



# MAKE TO INNOVATE

Final Review – Spring 2019

MAVRIC – Mars Analog Vehicle for Robotic Inspection and Construction

# AGENDA

Project Overview

Activity Report

Project Review

- Design Constraints
- Final Design
- Future Plans
- Risks

Budget Status

Conclusion

# PROJECT OVERVIEW

Project Executive Summary

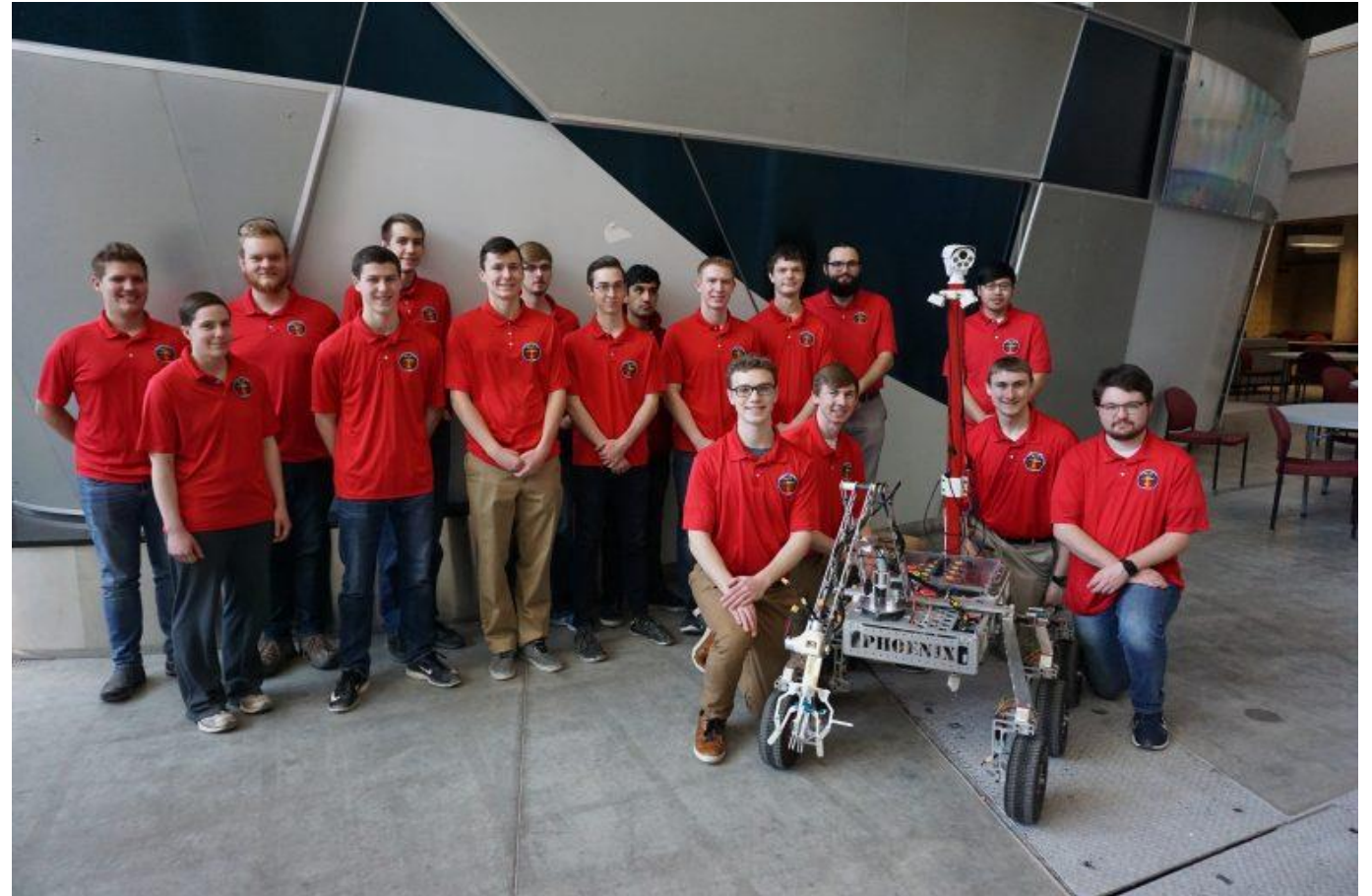




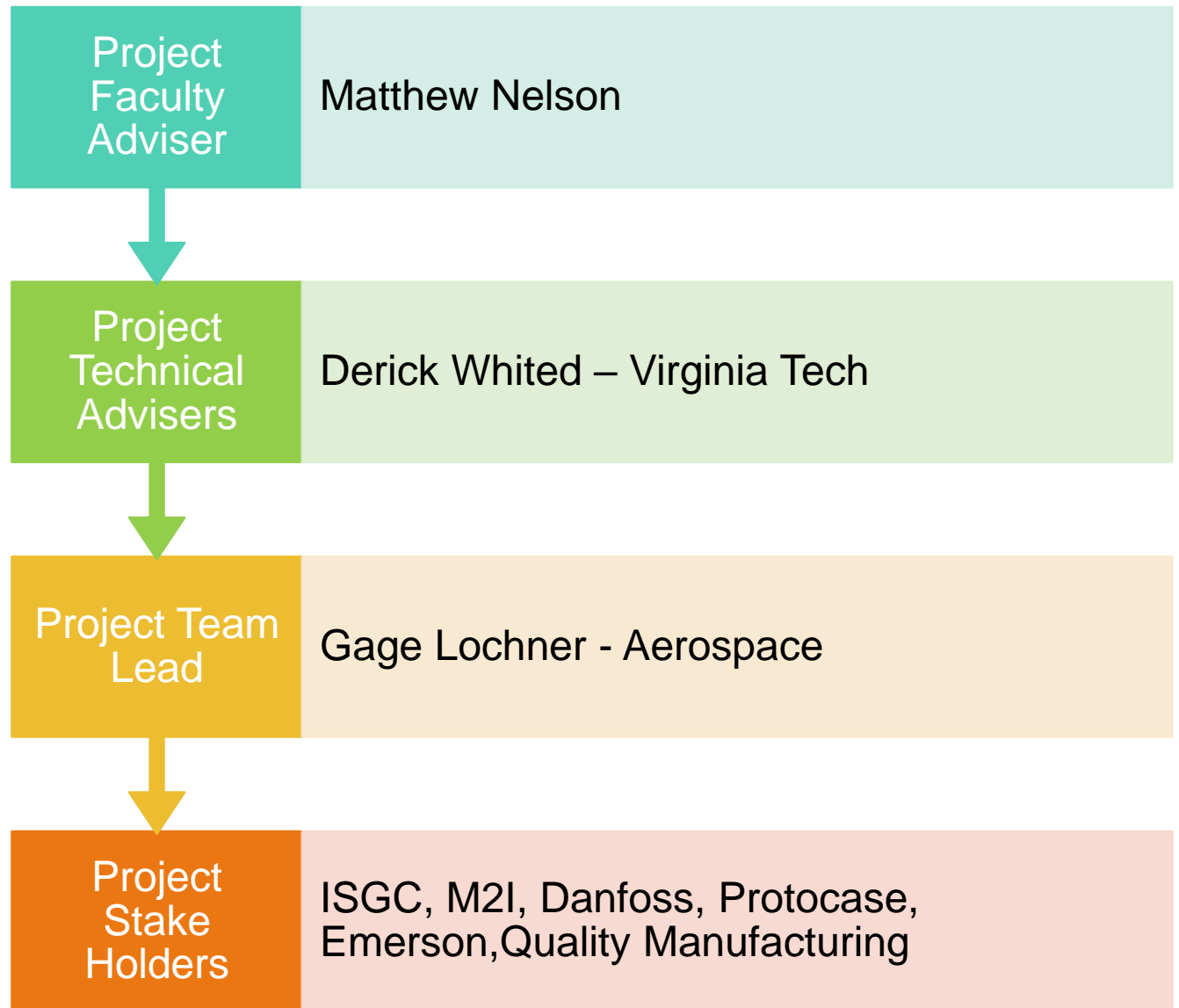
# Project Photo

From left to right : Reid Miller,  
Brooke Bradshaw, James Talbert,  
Austin Schmitz, Brady Anderson,  
Ryan Crall, Colton Marshall,  
Noah Brady, Shivam Vashi,  
Aaron McCrary, Nick Kilzer,  
Christian Tanberg, Jensen Mayes,  
Matthew Matejka, Billy Noy,  
Riley Roche, Gage Lochner

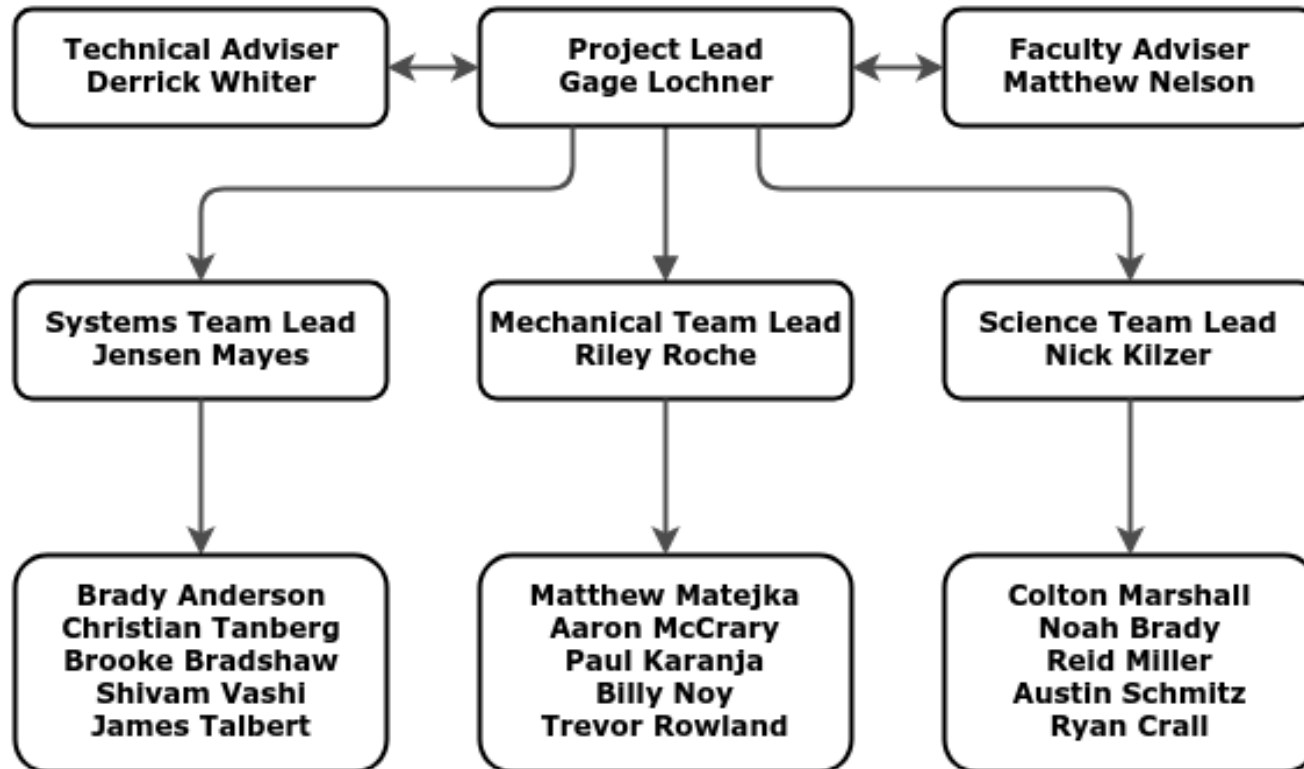
Not pictured: Trevor Rowland,  
Paul Karanja



# PROJECT OVERVIEW



# Project Organization Chart



# Project Accomplishments

## Project Objectives

- To build an analog next generation Mars rover

## Semester Goals

- Complete Phoenix
- Begin work on Mk2

## Semester Deliverables

- URC ready rover



# ACTIVITY REPORT

Milestones, Tasks, and Health Report





# MILESTONES – MECHANICAL TEAM

- Milestone 1 – Robotic Arm Improvements
  - Feedback
  - Base Rotation
  - Shoulder
  - End Effector
  - Cameras as a side task
- Milestone 2 – Suspension Upgrades and Weight Reduction
  - Add brass to suspension joints
  - Remove excess material from the rover
  - Replace aluminum components with lighter materials

# MILESTONES – SCIENCE TEAM

- Milestone 1 – Manufacturing and Testing
  - Complete manufacturing of Laser Orientation
  - Make prototype and final copy of optical housing
  - Perform known testing of system with easy-to-identify substances
- Milestone 2 – Competition Readiness
  - Complete biomarker identification script with Python
  - Identify biomarkers with script
  - Identify biomarkers with script (blind tests)
  - Develop and practice Science Report methodology

# MILESTONES – SYSTEM TEAM

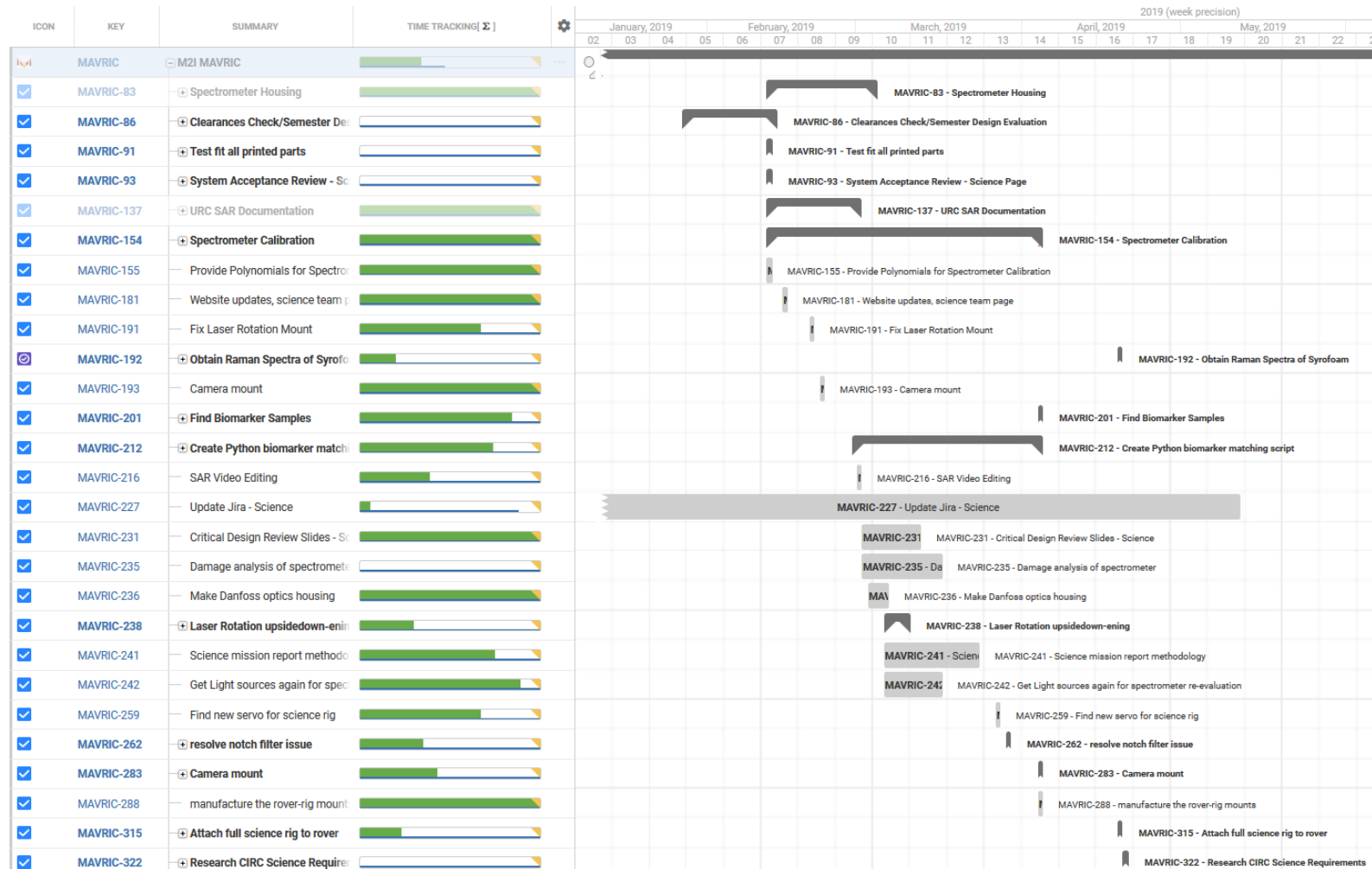
- Milestone 1
  - Arm Feedback Integrated
    - ROS Node
    - Custom ADC Hat
  - 360 View Cameras
    - Front & Rear
    - Left & Right
    - Mast PTZ
- Milestone 2
  - Fully Functional Autonomous Systems
  - Competition Readiness
  - User Friendly Base Station

# TASK BREAKDOWN - MECHANICAL

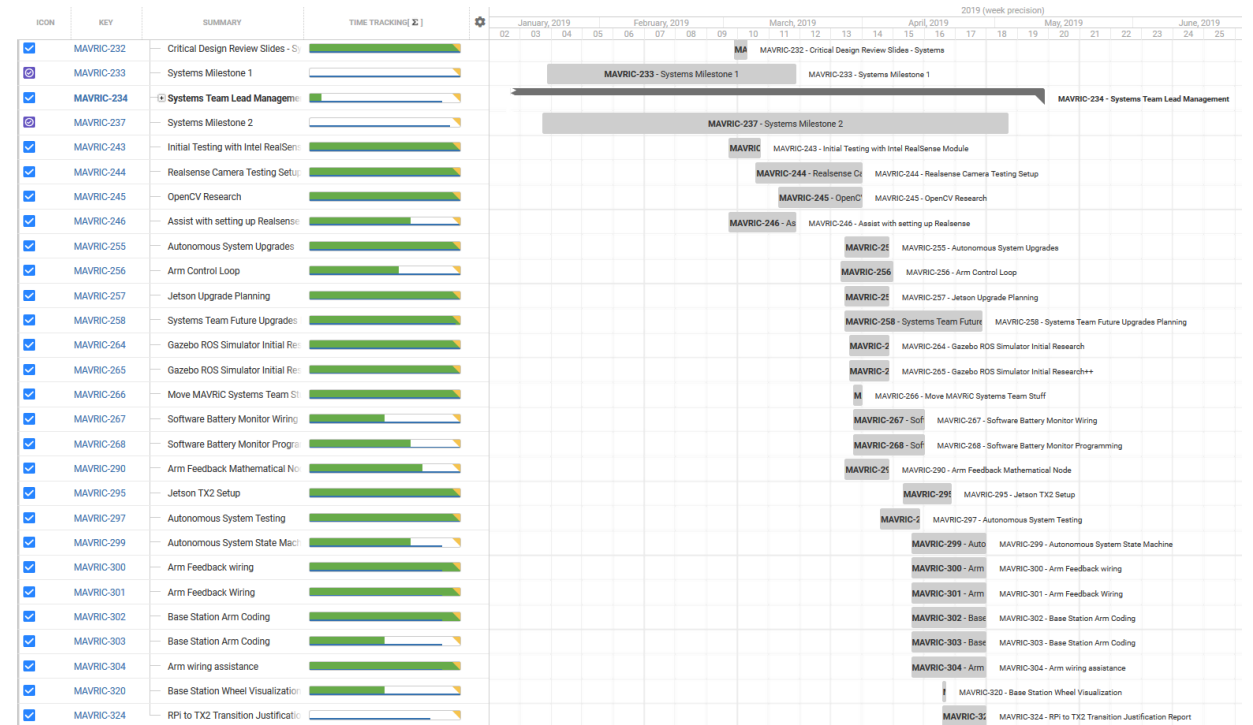
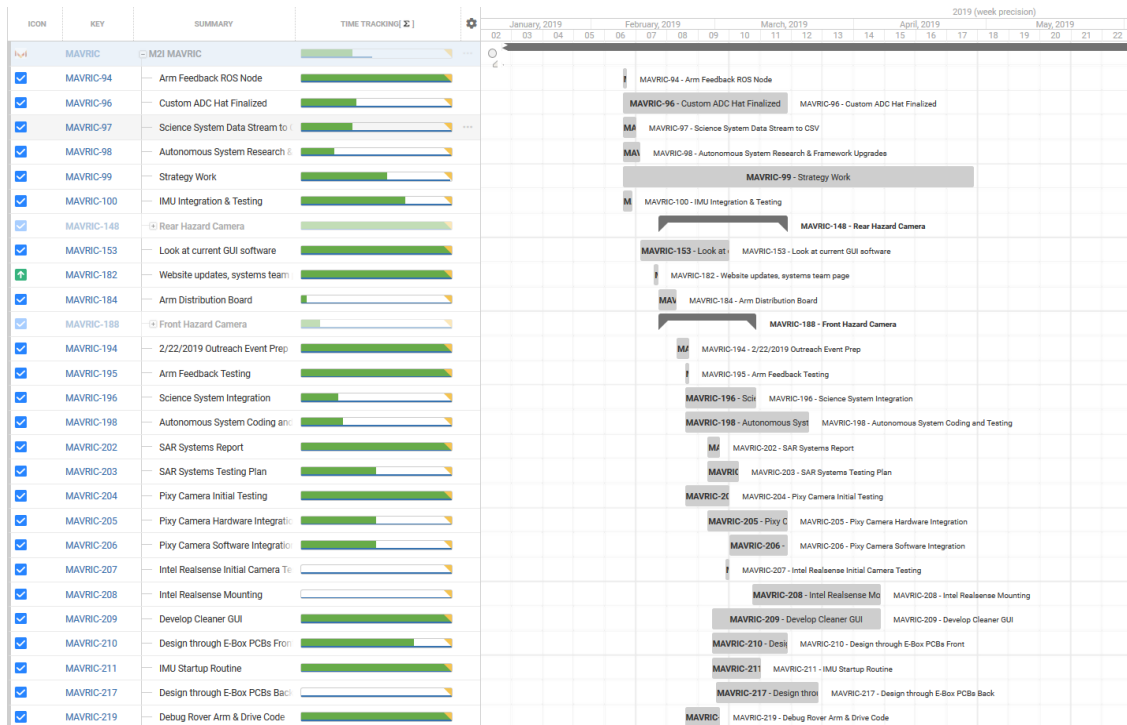




# TASK BREAKDOWN - SCIENCE



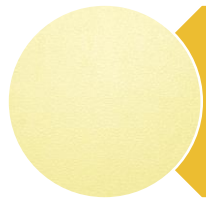
# TASK BREAKDOWN - SYSTEMS



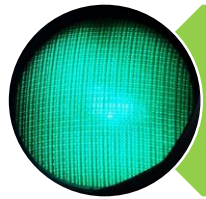
# PROJECT HEALTH REPORT



Confirmed issues with science system / no entry into competition



Autonomous has had only limited testing



Jetson integration, the rest of the rover

# PROJECT REVIEW

Overview





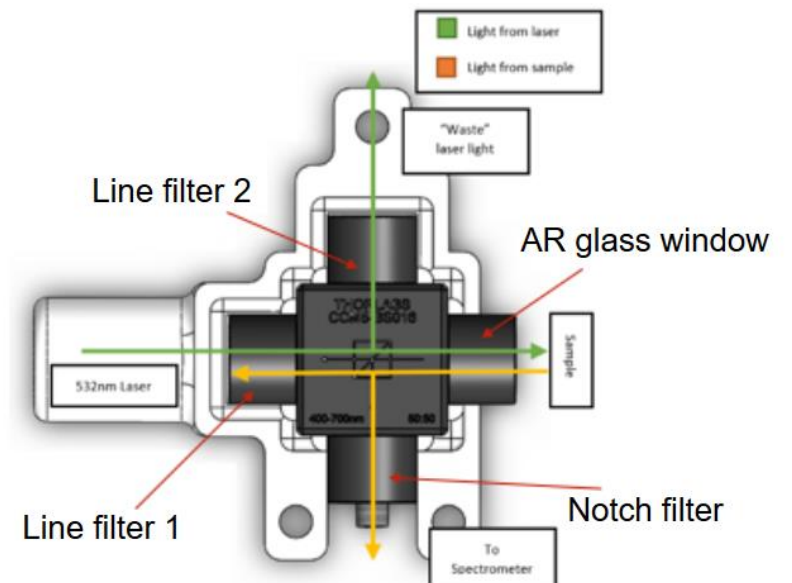
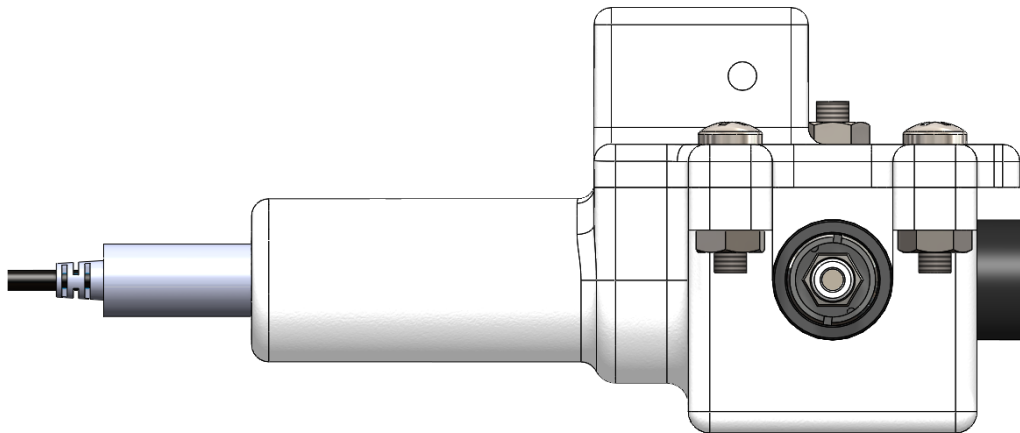
# PROJECT OVERVIEW - MECHANICAL

- Sheet Metal Chassis
  - Single, lightweight part
  - Hole pattern allows for modular design
  - Top plate allows for mounting subsystems
- Rocker-Bogie Suspension
  - Keeps chassis stable in rough terrain
  - Rocker has limited motion
  - Wheels are individually driven
- New Robotic Arm
  - 5 Degrees of freedom
  - Shoulder and elbow cannot be back-driven
  - Compact wrist with new end effector



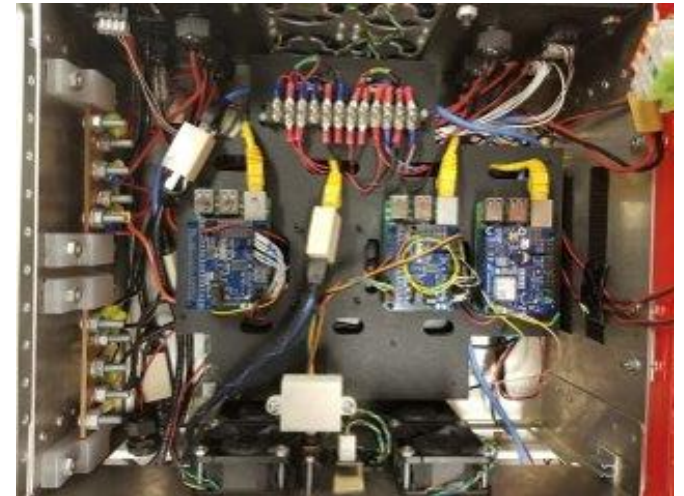
# PROJECT OVERVIEW - SCIENCE

- Raman spectroscopy used on soil samples
- Laser ensured to be within desired range by line filter
- Notch filter used to remove laser light from sample spectrum
- Spectrometer and python code used to analyze data
- Laser rotation system for aiming the spectra collector



# PROJECT OVERVIEW - SYSTEMS

- Control Systems
  - ROS (Robot Operating System)
- Autonomous System
  - State Machine
  - GPS & IMU
- Base Station
  - Python GUI
  - Standard IP Cameras
- Dual Batteries
  - Drive Battery
  - E-Box Battery
- Communications
  - Rocket M5





# PROJECT REVIEW

Constraints





# PROJECT CONSTRAINTS

- Budget
  - We anticipate needing additional outside funding next year
- Experience
  - Limited number of Juniors and Seniors on team with applicable experience
- Time
  - Limited number of man hours available at certain times of the year
- Competition requirements
  - 50 kg max weight
  - Max budget \$17.5k

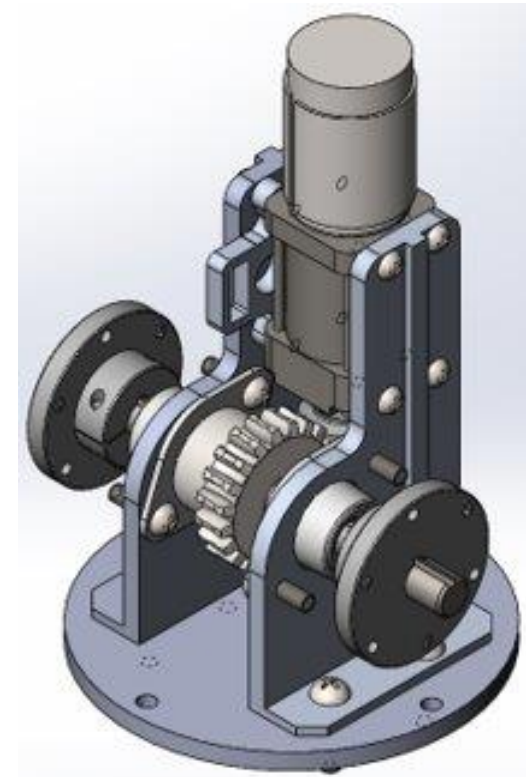
# PROJECT REVIEW

Final Design



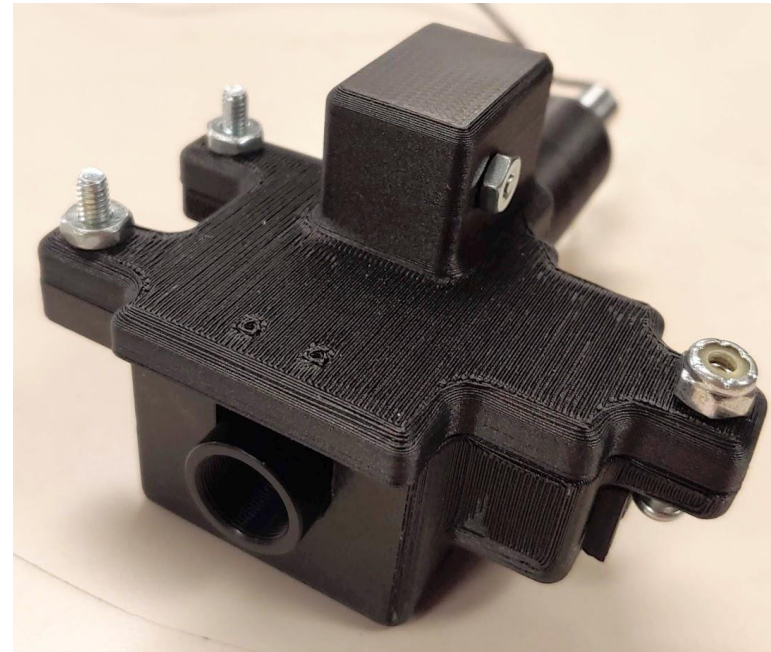
# FINAL DESIGN - MECHANICAL

- Robotic Arm Improvements
  - Feedback
  - Base rotation
  - Shoulder
  - End effector
- New Camera Mounts
- New Electrical Box Lid
- New Power Distribution Box
- Reduced Total Mass
- Arm Practice Board and Off-Rover Stand



# FINAL DESIGN - SCIENCE

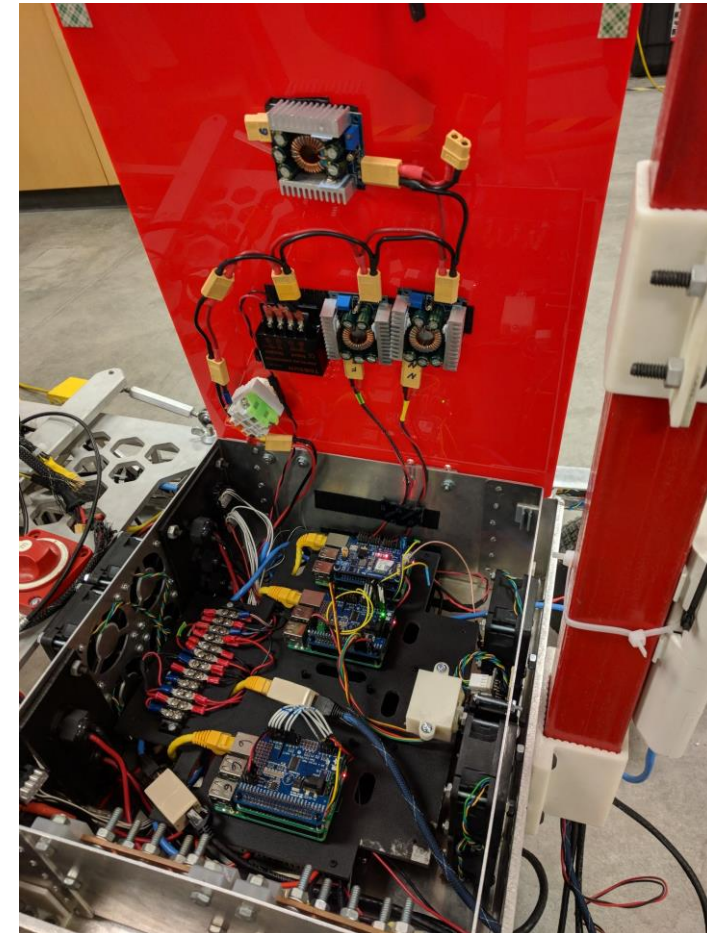
- All printed mounts fit and hold
- Protocase spectrometer box
  - Vibration dampening foam on its way
- Danfoss print fits excellently
- Sorting software complete
- Notch problem identified
  - New notch on its way
- Spectrometer calibrated





# FINAL DESIGN - SYSTEMS

- Transitioning to the Jetson TX2
  - Hats are working
  - Everything tested has been successful
- 360 degree camera view
- Ongoing base station improvements
- Working point to point autonomous
- Separate batteries for drive and E-Box
- Custom power distribution PCBs
- Working arm with positional feedback



# PROJECT REVIEW

Future Work



# PROPOSED CHANGES - MECHANICAL

- Focus on Learning from Past Successes and Failures
  - Design for manufacturability and maintenance
- Restructuring the Design and Manufacturing Process
  - Better organization of design files
  - Tight control of manufacturing documents and revisions
- Working on the 2020 Rover over the Summer
  - Started work on suspension and chassis
    - New suspension style: 3-bogie
    - Focus on stability and mass
    - Easy to remove
  - Better electronics integration
- Working toward a full rover design at beginning of fall semester





# PROPOSED CHANGES - SCIENCE

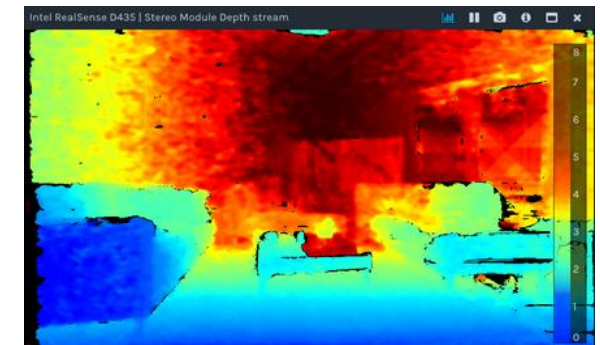
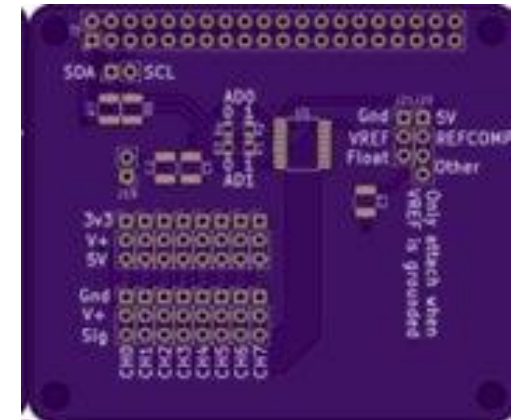
- Currently waiting on new notch filter
- Complete polystyrene benchmark Raman test
- Complete biomarker Raman tests

Table 2. Raman bands of the most common geo- and biomarkers in extremophile exemplars and their chemical formulae (cm<sup>-1</sup> with 532 nm excitation). Corroborative bands appear in bold.

calcite	CaCO <sub>3</sub>	<b>1086</b>	<b>712</b>	<b>282</b>	156														
aragonite	CaCO <sub>3</sub>	<b>1086</b>	<b>704</b>	<b>208</b>	154														
dolomite	CaMg(CO <sub>3</sub> ) <sub>2</sub>	<b>1098</b>	<b>725</b>	<b>300</b>	177														
magnesite	MgCO <sub>3</sub>	<b>1094</b>	<b>738</b>	<b>330</b>	<b>213</b>	119													
hydromagnesite	Mg <sub>3</sub> (CO <sub>3</sub> ) <sub>2</sub> (OH) <sub>2</sub> ·4H <sub>2</sub> O	<b>1119</b>	<b>728</b>	326	<b>232</b>	202	184	147											
gypsum	CaSO <sub>4</sub> ·2H <sub>2</sub> O	<b>1133</b>	<b>1007</b>	669	628	<b>492</b>	<b>413</b>												
anhydrite	CaSO <sub>4</sub>	<b>1015</b>	674	628	500	456													
quartz	SiO <sub>2</sub>	1081	1064	808	796	696	500	542	<b>463</b>	354	263	<b>206</b>	128						
haemetite	Fe <sub>2</sub> O <sub>3</sub>	<b>610</b>	500	<b>411</b>	<b>293</b>	245	<b>226</b>												
limonite	FeO(OH)·nH <sub>2</sub> O	693	<b>555</b>	481	<b>303</b>	<b>299</b>	<b>203</b>												
apatite	Ca <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> (F,Cl,OH)	1034	<b>963</b>	<b>586</b>	<b>428</b>														
weddellite	Ca <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> ·2H <sub>2</sub> O	1630	<b>1475</b>	1411	<b>910</b>	869	597	<b>506</b>	<b>188</b>										
whewellite	Ca <sub>3</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> ·H <sub>2</sub> O	1629	<b>1490</b>	<b>1463</b>	1316	942	<b>896</b>	865	596	521	<b>504</b>	223	207	<b>185</b>	<b>141</b>				
chlorophyll	C <sub>55</sub> H <sub>72</sub> O <sub>7</sub> N <sub>4</sub> Mg	1438	1387	<b>1326</b>	1287	1067	1048	<b>988</b>	<b>916</b>	<b>744</b>	<b>517</b>	351							
c-phyocyanin	C <sub>50</sub> H <sub>48</sub> O <sub>4</sub> N <sub>4</sub>	1655	<b>1638</b>	1582	1463	<b>1369</b>	1338	<b>1272</b>	1241	1109	1054	<b>815</b>	<b>665</b>	499					
β-carotene	C <sub>40</sub> H <sub>56</sub>	<b>1515</b>	<b>1155</b>	<b>1006</b>															
rhizocarpic acid	C <sub>20</sub> H <sub>20</sub> O <sub>6</sub>	<b>1665</b>	1610	<b>1595</b>	<b>1518</b>	<b>1496</b>	1477	1347	1303	1032	944	902	768	448					
scytonemin	C <sub>30</sub> H <sub>30</sub> N <sub>2</sub> O <sub>4</sub>	1605	<b>1590</b>	<b>1549</b>	1444	<b>1323</b>	1283	1245	<b>1172</b>	1163	984	752	675	574	270				
calycin	C <sub>19</sub> H <sub>20</sub> O <sub>5</sub>	1633	<b>1625</b>	<b>1611</b>	<b>1595</b>	<b>1380</b>	1344	1240	1155	1034	<b>960</b>	878	498	484					
paretin	C <sub>16</sub> H <sub>20</sub> O <sub>5</sub>	<b>1671</b>	1631	1613	<b>1153</b>	1107	1170	<b>1277</b>	1255	<b>926</b>	571	579	467	<b>458</b>					
usnic acid	C <sub>13</sub> H <sub>16</sub> O <sub>7</sub>	<b>1694</b>	1627	<b>1607</b>	<b>1322</b>	<b>1289</b>	1192	1119	<b>992</b>	939	846	602	540						
emodin	C <sub>15</sub> H <sub>10</sub> O <sub>5</sub>	<b>1659</b>	1607	1577	1557	<b>1298</b>	<b>1281</b>	942	<b>565</b>	<b>467</b>									
atanorin	C <sub>13</sub> H <sub>14</sub> O <sub>5</sub>	<b>1666</b>	<b>1658</b>	1632	<b>1303</b>	<b>1294</b>	1266	<b>588</b>											
pulvinic dilactone	C <sub>13</sub> H <sub>10</sub> O <sub>4</sub>	1672	1603	1455	1405	1311	981	504											
gyrophoric acid	C <sub>10</sub> H <sub>12</sub> O <sub>6</sub>	1662	1628	1612	1334	1304	1291	1235	1138	818	195								

# PROPOSED CHANGES - SYSTEMS

- Add computer vision for greater autonomous capabilities
  - Realsense integration ( we can now use full resolution)
  - Utilizing IP camera feeds
- Complete the Base Station GUI Upgrades
- Transition to more custom components
  - In places where applicable
- Improve documentation for future teams





# PROJECT REVIEW

Encountered Risks



# DESIGN RISKS - MECHANICAL

- From Jira

	TRIVIAL	LOW	MEDIUM	HIGH	SEVERE
ALWAYS NONE	<ul style="list-style-type: none"><li>MAVRIC-126</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-199</li><li>MAVRIC-122</li><li>MAVRIC-141</li><li>MAVRIC-143</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-277</li><li>MAVRIC-136</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-292</li><li>MAVRIC-328</li><li>MAVRIC-327</li><li>MAVRIC-142</li><li>MAVRIC-321</li></ul>	
	<ul style="list-style-type: none"><li>MAVRIC-145</li><li>MAVRIC-123</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-118</li><li>MAVRIC-185</li><li>MAVRIC-112</li><li>MAVRIC-119</li><li>MAVRIC-109</li><li>MAVRIC-116</li><li>MAVRIC-111</li><li>MAVRIC-115</li><li>MAVRIC-291</li><li>MAVRIC-144</li><li>MAVRIC-113</li><li>MAVRIC-132</li><li>MAVRIC-135</li><li>MAVRIC-280</li><li>MAVRIC-279</li><li>MAVRIC-124</li><li>MAVRIC-147</li><li>MAVRIC-146</li><li>MAVRIC-128</li><li>MAVRIC-128</li><li>MAVRIC-178</li><li>MAVRIC-110</li><li>MAVRIC-114</li><li>MAVRIC-133</li><li>MAVRIC-125</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-107</li><li>MAVRIC-309</li><li>MAVRIC-312</li><li>MAVRIC-308</li><li>MAVRIC-311</li><li>MAVRIC-307</li><li>MAVRIC-310</li><li>MAVRIC-223</li><li>MAVRIC-129</li><li>MAVRIC-186</li><li>MAVRIC-189</li><li>MAVRIC-306</li><li>MAVRIC-130</li><li>MAVRIC-313</li><li>MAVRIC-314</li><li>MAVRIC-148</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-197</li><li>MAVRIC-186</li><li>MAVRIC-103</li><li>MAVRIC-180</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-230</li><li>MAVRIC-218</li><li>MAVRIC-140</li></ul>
LOW					
PRIORITY					
REVISION			<ul style="list-style-type: none"><li>MAVRIC-117</li><li>MAVRIC-105</li><li>MAVRIC-104</li><li>MAVRIC-120</li><li>MAVRIC-121</li><li>MAVRIC-131</li><li>MAVRIC-127</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-102</li><li>MAVRIC-151</li><li>MAVRIC-222</li></ul>	<ul style="list-style-type: none"><li>MAVRIC-305</li><li>MAVRIC-229</li><li>MAVRIC-138</li><li>MAVRIC-139</li><li>MAVRIC-216</li><li>MAVRIC-137</li></ul>
STATUS					
TYPE / OWNER					

# DESIGN RISKS - SCIENCE

- From Jira

PROBABILITY	CONSEQUENCE				
	TRIVIAL	LOW	MEDIUM	HIGH	SEVERE
ALMOST NONE		<ul style="list-style-type: none"> <li>MAVRIC-317</li> <li>MAVRIC-322</li> <li>MAVRIC-286</li> </ul>	<ul style="list-style-type: none"> <li>MAVRIC-318</li> <li>MAVRIC-284</li> <li>MAVRIC-228</li> </ul>	<ul style="list-style-type: none"> <li>MAVRIC-238</li> <li>MAVRIC-240</li> <li>MAVRIC-239</li> </ul>	
LOW			<ul style="list-style-type: none"> <li>MAVRIC-315</li> <li>MAVRIC-288</li> <li>MAVRIC-319</li> <li>MAVRIC-316</li> </ul>	<ul style="list-style-type: none"> <li>MAVRIC-231</li> <li>MAVRIC-236</li> <li>MAVRIC-241</li> <li>MAVRIC-287</li> </ul>	<ul style="list-style-type: none"> <li>MAVRIC-218</li> </ul>
MEDIUM			<ul style="list-style-type: none"> <li>MAVRIC-263</li> </ul>	<ul style="list-style-type: none"> <li>MAVRIC-282</li> <li>MAVRIC-281</li> <li>MAVRIC-212</li> <li>MAVRIC-262</li> <li>MAVRIC-227</li> </ul>	<ul style="list-style-type: none"> <li>MAVRIC-216</li> </ul>
HIGH					<ul style="list-style-type: none"> <li>MAVRIC-235</li> </ul>
VERY HIGH					

# DESIGN RISKS - SYSTEMS

- From Jira

TRIVIAL	LOW	MEDIUM	HIGH	SEVERE
<input checked="" type="checkbox"/> MAVRC-304 <input checked="" type="checkbox"/> MAVRC-248	<input checked="" type="checkbox"/> MAVRC-211 <input checked="" type="checkbox"/> MAVRC-245	<input checked="" type="checkbox"/> MAVRC-300 <input checked="" type="checkbox"/> MAVRC-301 <input checked="" type="checkbox"/> MAVRC-277 <input checked="" type="checkbox"/> MAVRC-324		
<input checked="" type="checkbox"/> MAVRC-123	<input checked="" type="checkbox"/> MAVRC-118 <input checked="" type="checkbox"/> MAVRC-185 <input checked="" type="checkbox"/> MAVRC-119 <input checked="" type="checkbox"/> MAVRC-219 <input checked="" type="checkbox"/> MAVRC-125	<input checked="" type="checkbox"/> MAVRC-194 <input checked="" type="checkbox"/> MAVRC-188 <input checked="" type="checkbox"/> MAVRC-187 <input checked="" type="checkbox"/> MAVRC-148 <input checked="" type="checkbox"/> MAVRC-203 <input checked="" type="checkbox"/> MAVRC-238	<input checked="" type="checkbox"/> MAVRC-220 <input checked="" type="checkbox"/> MAVRC-207 <input checked="" type="checkbox"/> MAVRC-204 <input checked="" type="checkbox"/> MAVRC-226	<input checked="" type="checkbox"/> MAVRC-290 <input checked="" type="checkbox"/> MAVRC-232 <input checked="" type="checkbox"/> MAVRC-237 <input checked="" type="checkbox"/> MAVRC-218 <input checked="" type="checkbox"/> MAVRC-234
	<input checked="" type="checkbox"/> MAVRC-267 <input checked="" type="checkbox"/> MAVRC-302 <input checked="" type="checkbox"/> MAVRC-303 <input checked="" type="checkbox"/> MAVRC-217 <input checked="" type="checkbox"/> MAVRC-210	<input checked="" type="checkbox"/> MAVRC-236 <input checked="" type="checkbox"/> MAVRC-117 <input checked="" type="checkbox"/> MAVRC-120 <input checked="" type="checkbox"/> MAVRC-121 <input checked="" type="checkbox"/> MAVRC-209 <input checked="" type="checkbox"/> MAVRC-208 <input checked="" type="checkbox"/> MAVRC-205 <input checked="" type="checkbox"/> MAVRC-288 <input checked="" type="checkbox"/> MAVRC-287	<input checked="" type="checkbox"/> MAVRC-198 <input checked="" type="checkbox"/> MAVRC-299 <input checked="" type="checkbox"/> MAVRC-255 <input checked="" type="checkbox"/> MAVRC-244 <input checked="" type="checkbox"/> MAVRC-233 <input checked="" type="checkbox"/> MAVRC-221	<input checked="" type="checkbox"/> MAVRC-305 <input checked="" type="checkbox"/> MAVRC-295 <input checked="" type="checkbox"/> MAVRC-202 <input checked="" type="checkbox"/> MAVRC-216
	<input checked="" type="checkbox"/> MAVRC-284 <input checked="" type="checkbox"/> MAVRC-285	<input checked="" type="checkbox"/> MAVRC-243	<input checked="" type="checkbox"/> MAVRC-84	<input checked="" type="checkbox"/> MAVRC-227

# PROJECT WIDE RISKS

- Weather
  - Can limit outdoor testing
  - Limits ability to heat test rover
- Battery damage
  - One of our main drive batteries is damaged, but functional
- Mass limit
  - Can reduce effective score at competition
  - 5% per kilo over 50
- Loss of experienced team members



# BUDGET

Status and requests





# BUDGET STATUS

- \$6000 raised between ISGC and Emerson
- \$1000 from Emerson spent before beginning of Fall 2018
- \$5000 from ISGC spent over Fall and Spring semesters
- No funds remaining at this point
  
- Next year, large expenses expected as we start the next rover

CONCLUSION



**EXTRA SLIDES**

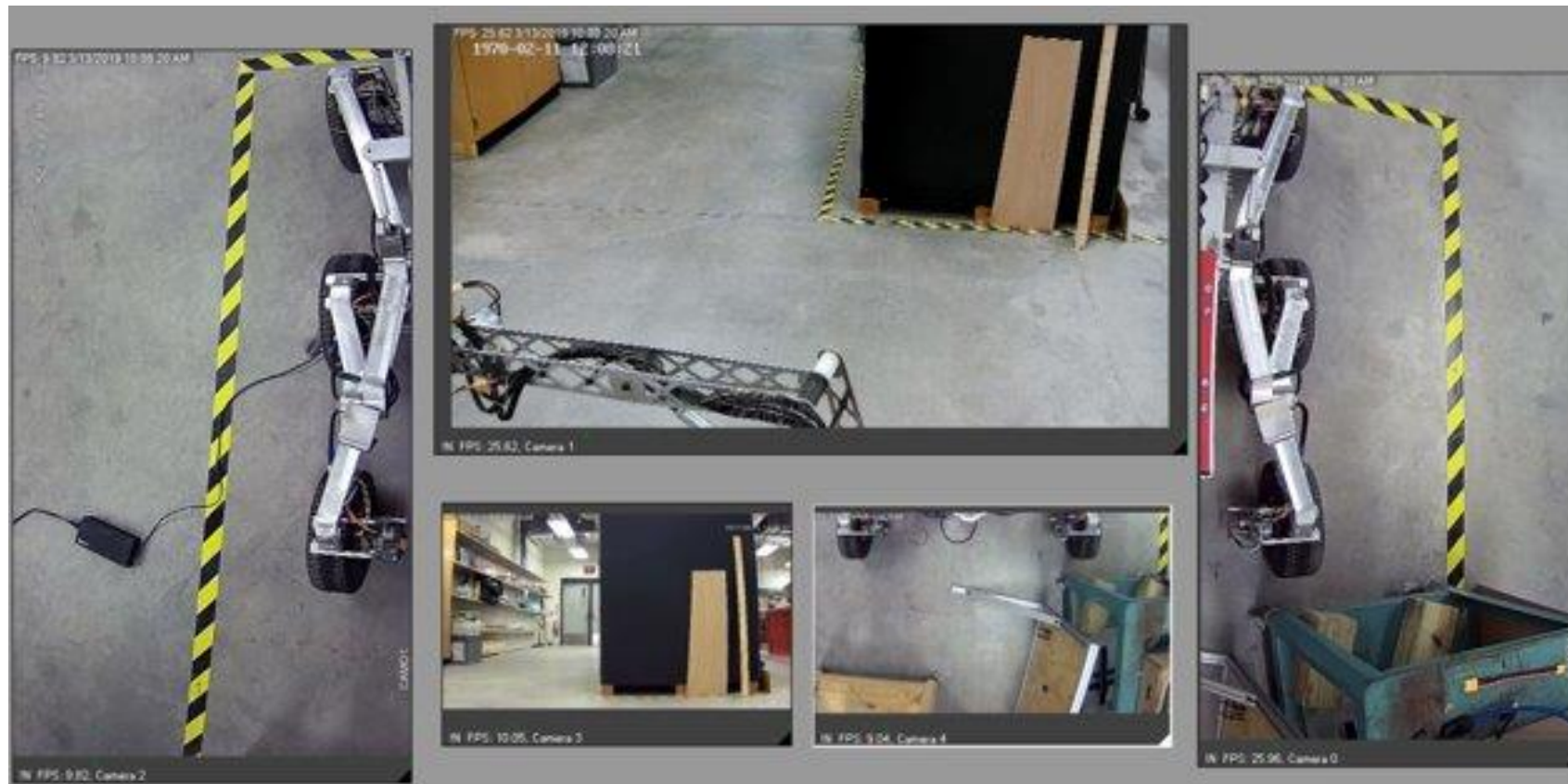




# EXTRA SLIDES – AUTONOMOUS

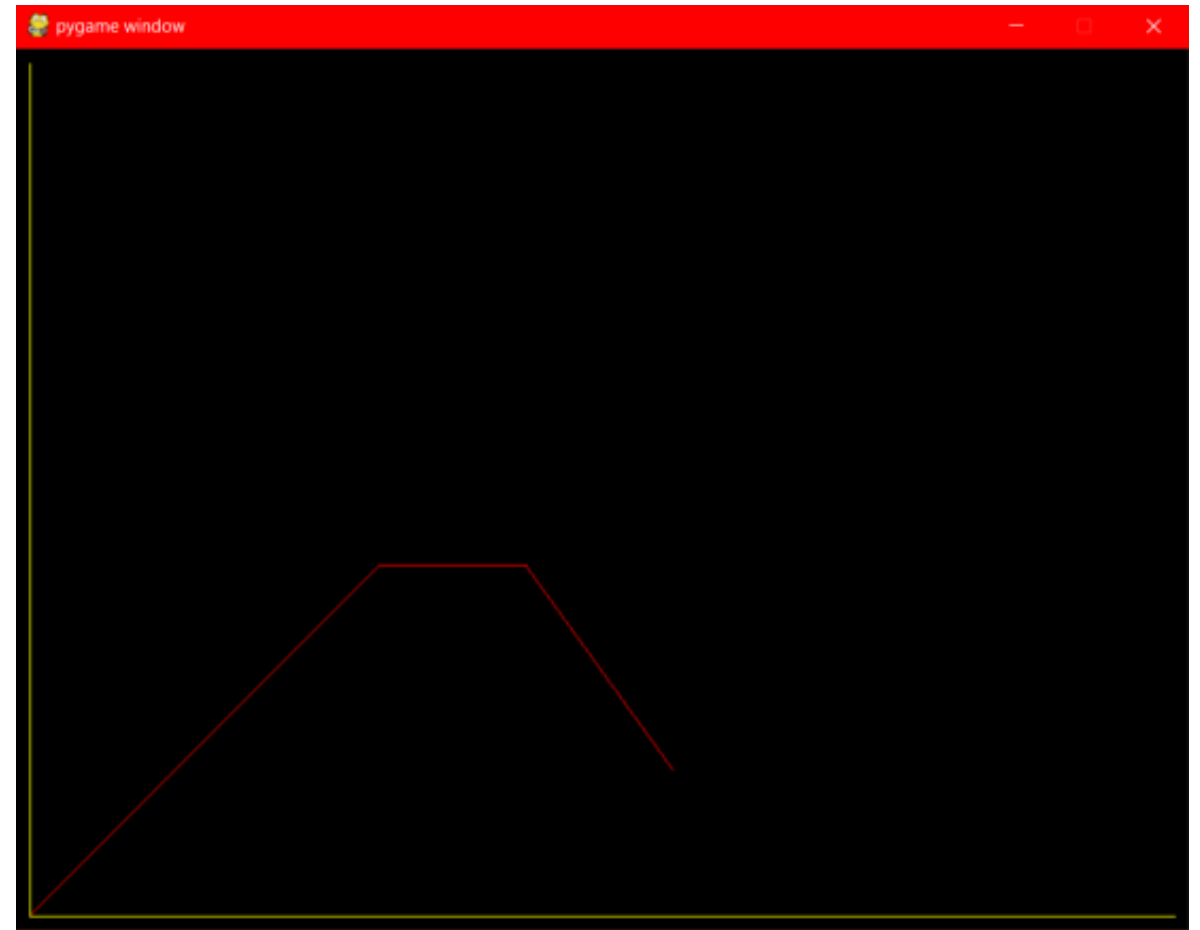
- Use GPS to navigate near the target (tested, working)
  - Use Intel RealSense to detect obstacles
  - Use IMU for compass heading
- Once GPS point is reached, begin moving in search pattern
  - Use Pixy2 camera to recognize tennis ball
  - Drive to tennis ball and flash indicator light
- Now looking into using more advanced computer vision with the TX2
  - Greatly increased processing power

# EXTRA SLIDES – CAMERA VIEW

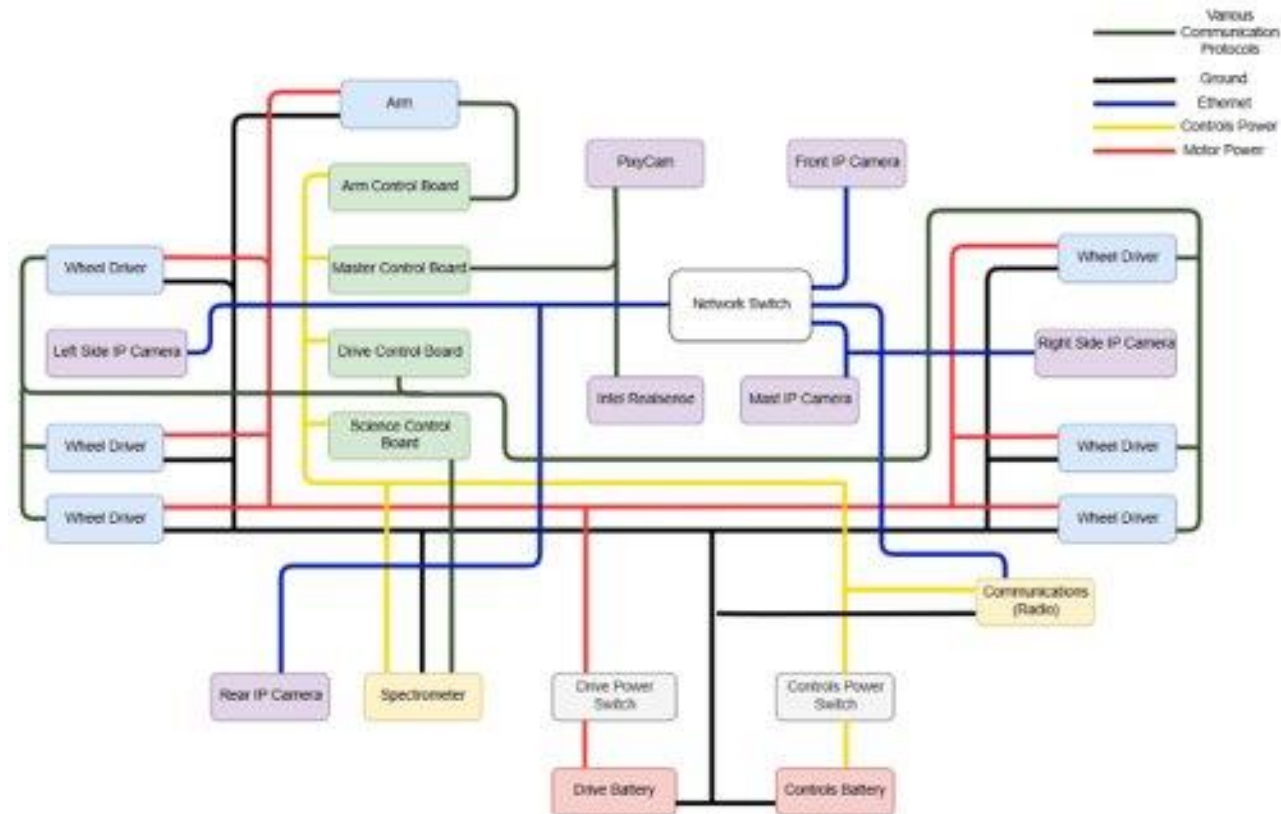


# EXTRA SLIDES – BASE STATION

- Written in Python
- Uses pygame library for dynamic model of arm
- Will display simple autonomous map
- Additionally will have live information on the various subsystems
  - Battery voltages
  - GPS Coordinates
  - Drive speed



# EXTRA SLIDES – BLOCK DIAGRAM





# EXTRA SLIDES – TX2 TRANSITION

- Motivation

- Increased focus on AI/ML from URC
- Limited graphics processing of Pi3
- 6 CPU Cores
- 128 Cuda Cores (20% of GTX 1060)
- 8GB Ram (8x more than Pi3)

- Transition

- Hardware Drivers
  - Physical interface unchanged
  - Software updated slightly
- Application software unchanged
- Launch Configuration
  - Re-built by combining RasPi launch configurations

# EXTRA SLIDES – TX2 UPGRADE

- Competition focus on computer vision
  - URC has required tasks
  - CIRC has bonuses for all tasks
- Limitations of Raspberry Pi's
  - Excess heat with single 720p camera
  - No CAN bus for motor controllers
- Applications of the TX2
  - Terrain mapping for obstacle avoidance
  - Object identification and arm control
- Advantages of the TX2
  - Increased Processing Power
    - 4x 2.0 GHz ARM cores
    - 2x NVIDIA Denver cores
    - 256 CUDA cores
  - Increased memory
    - 8 GB
      - 1GB on Pi
    - ~60 GB/s bandwidth
      - 5.5 GB/s on Pi
      - Allows for more flexibility in CV setup

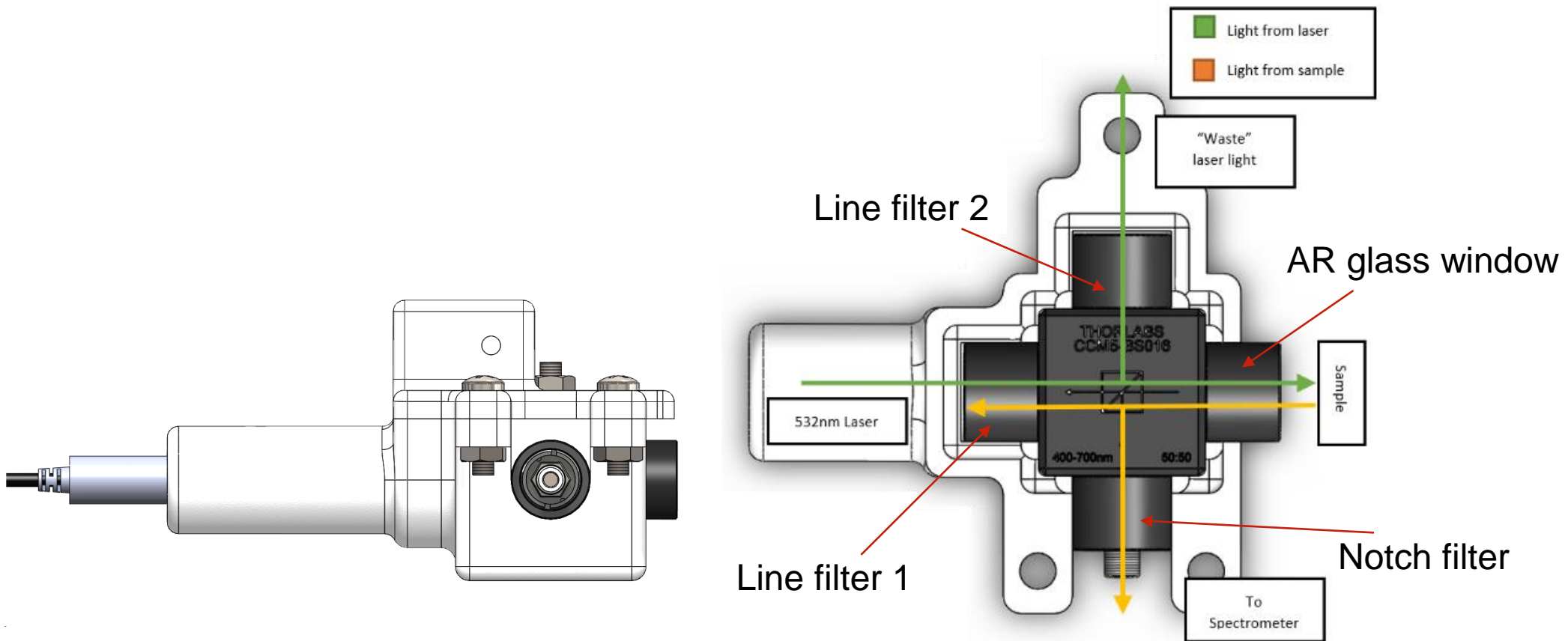


# EXTRA SLIDES – PYTHON BIOMARKER IDENTIFICATION SCRIPT

- The `convertPeaks()` function
  - Converts the spectrometer wavelength data to Raman wavenumber data
- The `findPeaks()` function
  - Sorts through the spectra data and finds peaks that we can consider for biomarker assignment
- The `determineMatch()` function
  - Looks at peaks from wavenumber data, determines the likelihood of the presence of biomarkers on our list



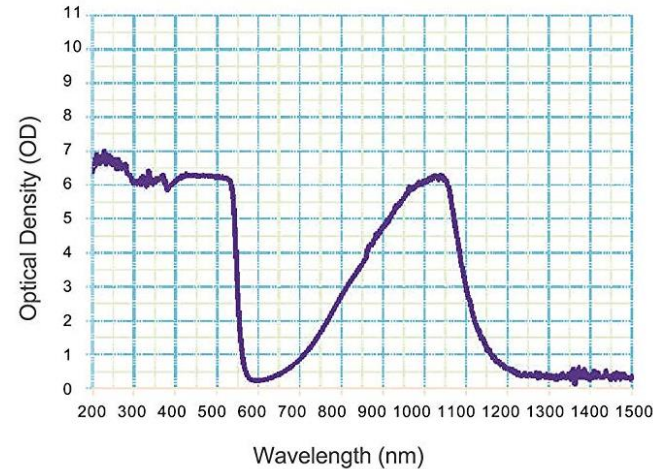
# EXTRA SLIDES – OPTICAL HOUSING AND LASER PATH





# EXTRA SLIDES – LASER SAFETY

- Laser is class 3R
  - Low-hazard laser
- Taking precautions and wearing safety glasses due to repeated exposure to beam
- Lowered eye exposure to beam while still being able to see dot



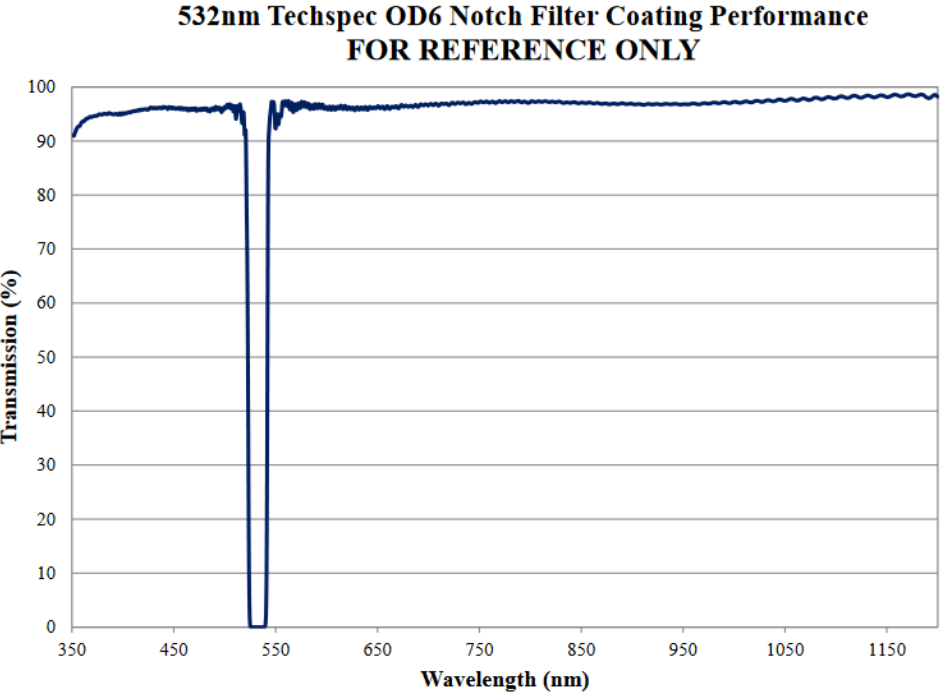
Unintentional or accidental exposure to direct or reflected beam has a low risk. Avoid intentional exposure to direct or reflected beam.

# EXTRA SLIDES – NOTCH FILTER GRAPH

Coating:	Hard Coated
Diameter (mm):	12.50 +0.0/-0.1
Optical Density OD:	≥6.0
Thickness Tolerance (mm):	±0.1
Transmission Wavelength (nm):	350 - 1200
Construction:	Mounted in Black Anodized Ring
Durability:	MIL-C-48497A
Transmitted Wavefront, RMS:	<1λ

**Regulatory Compliance**

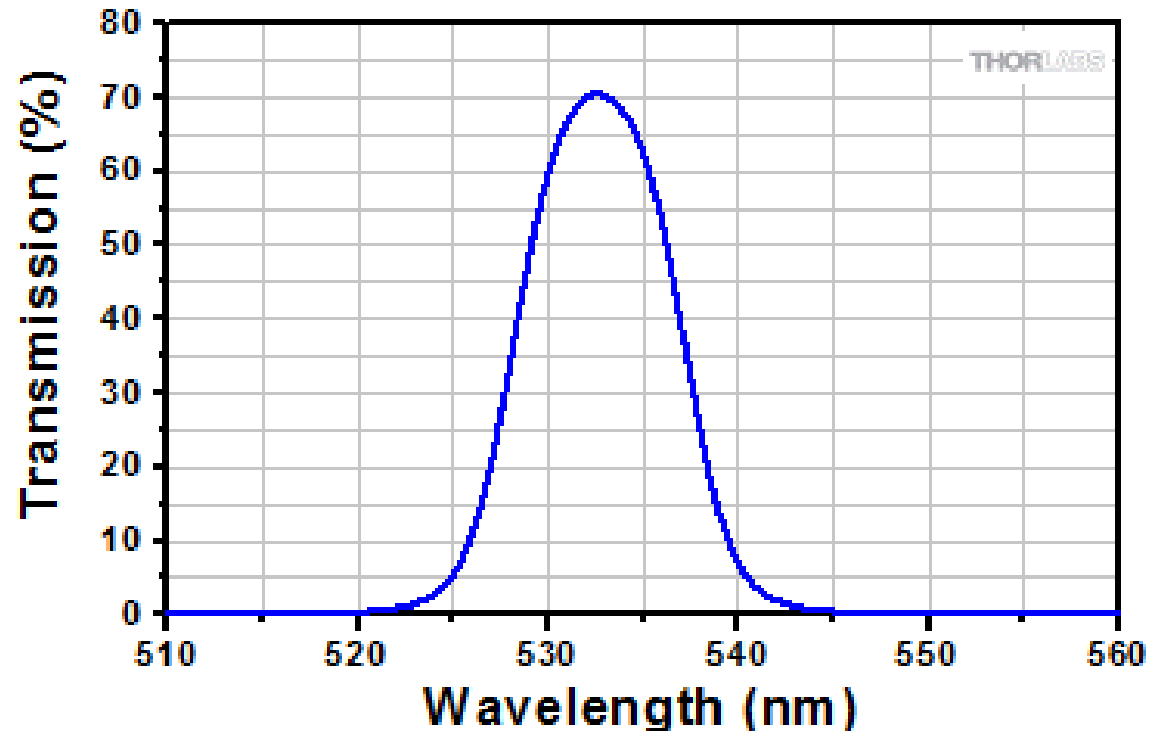
Reach 191:	Compliant
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Center Wavelength CWL (nm):	532
Full Width-Half Max FWHM (nm):	17.00
Surface Quality:	60-40
Transmission (%):	350 - 400nm: T <sub>avg</sub> >80 400 - 1200nm: T <sub>avg</sub> >90
Type:	Notch Filter
Clear Aperture (%):	85
Reflection at CWL (%):	>99.5
Mount Thickness (mm):	3.5
RoHS:	Compliant

# EXTRA SLIDES – LINE FILTER GRAPH

## FL05532-10 Transmission



CWL <sup>a</sup>	FWHM <sup>b</sup>	T (Min) <sup>c</sup>	Blocking <sup>d</sup>	Transmission/ OD Data <sup>e</sup>	Laser Line	Size
532 ± 2 nm	10 ± 2 nm	70%	200 - 1100 nm		Nd:YAG	Ø1/2"

# EXTRA SLIDES – LASER SPECS



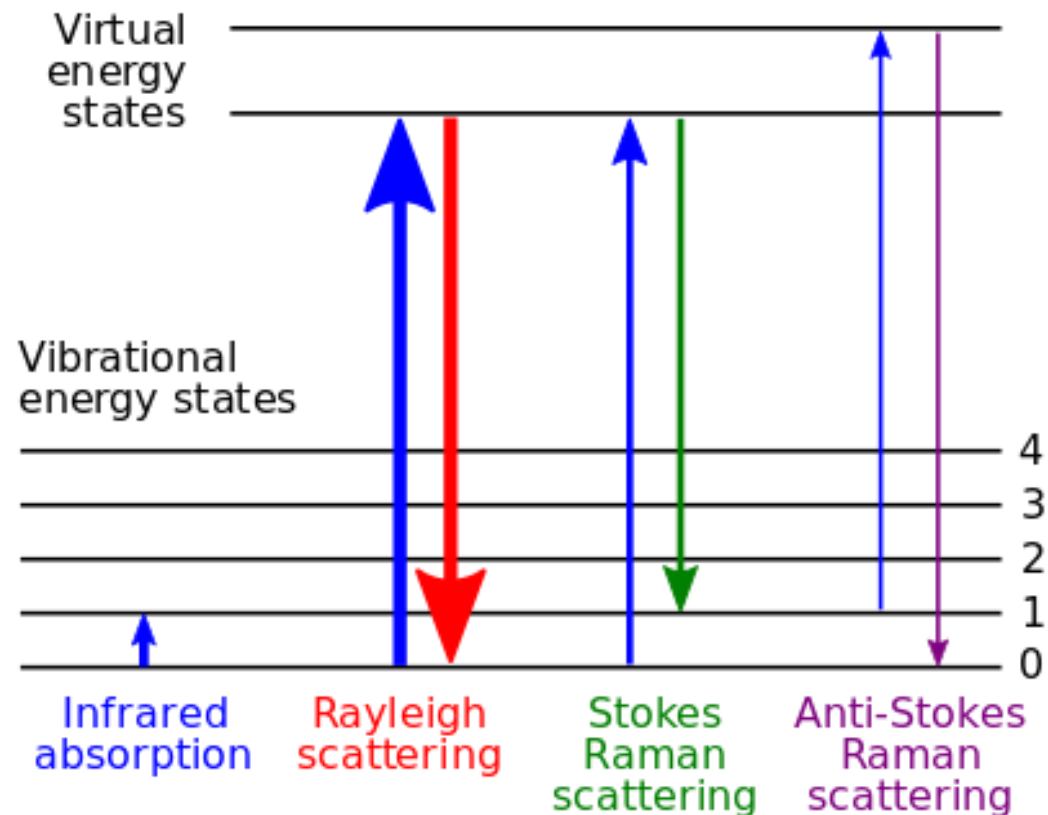
General Specifications	
Characteristic	
Housing Material	Aluminum
Housing Dimensions	Ø11.0 mm x 72.8 mm
Beam Size <sup>a</sup>	Round, Ø3.5 mm
Operating Temperature	10 to 40 °C
Storage Temperature	-30 to 70 °C
Operating Voltage (Nominal)	5 VDC
Laser Safety Class	3R

Optical Electrical Characteristics				
Characteristic	MIN	TYP	MAX	UNIT
Wavelength	531	532	533	nm
Optical Output Power (CW)	4.0	4.5	5.0	mW
Polarization State Extinction Ratio	-	4	-	dB
Power Stability (8 Hours)	-	-	2	%
Axis Deviation <sup>a</sup>	-	-	5	mrad
Beam Divergence	-	-	0.5	mrad
Operating Current (CW)	-	250	-	mA

# EXTRA SLIDES – RAMAN SPECTROSCOPY

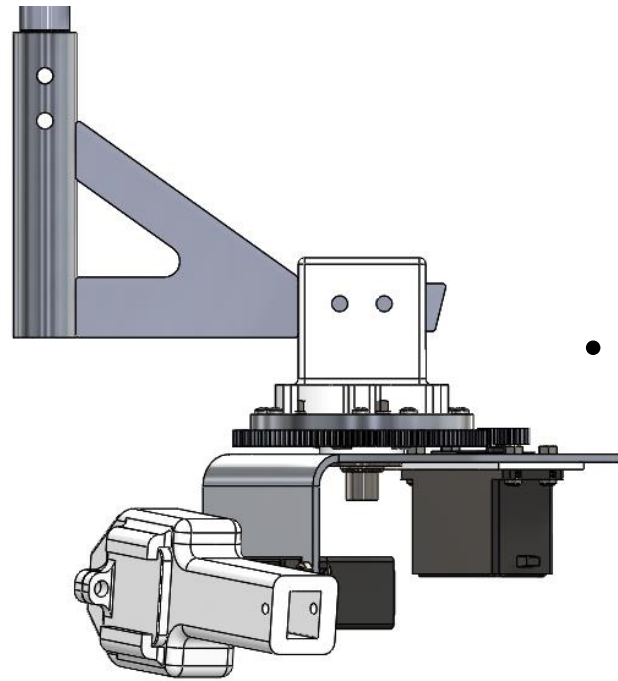
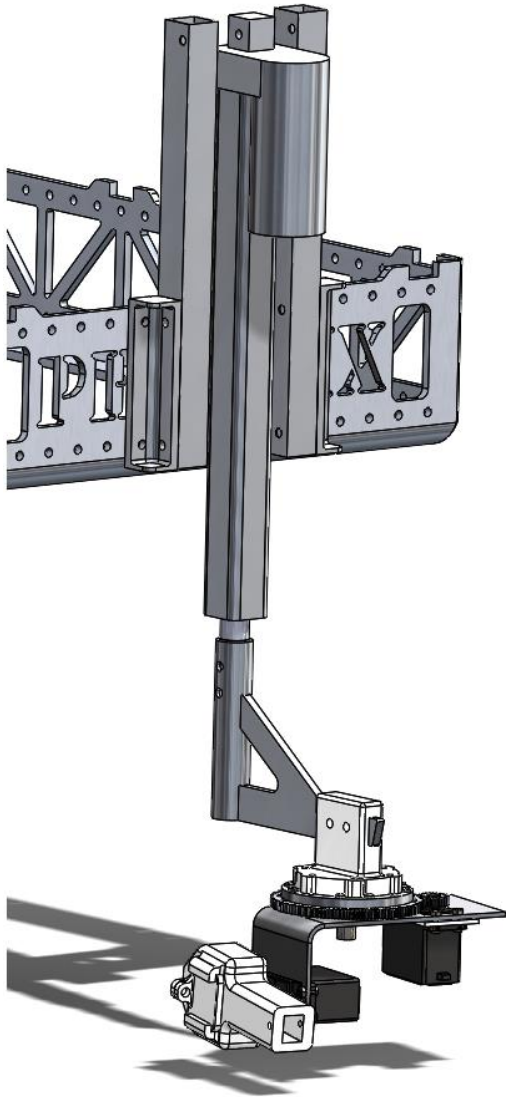
- Several different types of light return when a laser is incident to a surface
  - Rayleigh is easiest to see
  - Stokes and anti-Stokes are used for Raman spectroscopy

$$\bar{\nu} = \frac{1}{\lambda_{incident}} - \frac{1}{\lambda_{scattered}}$$





# EXTRA SLIDES – LASER ORIENTATION



- 4 degrees of freedom
  - Vertical actuation
  - Forward actuation
  - Pitch
  - Yaw
- Allows for fine control of laser
  - Does not rely on rover for specific location of test sample

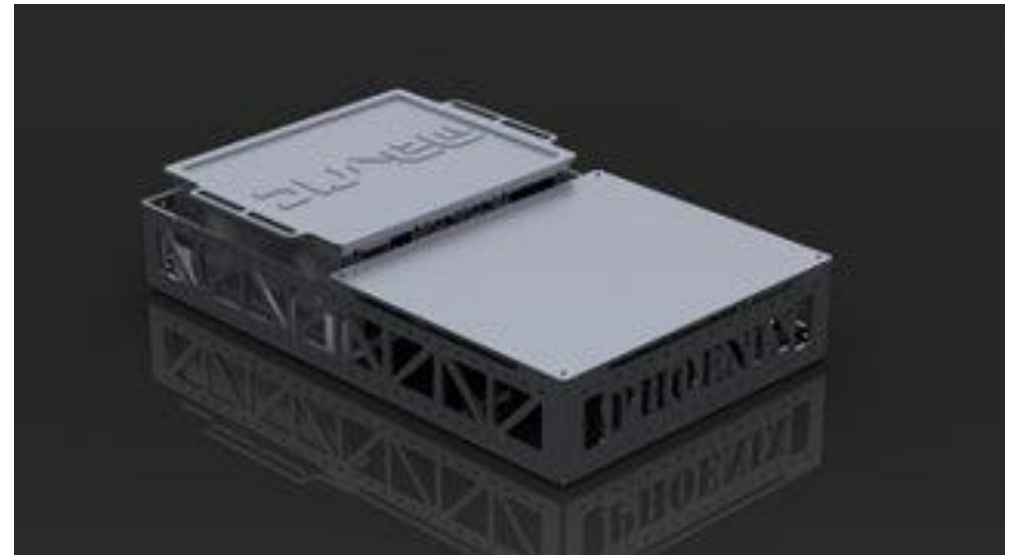
# EXTRA SLIDES – WEIGHT REDUCTION

- Replace excessively long/bulky hardware (Completed)
- Suspension
  - Flip stops – Mill (Completed)
  - Beams – Mill (Skipped)
  - Wheel nuts – Grind (Skipped)
  - Drop plate blocks – Mill (Completed)
  - Motor mounts – Replace (Skipped)
  - Wheels – Replace (Skipped)
- Chassis
  - Top plate – Replace (In Progress)
  - Battery mount – Mill (In Progress)



# EXTRA SLIDES - CHASSIS

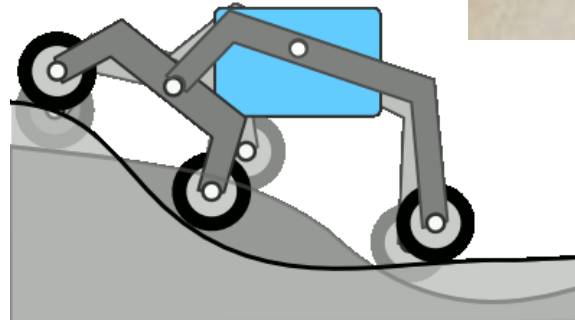
- Generously donated by Quality Manufacturing
- ¼" aluminum plate, formed and welded
- Lighter, stronger, and easier to work with than past chassis
- Allows modular design due to mounting hole pattern
  - Easy to perform upgrades and maintenance
  - Can easily test new designs
- Top plate for mounting various subsystems
  - Robotic arm
  - Light spectrometer
  - Suspension differential bar
  - Batteries
  - Arm power distribution box
  - Autonomous cameras and lights





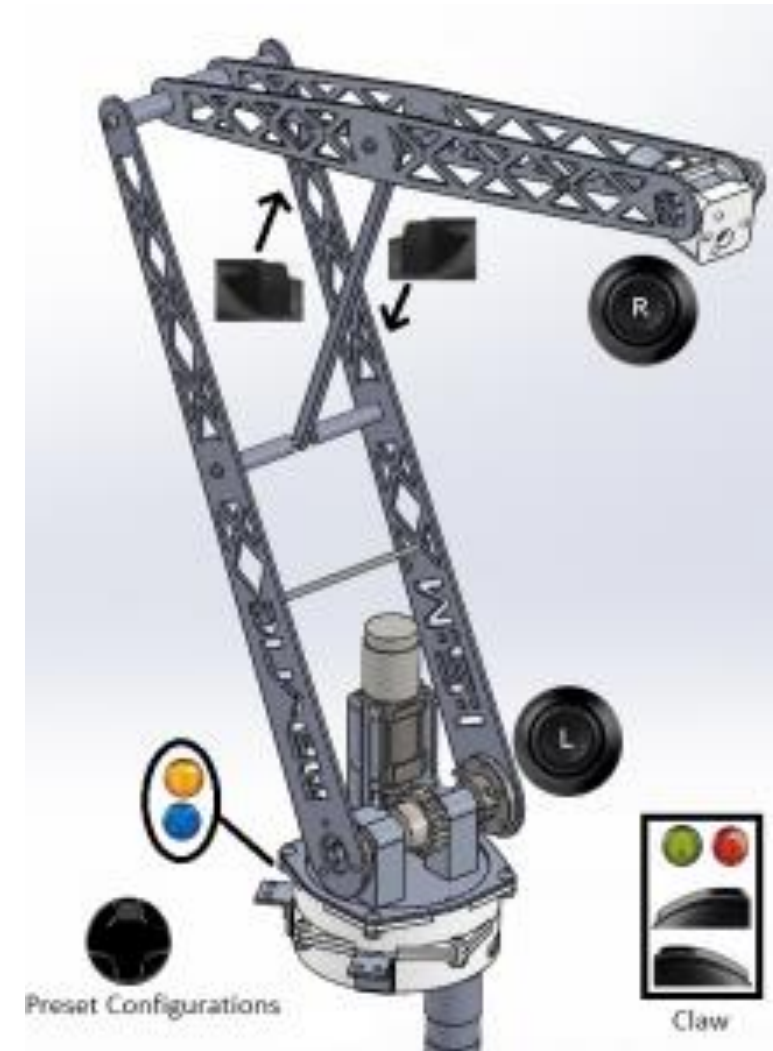
# EXTRA SLIDES - SUSPENSION

- Rocker bogie suspension
- Keeps chassis stable in rough terrain
- Rocker has motion limited by flip-stops
  - Prevents flipping in extreme terrain
- Wheels individually driven by in-hub motors
- Skid-steering
  - Lightweight
  - Works on desert soil
- Tested successfully in fall 2018



# EXTRA SLIDES – ROBOTIC ARM

- Base rotation – motor and internal ring gear
- Shoulder – motor with worm drive
- Elbow – linear actuator
- Wrist – two direct-drive motors
- Arm control box attached beneath top plate
- Subsystem is easily removeable





# EXTRA SLIDES – END EFFECTOR

- Old End Effector
  - Driven by a single mini linear actuator
  - Four fingers
  - Narrow grips on all sides
- Revised End Effector
  - Driven by a single mini linear actuator
  - Two fingers
  - Wide, flexible grip surfaces
  - Rotates on-center for ease of use
  - Limit switches control position

