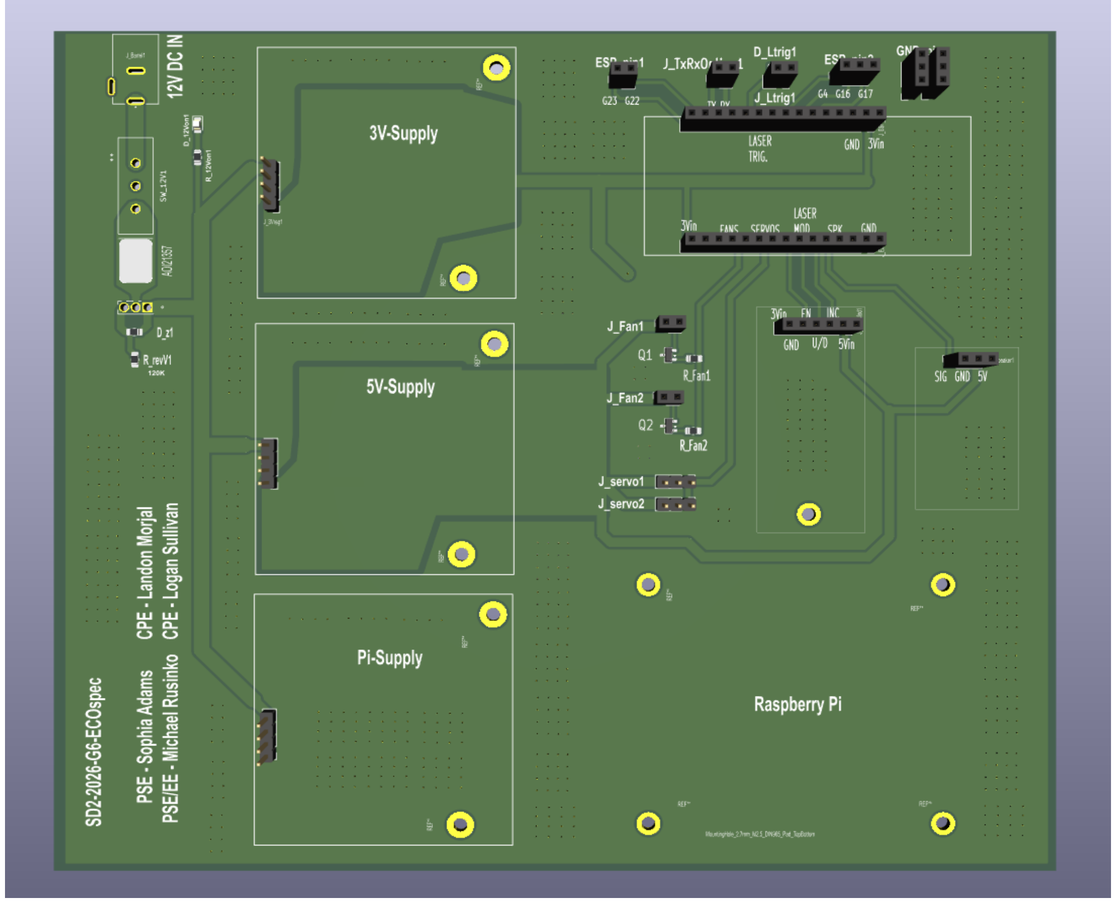


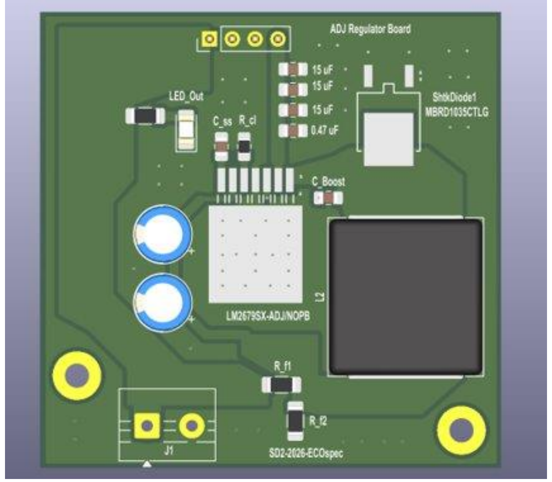
- ESP32 MCU Board
  - CP2102 USB Bridge
  - Controls servos, fans, laser trigger, and peripherals
  - Extra pinouts included
- Laser Mod. Board
  - X9C104 100k Digital Potentiometer
  - AP7366EA ADJ LDO – 1.0 V
  - BNC Output
- Speaker Board.
  - LM386 Audio Amplifier

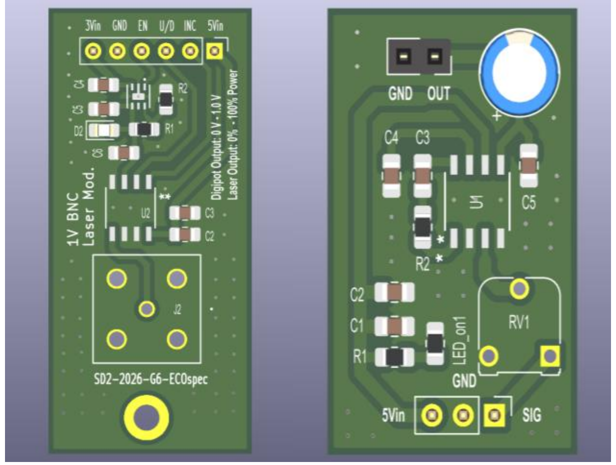


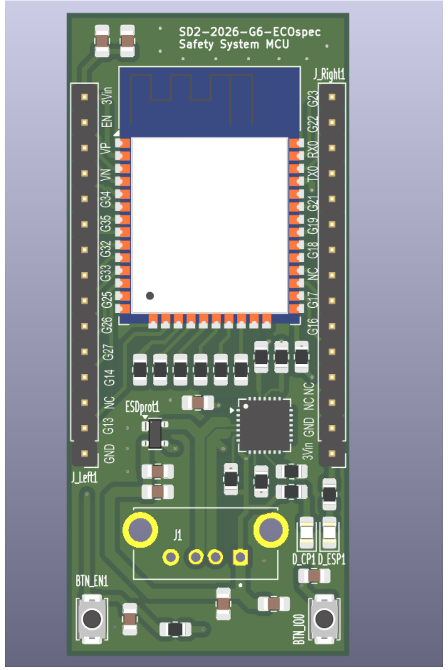
ELECTRICAL – PCB MODELS



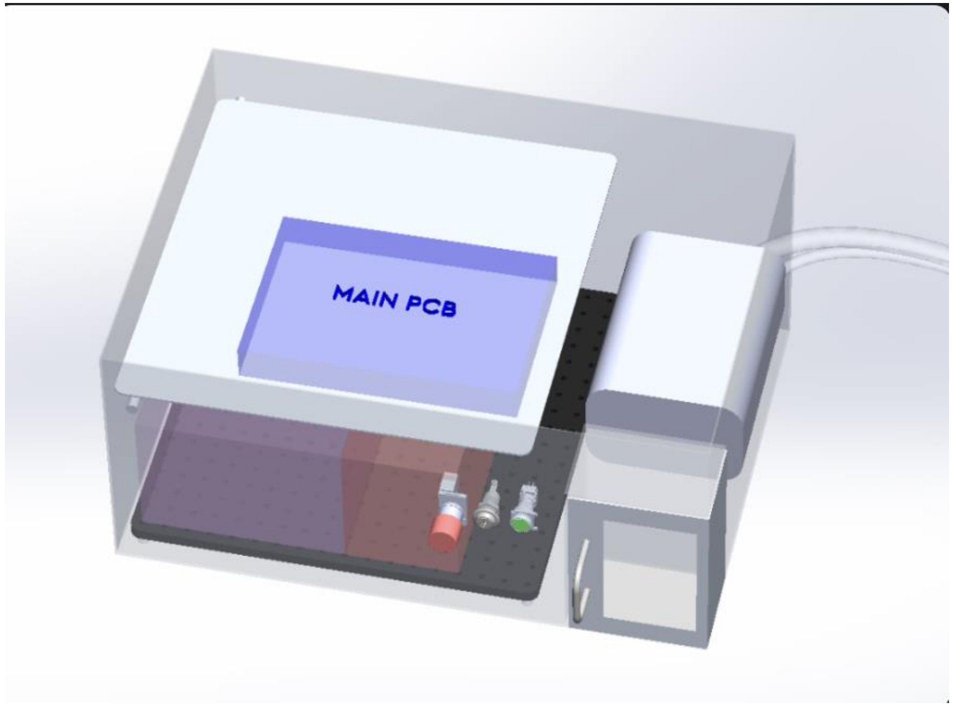




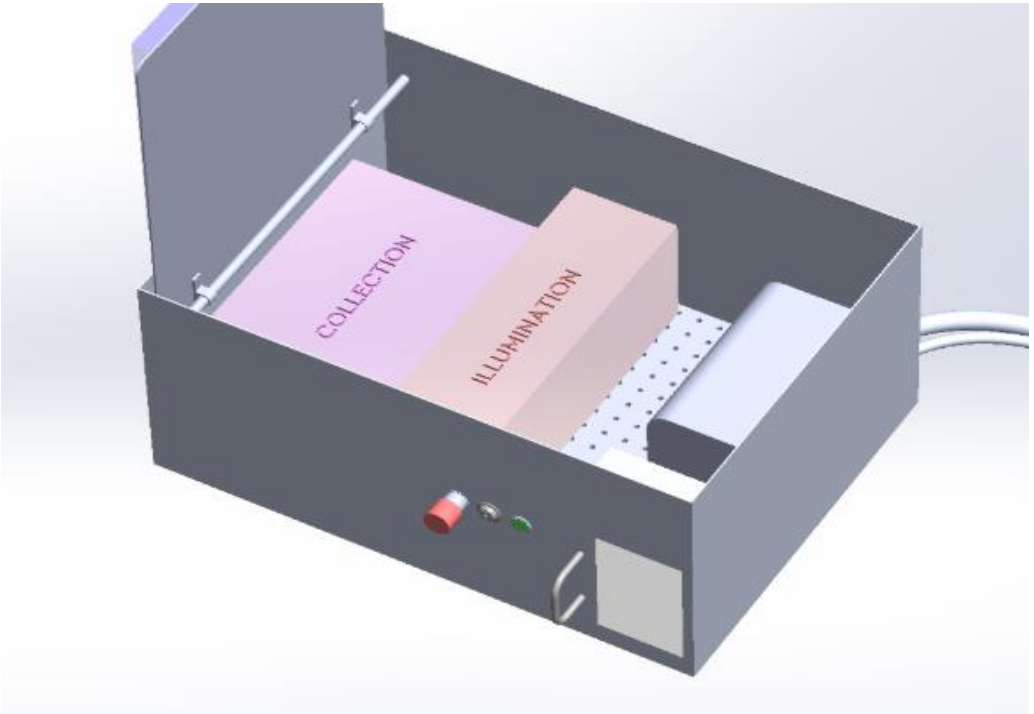




HOUSING



Isometric top view, illustrating potential board placement. A hinge system will be employed for placement of the electrical boards and compactness of the device.



Dimetric top-down view displaying the optical subsystems placed underneath the hinge system.

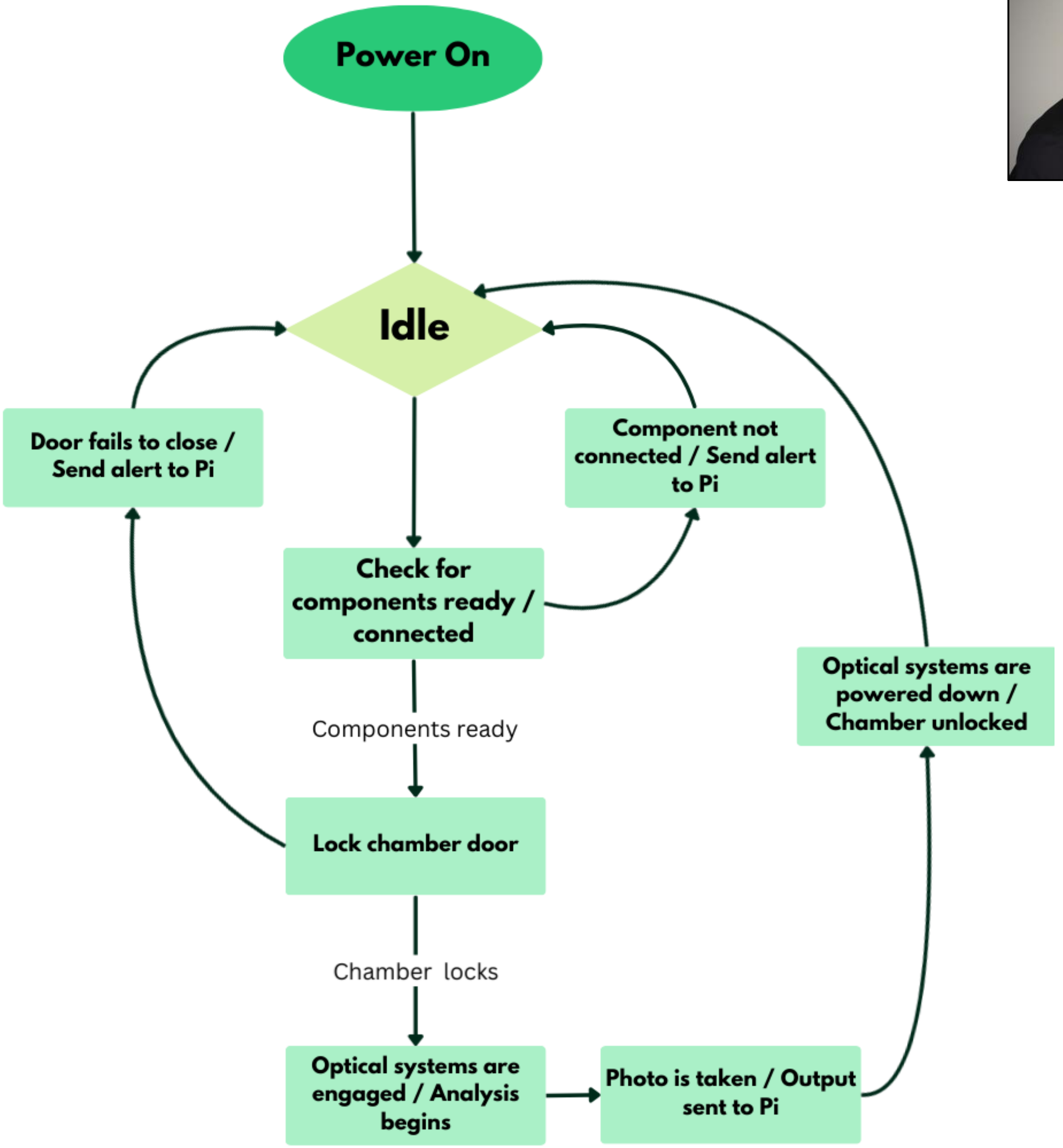
SOFTWARE DESIGN – TECHNOLOGY CHOICE

- Two points of computation
  - ESP32
    - System control / upkeep
  - Raspberry Pi
    - User-Facing
    - Data processing

Language	Python	Java	C/C++
Execution Method	Interpreted	Interpreted/Compiled Hybrid	Compiled
Memory Management	Automatic	Automatic	Manual
Embedded Support	MicroPython	Not Feasible	Arduino, ESP-IDF

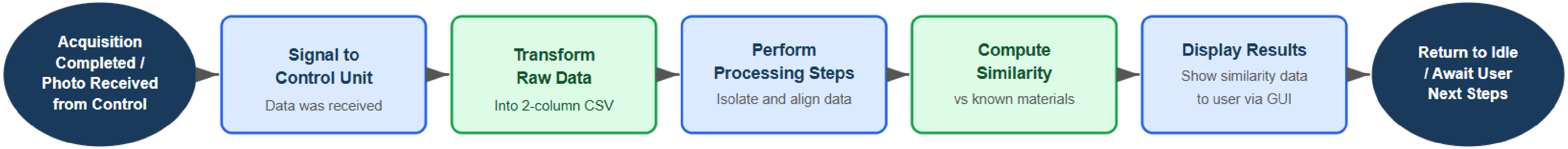
SOFTWARE BLOCK DIAGRAM – ESP32

- Handles operation of the test chamber
- Communicates with Pi via UART
- System status checked before any optical components are triggered



SOFTWARE BLOCK DIAGRAM – RASPBERRY PI

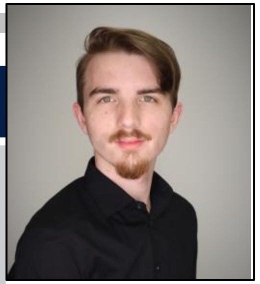
- Pi handles more computationally intense tasks
  - Control & display GUI
  - Data processing pipeline
  - Communicates with ESP32 using a system of codes.



DATA PROCESSING PIPELINE

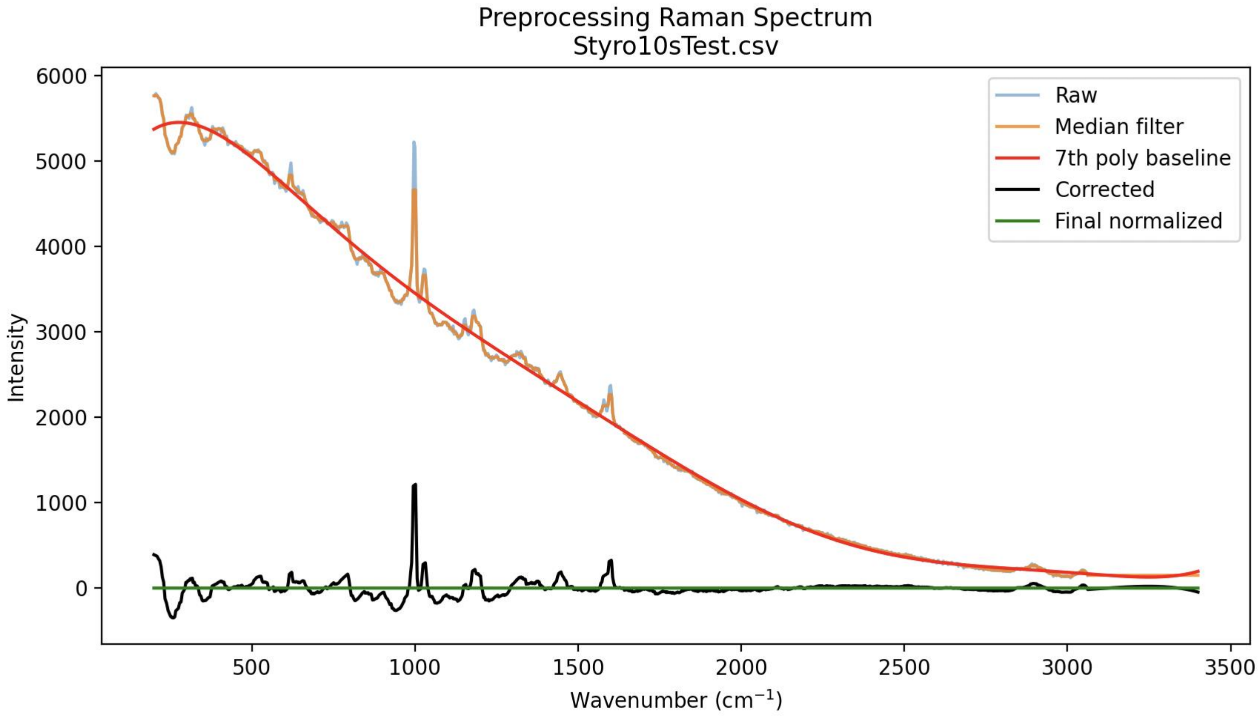
- Multi-stage pipeline focused on isolating Raman signals before identification
  - 4 data transformations
  - Processed data used for comparison
  - Library entries also processed

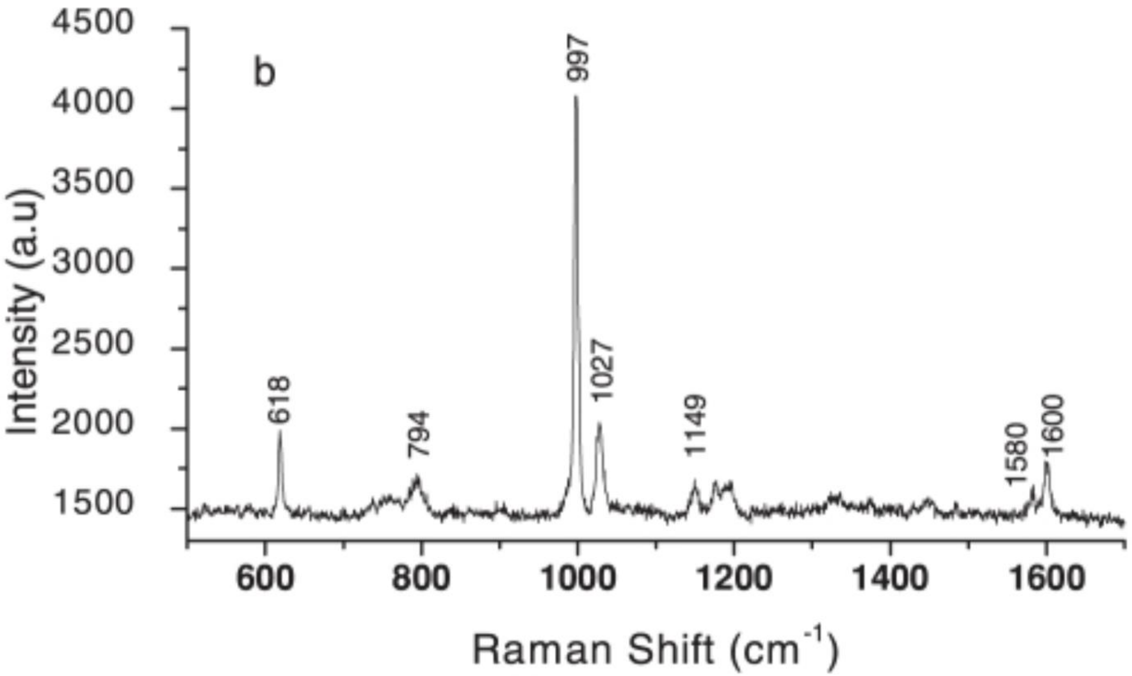
Step	Purpose
Negative Removal / Rounding	Clean up the data for ease of computation later
Interpolation	Put dataset on a uniform grid
Median Filter	Removes noise and cosmic rays
Baseline Correction	Removes the fluorescence background from the spectra
Normalization	Additional removal of noise, baseline shifts, and light-scattering effects
Scaling	Removes differences in magnitude, brings focus to shape of the data
Comparison	Compare sample data to known material data to find a best match



SOFTWARE TESTING – DATA PROCESSING

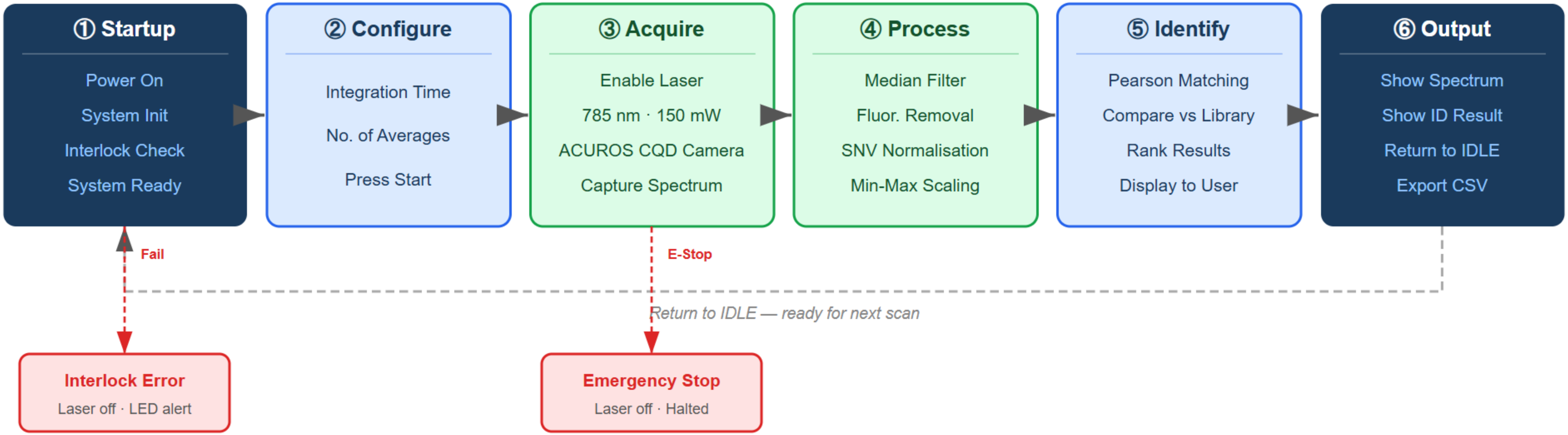
- Processing pipeline tested on lab-acquired data
  - Compared to publicly available spectra





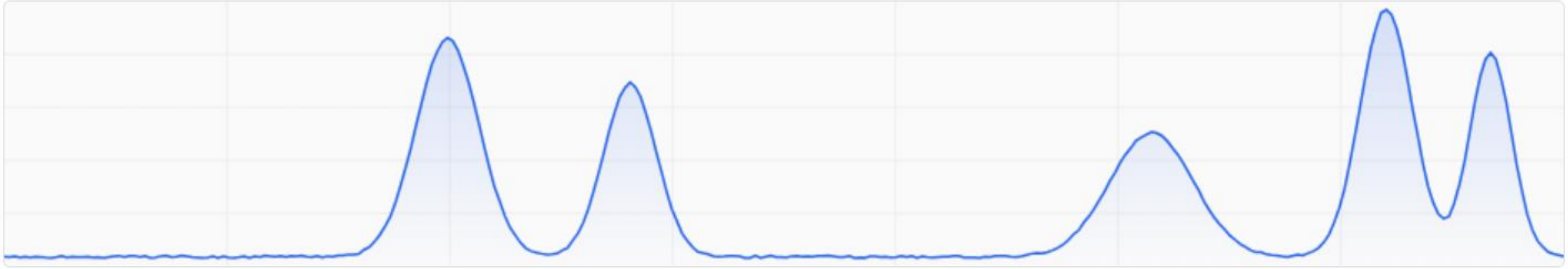
Bankapur, Dr. Aseefhali & Zachariah, Elsa & Chidangil, Santhosh & Valiathan, Manna & Mathur, Deepak. (2010). Raman Tweezers Spectroscopy of Live, Single Red and White Blood Cells. PloS one. 5. e10427. 10.1371/journal.pone.0010427.

USER INTERFACE FLOWCHART



GRAPHICAL USER INTERFACE

LIVE RAMAN SPECTRUM



SETTINGS

Integration Time 250 ms

Averages 5

▶ Start Scan

■ Stop

IDENTIFICATION RESULT

Polyethylene (PE)

Pearson Similarity: 93.6%

#1 — Polyethylene (PE)	93.6%
#2 — Polypropylene (PP)	71.2%
#3 — Polystyrene (PS)	44.8%
#4 — PET	31.5%

⬇ Export Data (CSV)

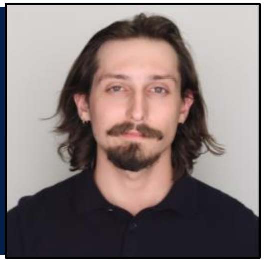
SYSTEM STATUS

Raspberry Pi 5	ONLINE
ESP32 MCU	ONLINE
ACUROS CQD Camera	LINKED
785 nm Laser	STANDBY
TEC Detector (−15°C)	OK
Interlocks	ALL CLEAR

SYSTEM LOG

```
[15:55:38] Acquiring raw frames...
[15:55:39] Noise filter (median)...
[15:55:39] Fluorescence removal (7th-order polynomial)...
[15:55:40] SNV normalization...
[15:55:41] Min-max scaling...
[15:55:41] Pearson similarity matching...
[15:55:42] Result: Polyethylene (PE) — 93.6%
```

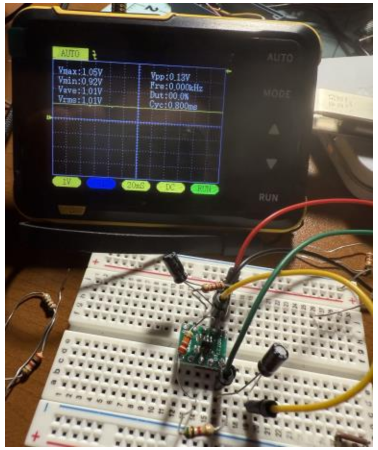
PROTOTYPING – ILLUMINATION + ELECTRICAL



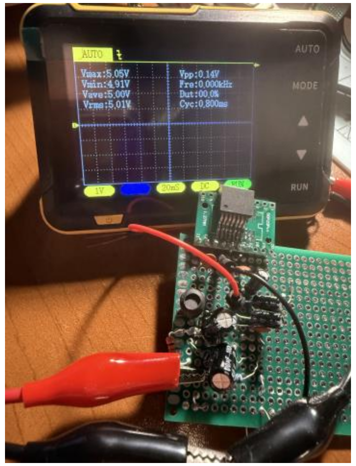
- Illumination Optics
  - Laser
    - Lossy Fiber Collimator
  - Microscope Objective
    - Finite conjugate objective enlarges optical setup (160mm+) and another lens
    - Many objectives are lossy for NIR

785 in Fiber

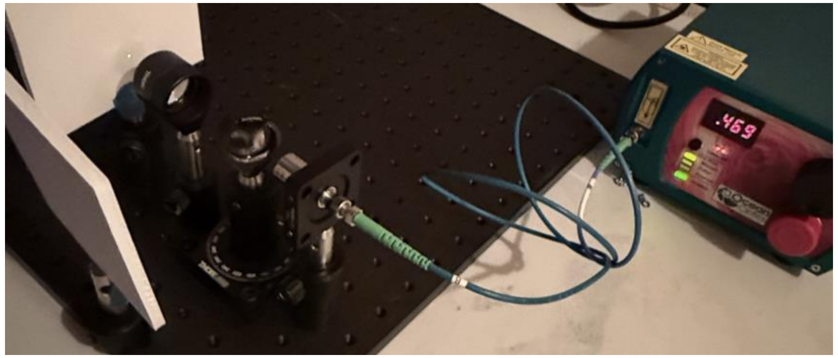
- Electrical
  - Regulators
  - Interlock choice
  - Servo PWM Control
  - NMOS Fan Switch
  - Detector



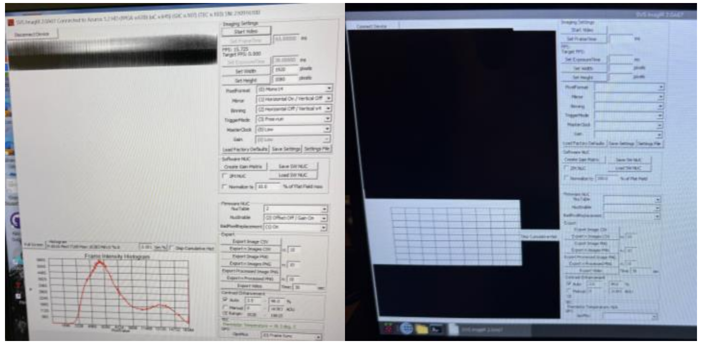
1V LDO Protoboard



ADJ Regulator Protoboard



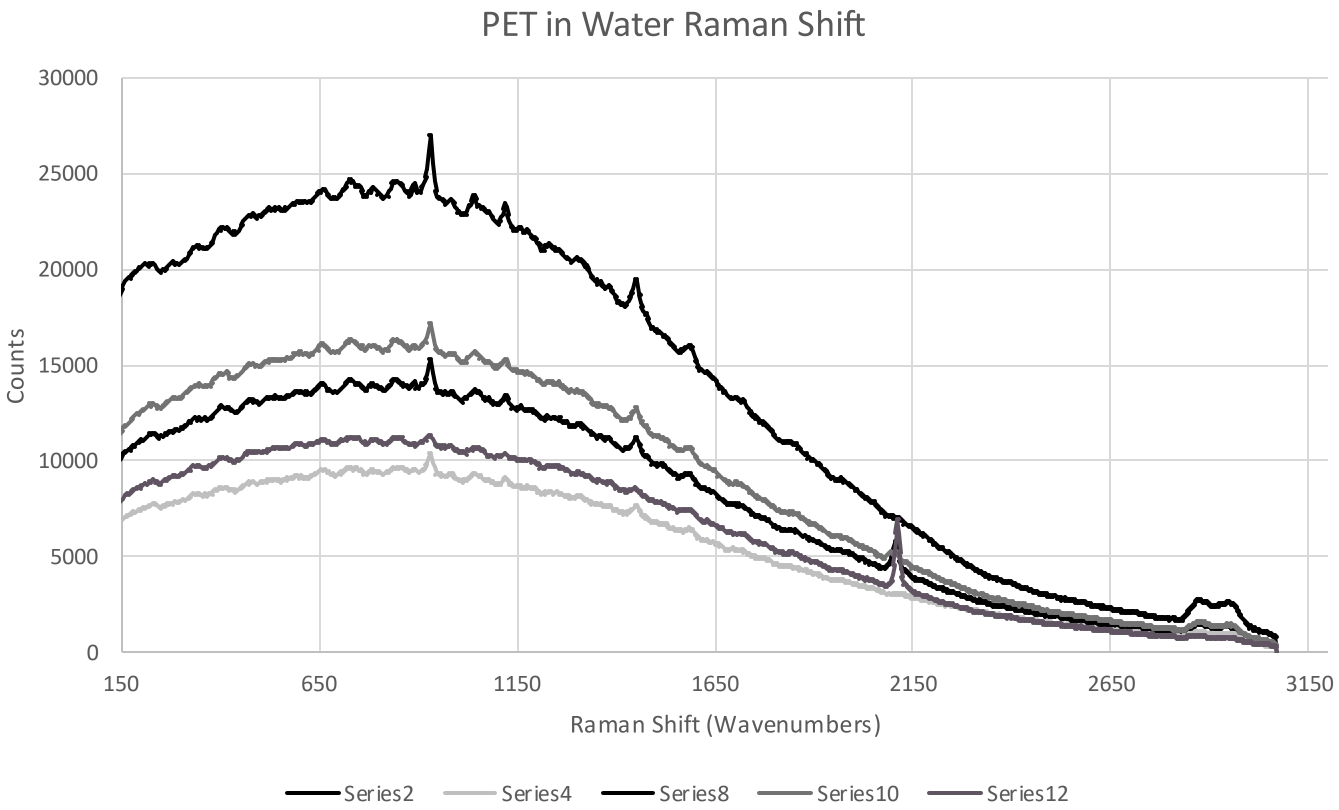
Laser Output Demo

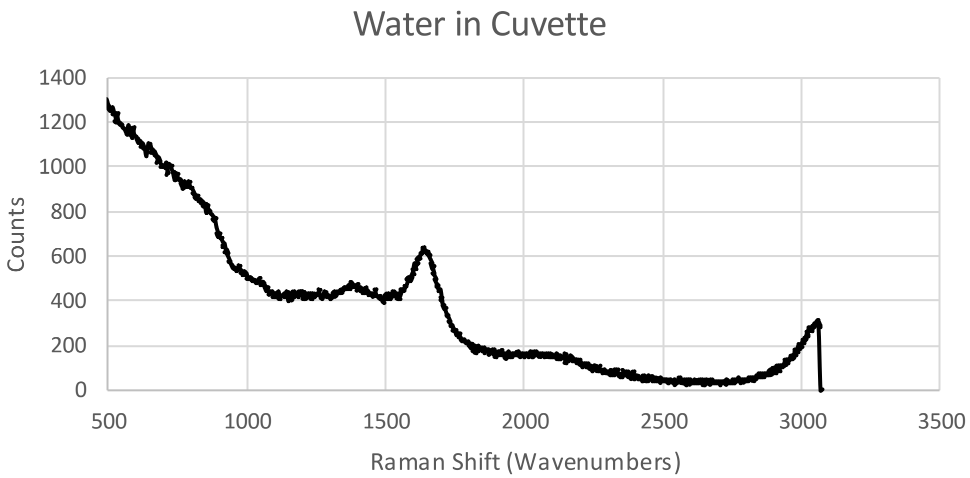


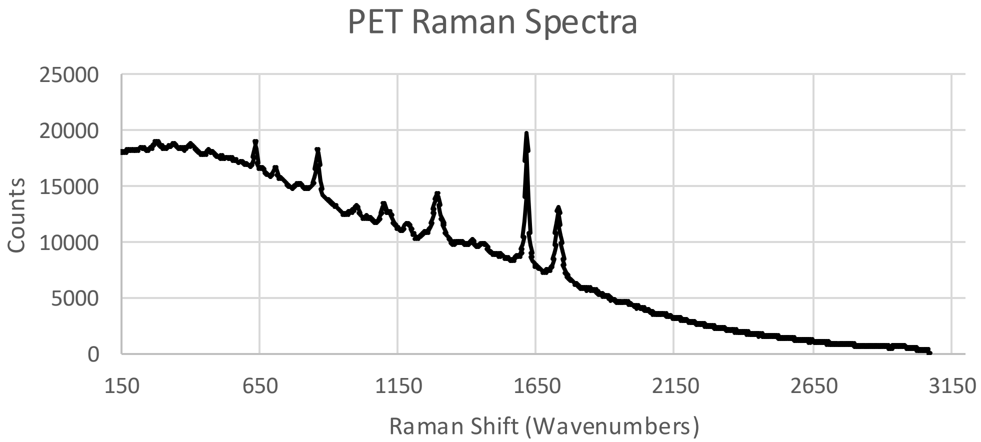
OEM Camera GUI - Win11 vs. Raspbian

COLLECTED SAMPLE SPECTRA

- Test validation Raman signal of plastics sized 1 – 5 mm^2 in water using a Raman probe and spectrometer using a 785 nm laser

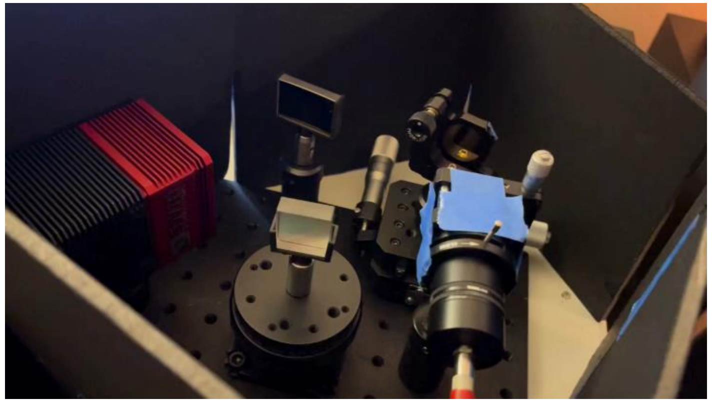




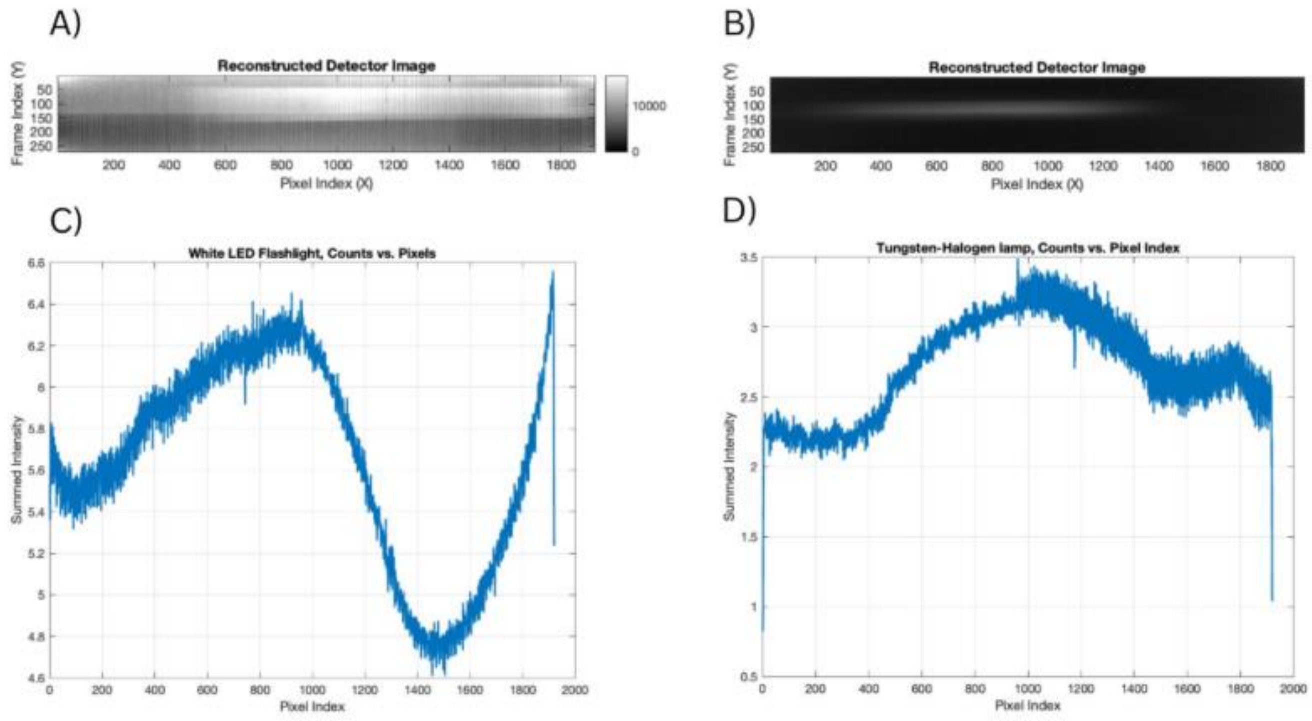


PROTOTYPING AND TESTING- COLLECTION OPTICS

- **Problem:** Can't start alignment with Raman signal = too weak, and invisible (NIR)
- **Solution:** alignment began with a White LED and a broadband light source for mirror alignment
- continuing alignment with sulfer with system before moving to plastics because it has a very strong Raman signal in the 0 – 300 wavenumber range



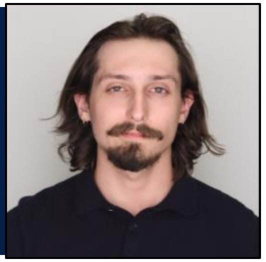
Spectrometer Prototype



WORK DISTRIBUTION

Member	Responsibilities
Sophia Adams	Project Lead
	Collection Optics
	Detector Choice
Michael Rusinko	Illumination Optics
	PCB Design
	Detector Choice and Integration
Landon Morjal	Data Processing
	Detector Interfacing
	Safety MCU Firmware Development
Logan Sullivan	MCU Integration
	User Interface Integration
	Safety MCU Firmware Development

BUDGET



Subsystem	Part	Quantity	Price	Total
Optical	Laser + Fiber	1x	Borrowed	-
	Lenses	2x	Borrowed	-
	Dichroic Mirror	1x	Borrowed	-
	Microscope Objective	1x	Borrowed	-
	Optomechanics	-	Borrowed	-
	Curved Mirrors	2x	Borrowed	-
	Reflective Grating	1x	Borrowed	-
Electrical	CQD Detector	1x	Borrowed	-
	Rasp Pi 5	1x	$95.40	$95.40
	PCBs	-	$294.53	$294.53
	PCB Components	-	~$200.00	~$200.00
	12V Power Supply	1x	$34.97	$34.97
	LCD	1x	$52.24	$52.24
	Fans (4-pack)	1x	$7.35	$7.35
	Servos (4-pack)	1x	$12.50	$12.50
	Misc	-	$200.00	$200.00
			Grand Total: $896.99	

PROGRESS PLAN FOR COMPLETION

Tasks	Start Date	Notes
Testing	1/12/26	Begin testing of all subsystems
Fabricate PCB	When boards arrive	Fabricate PCB boards with necessary components
Begin fabrication of housing	3/2/26	Start building housing
PCB design revision	When/if needed	Revise PCB design if needed
Calibration of spectrometer	3/9/26	Finalize calibration of spectrometer
Begin Building Raman Library	3/9/26	Collecting Raman spectra of plastics for library
Finalize housing	3/16/26	Finish housing and seating of components in housing
Final Adjustments	Up until the week before Demo	Ensure all systems are running properly
Final Demonstration	April 20- 23rd	Show the work

QUESTIONS?