MAKE TO INNOVATE

Mid-Term Review – Spring 2019

MAVRIC – Mars Analog Vehicle for Robotic Inspection and Construction

AGENDA

- Project Overview
- Activity Report
- Design Review
  - Design Constraints
  - Current Design
  - Proposed Changes
  - Design Risks
- Budget Status
- Conclusion

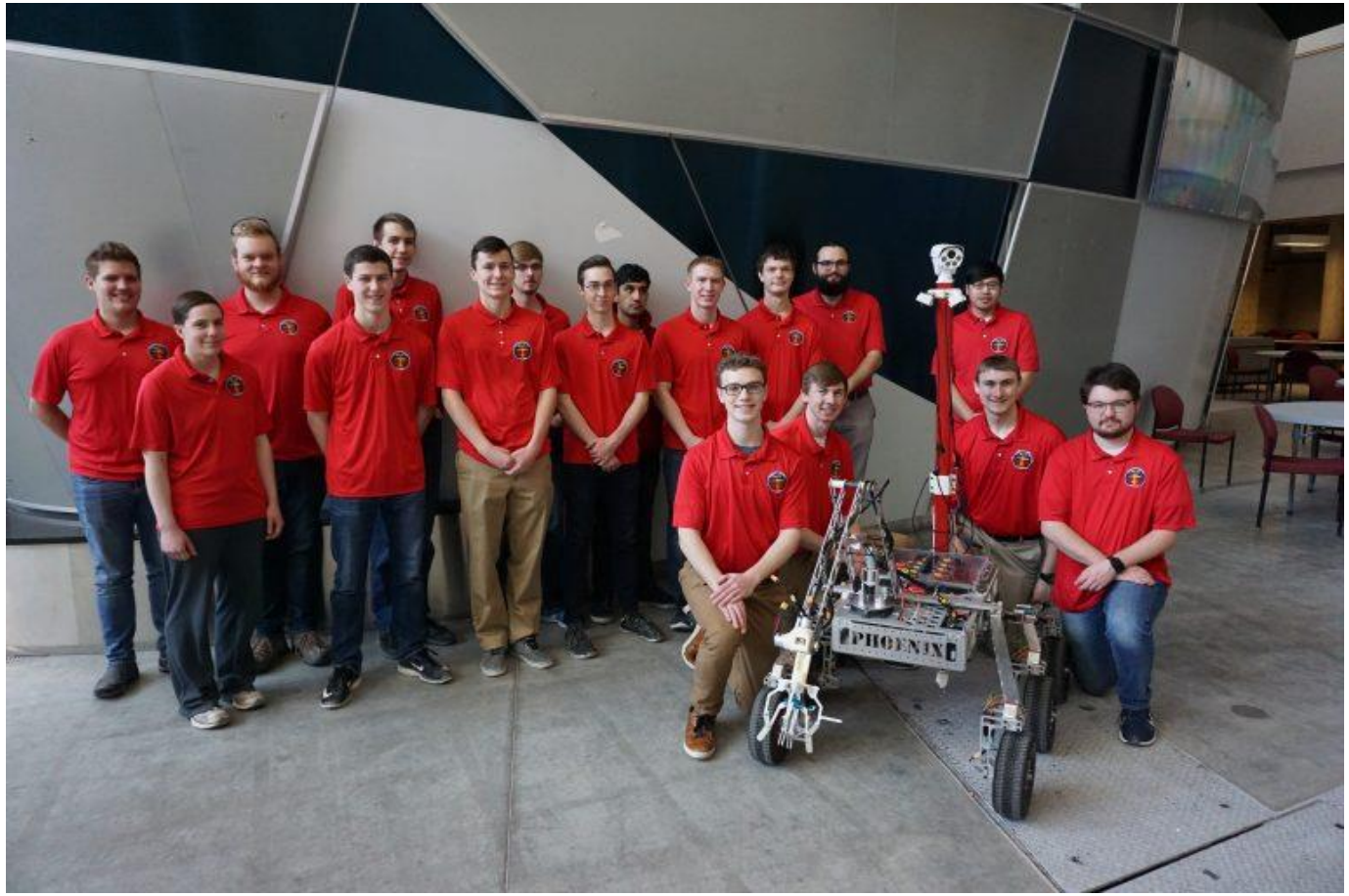
PROJECT OVERVIEW

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

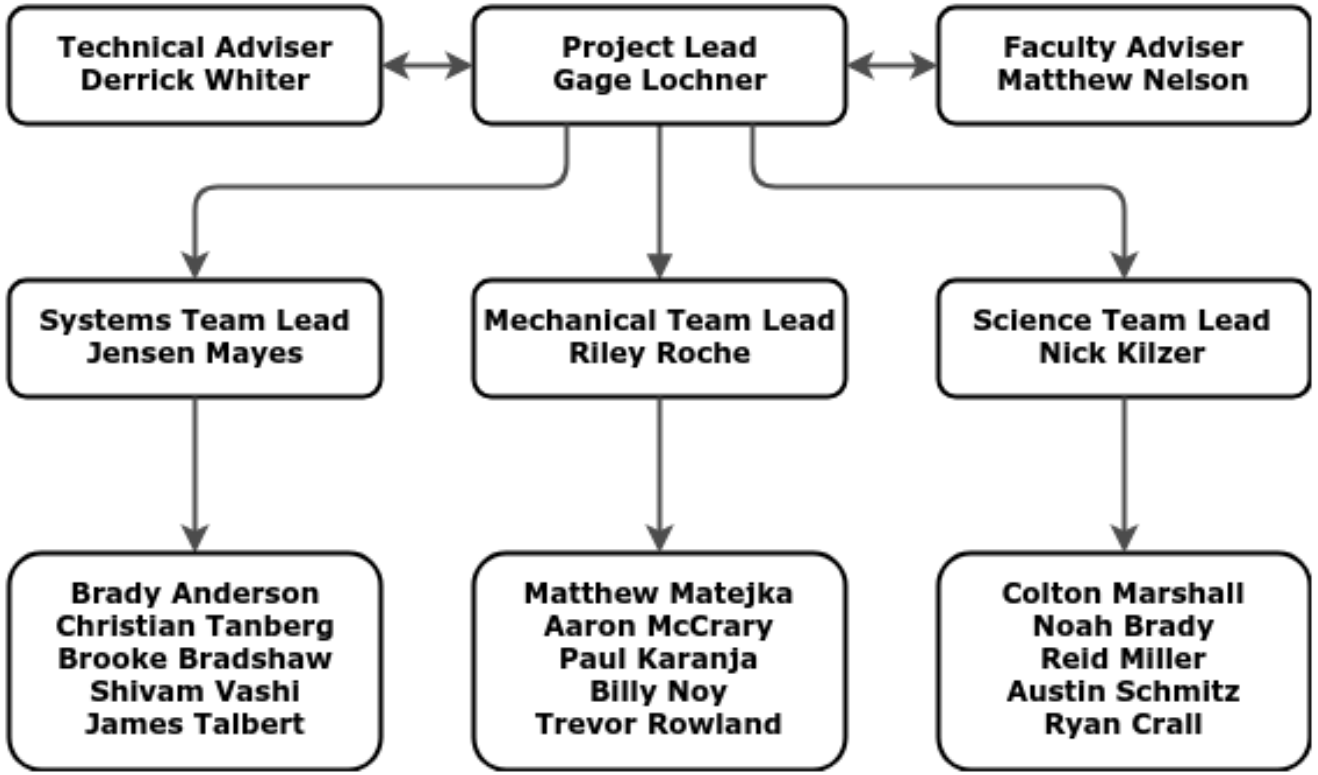
Not pictured: Trevor Rowland, Paul Karanja



PROJECT OVERVIEW

Project Faculty Adviser	Matthew Nelson
Project Technical Advisers	Derick Whited – Virginia Tech
Project Team Lead	Gage Lochner - Aerospace
Project Stake Holders	ISGC, M2I, Danfoss, Protocase, Emerson,Quality Manufacturing

Project Organization Chart



Project Plan

Project Objectives

- To build an analog next generation Mars rover

Semester Goals

- Get accepted into URC competition
- Complete Phoenix

Semester Deliverables

- Competition 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

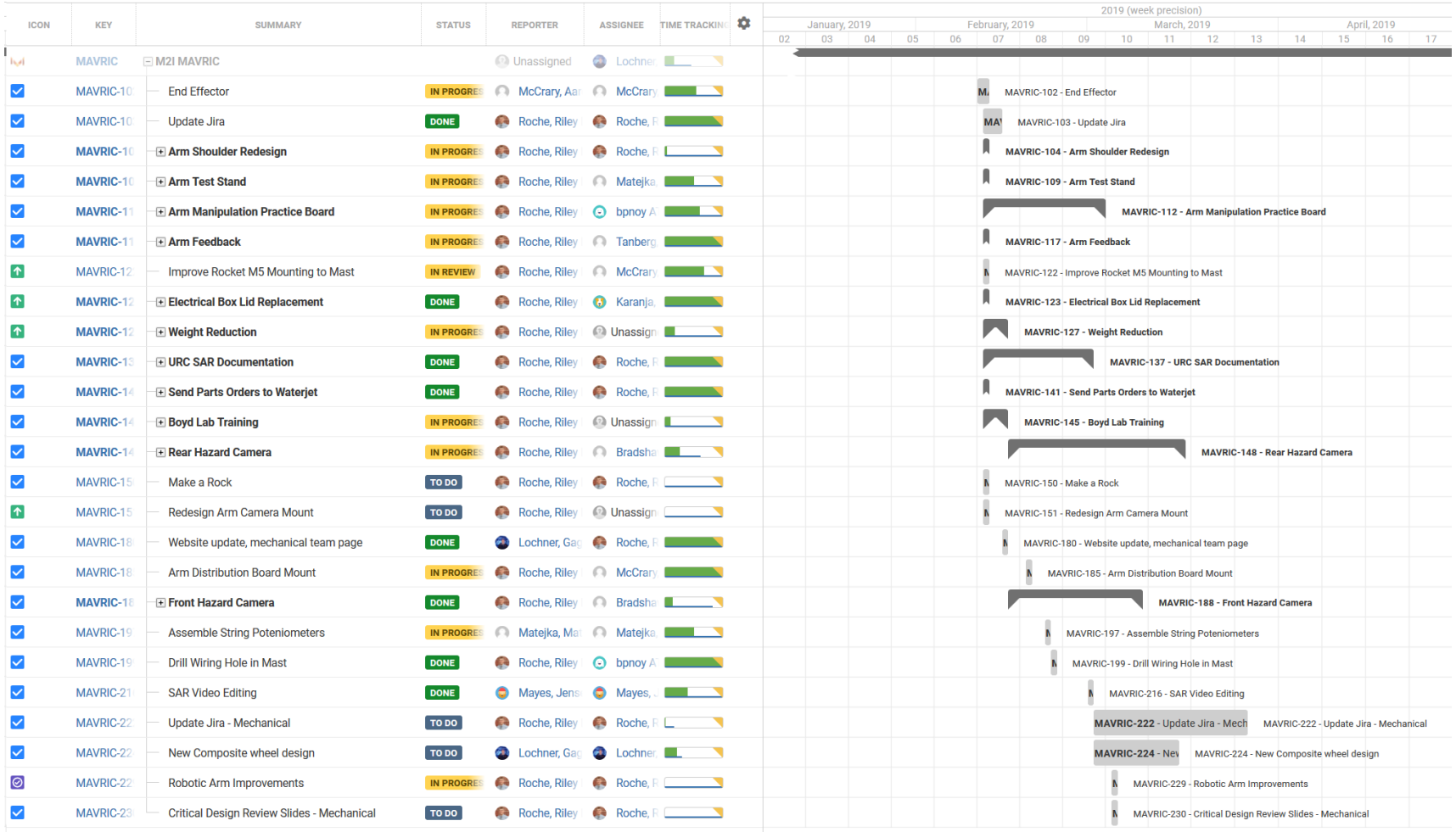
- Milestone 1 – Manufacturing and Testing
  - Complete manufacturing of Laser Orientation
  - Make prototype and final copy of optical housing
  - Perform known testing of system with easy-to-identify substances
- Milestone 2 – Competition Readiness
  - Complete biomarker identification script with Python
  - 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

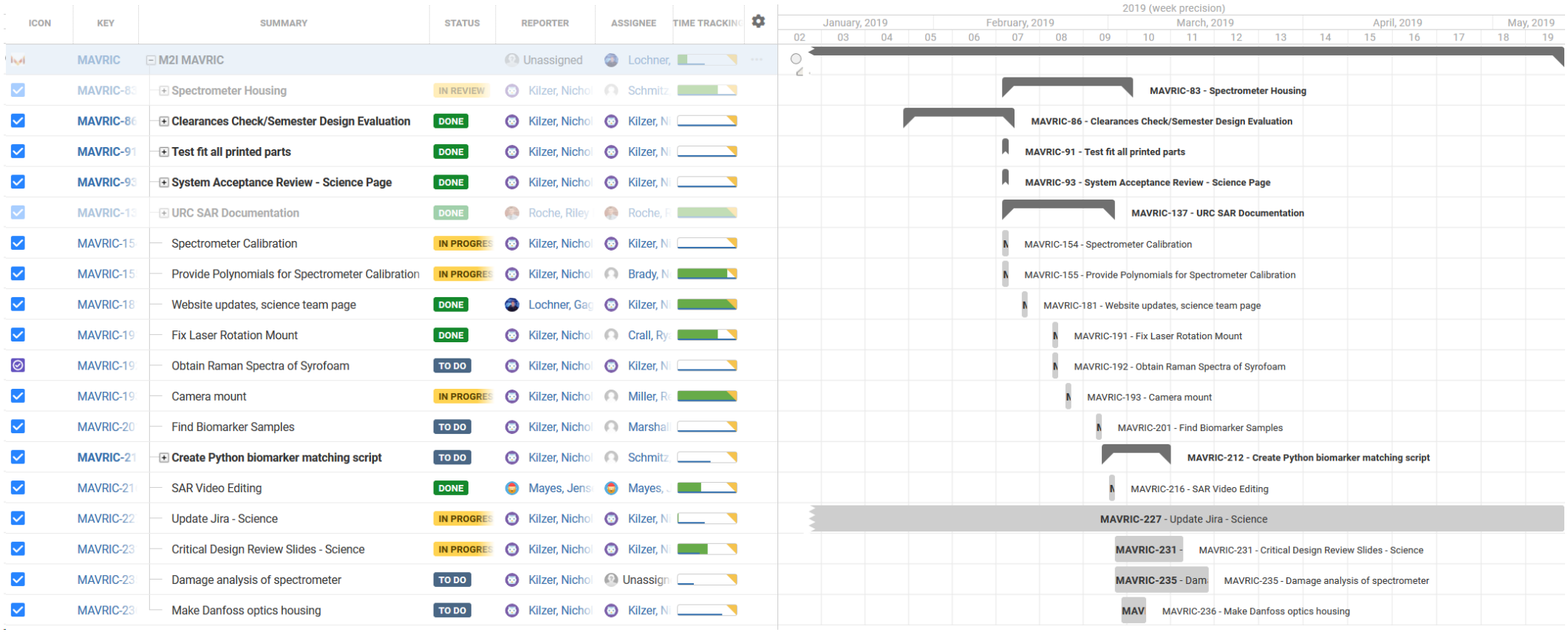
- Milestone 2
  - Fully Functional Autonomous Systems
  - Competition Readiness
  - User Friendly Base Station

TASK BREAKDOWN - MECHANICAL



ICON	KEY	SUMMARY	STATUS	REPORTER	ASSIGNEE	TIME TRACKING
	MAVRIC	M2I MAVRIC		Unassigned	Lochner	
	MAVRIC-10	End Effector	IN PROGRES	McCrary, Aar	McCrary	
	MAVRIC-10	Update Jira	DONE	Roche, Riley	Roche,	
	MAVRIC-10	**Arm Shoulder Redesign**	IN PROGRES	Roche, Riley	Roche,	
	MAVRIC-10	**Arm Test Stand**	IN PROGRES	Roche, Riley	Matejka	
	MAVRIC-11	**Arm Manipulation Practice Board**	IN PROGRES	Roche, Riley	bpnoy A	
	MAVRIC-11	**Arm Feedback**	IN PROGRES	Roche, Riley	Tanberg	
	MAVRIC-12	Improve Rocket M5 Mounting to Mast	IN REVIEW	Roche, Riley	McCrary	
	MAVRIC-12	**Electrical Box Lid Replacement**	DONE	Roche, Riley	Karanja	
	MAVRIC-12	**Weight Reduction**	IN PROGRES	Roche, Riley	Unassign	
	MAVRIC-13	**URC SAR Documentation**	DONE	Roche, Riley	Roche,	
	MAVRIC-14	**Send Parts Orders to Waterjet**	DONE	Roche, Riley	Roche,	
	MAVRIC-14	**Boyd Lab Training**	IN PROGRES	Roche, Riley	Unassign	
	MAVRIC-14	**Rear Hazard Camera**	IN PROGRES	Roche, Riley	Bradsha	
	MAVRIC-15	Make a Rock	TO DO	Roche, Riley	Roche,	
	MAVRIC-15	Redesign Arm Camera Mount	TO DO	Roche, Riley	Unassign	
	MAVRIC-18	Website update, mechanical team page	DONE	Lochner, Gag	Roche,	
	MAVRIC-18	Arm Distribution Board Mount	IN PROGRES	Roche, Riley	McCrary	
	MAVRIC-18	**Front Hazard Camera**	DONE	Roche, Riley	Bradsha	
	MAVRIC-19	Assemble String Poteniometers	IN PROGRES	Matejka, Mat	Matejka	
	MAVRIC-19	Drill Wiring Hole in Mast	DONE	Roche, Riley	bpnoy A	
	MAVRIC-21	SAR Video Editing	DONE	Mayes, Jens	Mayes,	
	MAVRIC-22	Update Jira - Mechanical	TO DO	Roche, Riley	Roche,	
	MAVRIC-22	New Composite wheel design	TO DO	Lochner, Gag	Lochner	
	MAVRIC-22	Robotic Arm Improvements	IN PROGRES	Roche, Riley	Roche,	
	MAVRIC-23	Critical Design Review Slides - Mechanical	TO DO	Roche, Riley	Roche,	

TASK BREAKDOWN - SCIENCE



ICON	KEY	SUMMARY	STATUS	REPORTER	ASSIGNEE	TIME TRACKING
	MAVRIC	M2I MAVRIC		Unassigned	Lochner,	
	MAVRIC-83	Spectrometer Housing	IN REVIEW	Kilzer, Nicho	Schmitz	
	MAVRIC-86	**Clearances Check/Semester Design Evaluation**	DONE	Kilzer, Nicho	Kilzer, N	
	MAVRIC-91	**Test fit all printed parts**	DONE	Kilzer, Nicho	Kilzer, N	
	MAVRIC-93	**System Acceptance Review - Science Page**	DONE	Kilzer, Nicho	Kilzer, N	
	MAVRIC-13	URC SAR Documentation	DONE	Roche, Riley	Roche,	
	MAVRIC-15	Spectrometer Calibration	IN PROGRES	Kilzer, Nicho	Kilzer, N	
	MAVRIC-15	Provide Polynomials for Spectrometer Calibration	IN PROGRES	Kilzer, Nicho	Brady, N	
	MAVRIC-18	Website updates, science team page	DONE	Lochner, Gag	Kilzer, N	
	MAVRIC-19	Fix Laser Rotation Mount	DONE	Kilzer, Nicho	Crall, Ry	
	MAVRIC-19	Obtain Raman Spectra of Syrofoam	TO DO	Kilzer, Nicho	Kilzer, N	
	MAVRIC-19	Camera mount	IN PROGRES	Kilzer, Nicho	Miller, R	
	MAVRIC-20	Find Biomarker Samples	TO DO	Kilzer, Nicho	Marshal	
	MAVRIC-21	**Create Python biomarker matching script**	TO DO	Kilzer, Nicho	Schmitz	
	MAVRIC-21	SAR Video Editing	DONE	Mayes, Jens	Mayes,	
	MAVRIC-22	Update Jira - Science	IN PROGRES	Kilzer, Nicho	Kilzer, N	
	MAVRIC-23	Critical Design Review Slides - Science	IN PROGRES	Kilzer, Nicho	Kilzer, N	
	MAVRIC-23	Damage analysis of spectrometer	TO DO	Kilzer, Nicho	Unassign	
	MAVRIC-23	Make Danfoss optics housing	TO DO	Kilzer, Nicho	Kilzer, N	

TASK BREAKDOWN - SYSTEMS

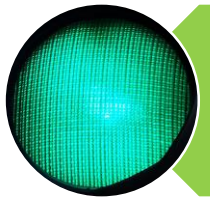
ICON	KEY	SUMMARY	STATUS	REPORTER	ASSIGNEE	TIME TRACKING
	MAVRIC	M2I MAVRIC		Unassigned	Lochner,	
	MAVRIC-94	Arm Feedback ROS Node	DONE	Mayes, Jens	Tanberg	
	MAVRIC-96	Custom ADC Hat Finalized	IN PROGRESS	Mayes, Jens	Talbert,	
	MAVRIC-97	Science System Data Stream to CSV	DONE	Mayes, Jens	Bradsha	
	MAVRIC-98	Autonomous System Research & Framework Upgr	DONE	Mayes, Jens	Anderso	
	MAVRIC-99	Strategy Work	IN PROGRESS	Mayes, Jens	Vashi, S	
	MAVRIC-10	IMU Integration & Testing	DONE	Mayes, Jens	Anderso	
	MAVRIC-11	Arm Feedback	IN PROGRESS	Roche, Riley	Tanberg	
	MAVRIC-12	Electrical Box Lid Replacement	DONE	Roche, Riley	Karanja	
	MAVRIC-13	Weight Reduction	IN PROGRESS	Roche, Riley	Unassigned	
	MAVRIC-13	URC SAR Documentation	DONE	Roche, Riley	Roche,	
	MAVRIC-14	Rear Hazard Camera	IN PROGRESS	Roche, Riley	Bradsha	
	MAVRIC-15	Look at current GUI software	IN PROGRESS	Mayes, Jens	Vashi, S	
	MAVRIC-18	Website updates, systems team page	DONE	Lochner, Ga	Mayes,	
	MAVRIC-18	Arm Distribution Board	DONE	Mayes, Jens	Talbert,	
	MAVRIC-18	Arm Distribution Board Mount	IN PROGRESS	Roche, Riley	McCrar	
	MAVRIC-18	Front Hazard Camera	DONE	Roche, Riley	Bradsha	
	MAVRIC-19	2/22/2019 Outreach Event Prep	DONE	Talbert, Jam	Talbert,	
	MAVRIC-19	Arm Feedback Testing	DONE	Mayes, Jens	Bradsha	
	MAVRIC-19	Science System Integration	TO DO	Mayes, Jens	Vashi, S	
	MAVRIC-19	Autonomous System Coding and Testing	TO DO	Vashi, Shiva	Vashi, S	
	MAVRIC-20	SAR Systems Report	DONE	Mayes, Jens	Mayes,	
	MAVRIC-20	SAR Systems Testing Plan	TO DO	Mayes, Jens	Mayes,	
	MAVRIC-20	Pixy Camera Initial Testing	DONE	Mayes, Jens	Anderso	
	MAVRIC-20	Pixy Camera Hardware Integration	TO DO	Mayes, Jens	Anderso	
	MAVRIC-20	Pixy Camera Software Integration	TO DO	Mayes, Jens	Anderso	
	MAVRIC-20	Intel Realsense Initial Camera Testing	TO DO	Mayes, Jens	Vashi, S	
	MAVRIC-20	Intel Realsense Mounting	TO DO	Mayes, Jens	Vashi, S	
	MAVRIC-20	Develop Cleaner GUI	IN PROGRESS	Mayes, Jens	Vashi, S	
	MAVRIC-21	Design through E-Box PCBs Front	IN PROGRESS	Mayes, Jens	Talbert,	
	MAVRIC-21	IMU Startup Routine	TO DO	Mayes, Jens	Anderso	
	MAVRIC-21	SAR Video Editing	DONE	Mayes, Jens	Mayes,	
	MAVRIC-21	Design through E-Box PCBs Back	TO DO	Mayes, Jens	Talbert,	
	MAVRIC-21	Debug Rover Arm & Drive Code	DONE	Mayes, Jens	Bradsha	
	MAVRIC-22	Debug Rover ADC Code	IN PROGRESS	Mayes, Jens	Tanberg	
	MAVRIC-23	Critical Design Review Slides - Systems	IN PROGRESS	Mayes, Jens	Mayes,	
	MAVRIC-23	Systems Milestone 1	TO DO	Mayes, Jens	Mayes,	

PROJECT HEALTH REPORT

- Green, Yellow, Red. This is an honest assessment on how the project is doing currently

Science system – possible notch filter issues

Autonomous, arm feedback and shoulder



All other arm systems, suspension reworks, base station operation, overall system stability

DESIGN REVIEW

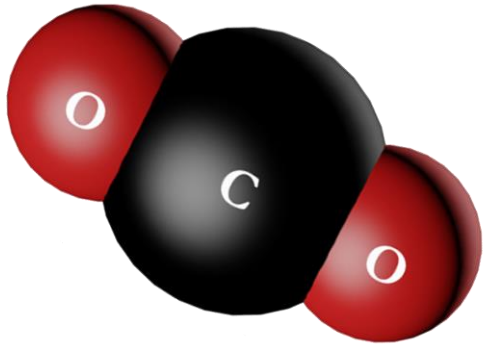
Overview

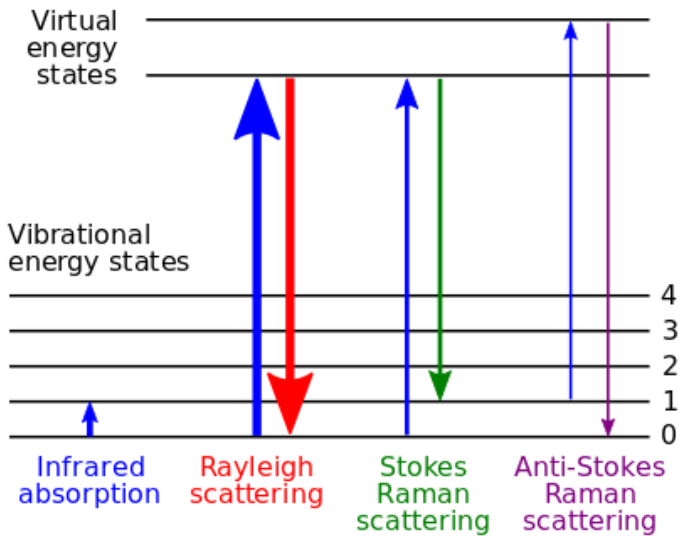
DESIGN OVERVIEW - MECHANICAL

- New 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 4-finger end effector

DESIGN OVERVIEW - SCIENCE

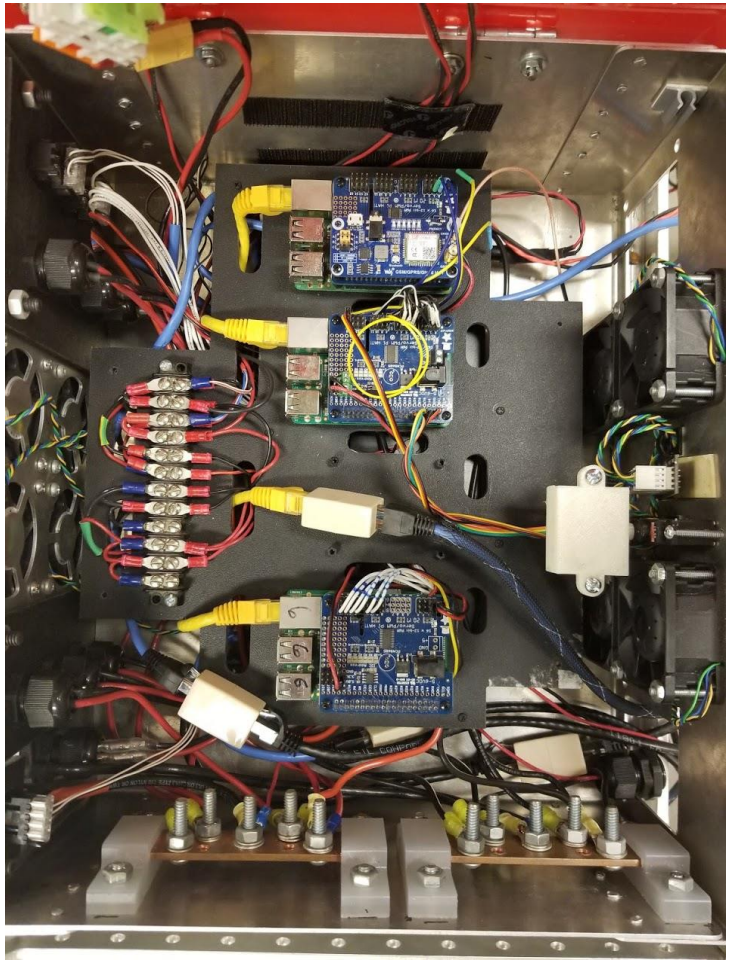
- Research
  - Spectroscopy
    - LIBS and Raman
  - Epi-fluorescence Microscopy
  - Agarose gel electrophoresis
  - Water-induced CO2 emission analysis
- Raman spectroscopy
  - Parts research
  - Biomarker research
  - Initial design work





DESIGN OVERVIEW - SYSTEMS

- Control Systems
  - Stable control systems
  - Utilizes ROS for communication within the rover
  - Commands are send over the network into ROS
- Autonomous system
  - GPS and IMU for waypoint to waypoint navigation
- Power supply
  - Separate supplies for the control and drive systems
  - Polarized connectors on all connections
- Communications
  - Rocket M5 for remote control and video feeds.



DESIGN REVIEW

Constraints

DESIGN CONSTRAINTS

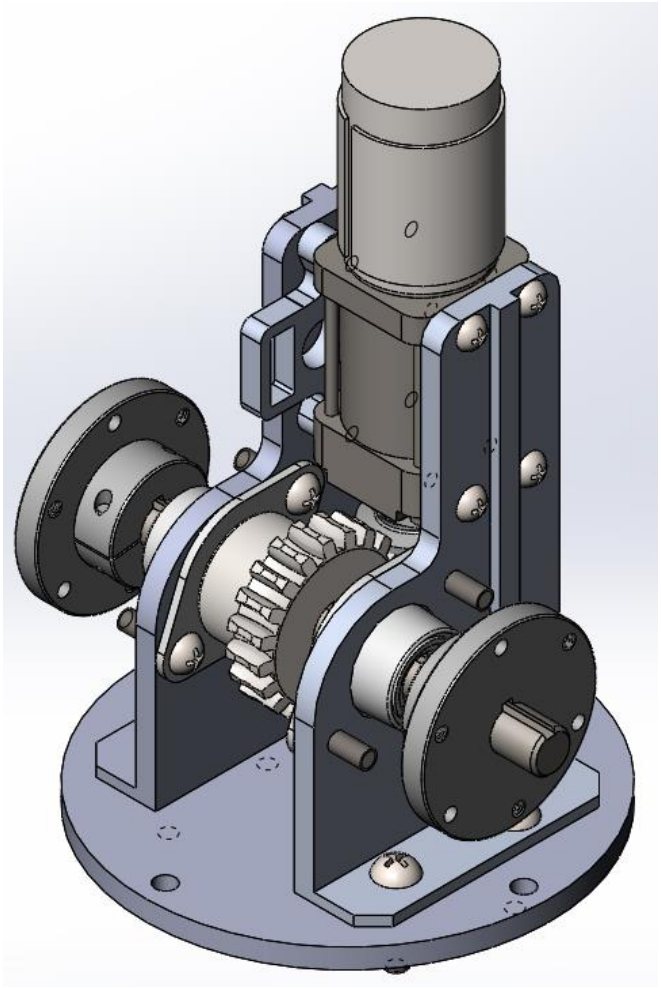
- Budget
  - Working on limited income has some unique challenges
- Man hours
  - One of the smaller teams to consistently make URC
  - Programming has been very time consuming
- Manufacturing resources
- Competition requirements
  - Budget – $18.5k maximum
  - Rover mass - <50kg
  - Rover dimensions – 0.8m square
  - Travel requirements – Competition site is a 16 hour drive, requires multiple day stay

DESIGN REVIEW

Current Design

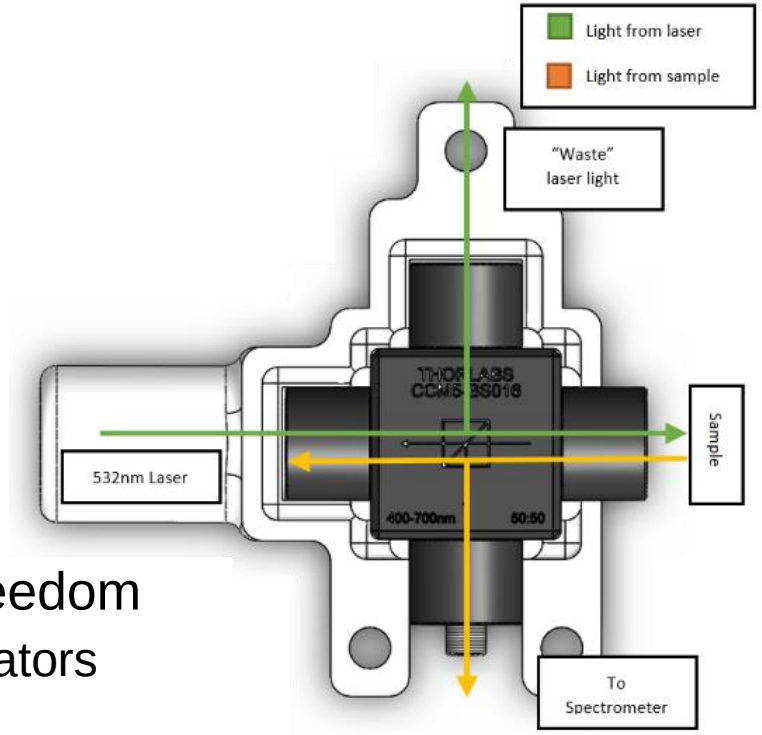
CURRENT DESIGN - MECHANICAL

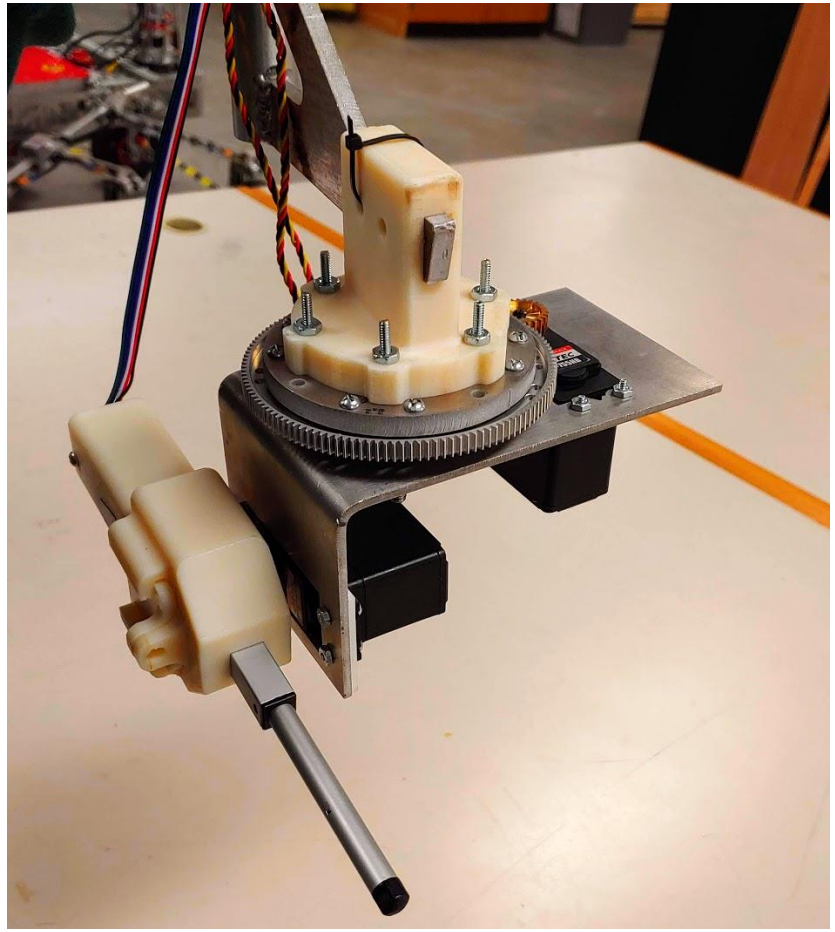
- Robotic Arm Improvements
  - Feedback
  - Base Rotation
  - Shoulder
  - End Effector
- New Camera Mounts
- New Electrical Box Lid



CURRENT DESIGN - SCIENCE

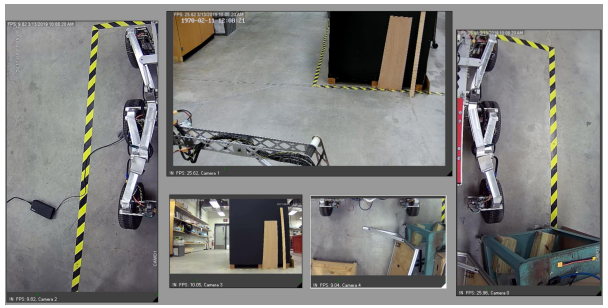
- Optical Housing
  - 532 nm laser
  - Line filters
  - "Waste" hole
  - Notch filter
- Laser Rotation
  - 4 degrees of freedom
    - 2 linear actuators
    - 2 servos

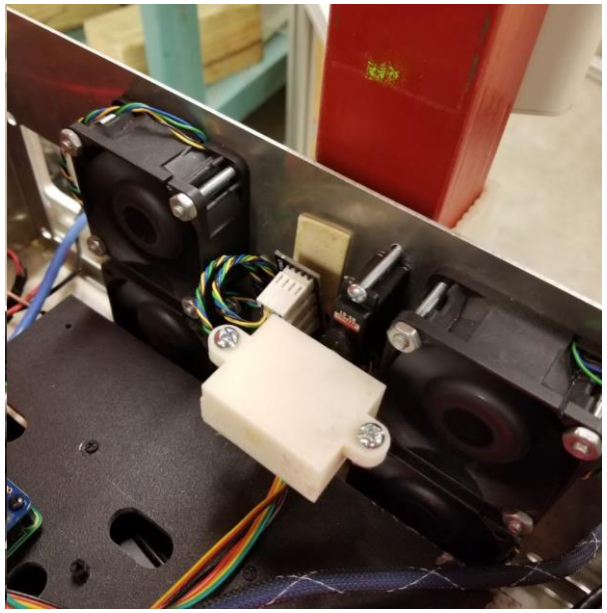




CURRENT DESIGN - SYSTEMS

- 360 Degree View
  - 6 Cameras total
  - PTZ Mast Camera
- Arm Feedback
  - ROS Node
  - ADC Hat
- Power Distribution
  - Custom Arm PCB
- IMU Integration



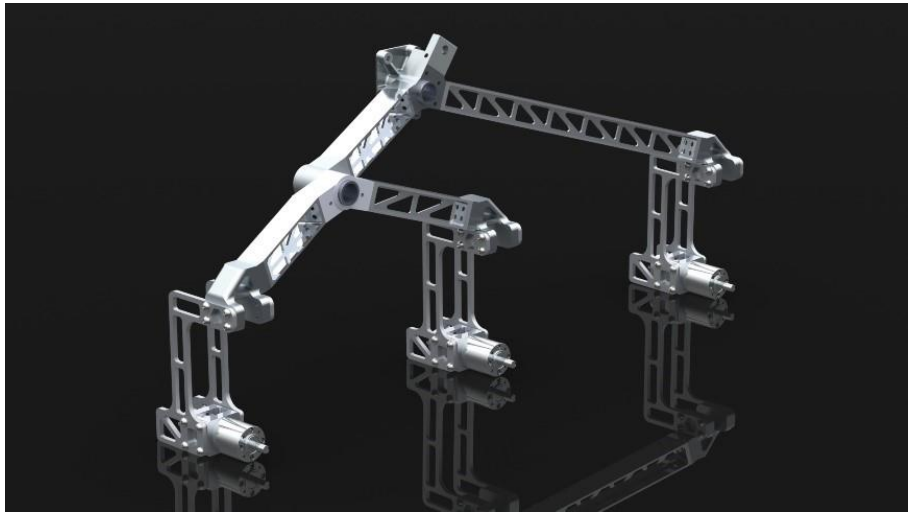


DESIGN REVIEW

Proposed Changes

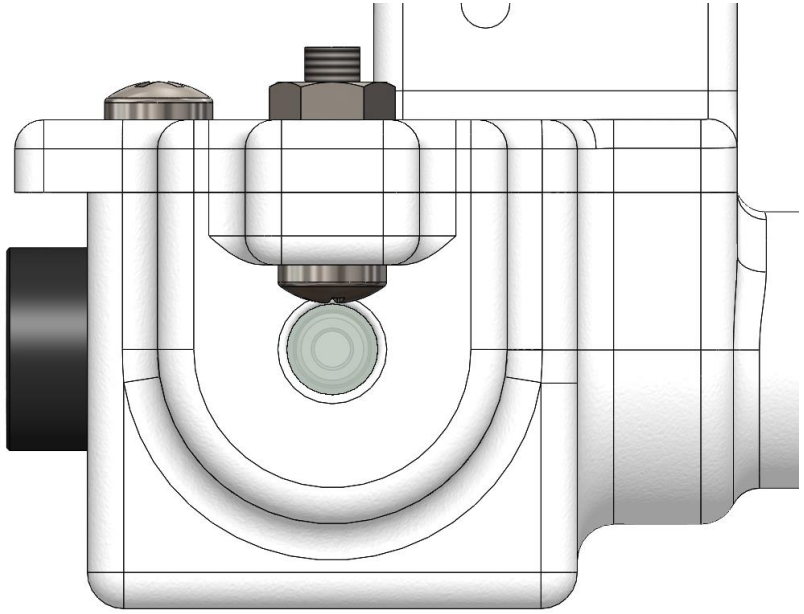
PROPOSED CHANGES - MECHANICAL

- Weight Reduction
  - Removing excess material
  - Replacing aluminum components with composite and plastic ones
- Suspension
  - Adding brass to joints to reduce friction
  - Weight reduction
- Wheels
  - Replacement with lighter wheels



PROPOSED CHANGES - SCIENCE

- Laser Orientation
  - Modified for inverted use
- Optics housing
  - Addition of "waste hole"
  - Danfoss print
- Python algorithm instead of MATLAB
  - Prevent MATLAB licensing issues in Utah



PROPOSED CHANGES - SYSTEMS

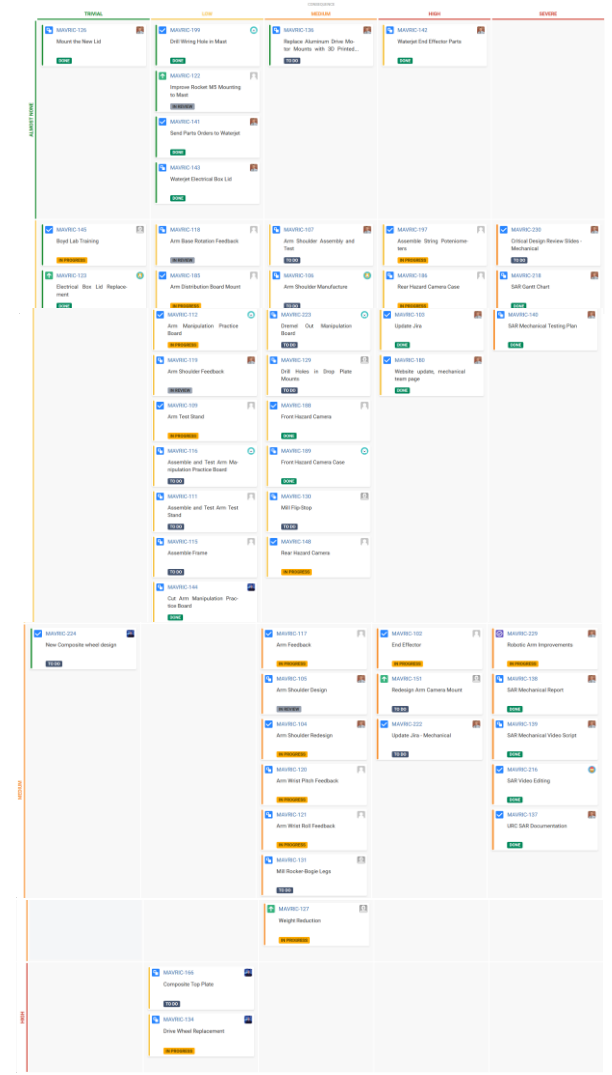
- Upgraded Autonomous Systems
  - PixyCam
  - Intel Realsense
- Cleaner GUI
  - Test with team to optimize for competition
- E-Box Connections
  - Custom PCBs for through box connections
- Testing
  - Further drive testing
  - Competition Condition simulations

DESIGN REVIEW

Design Risks

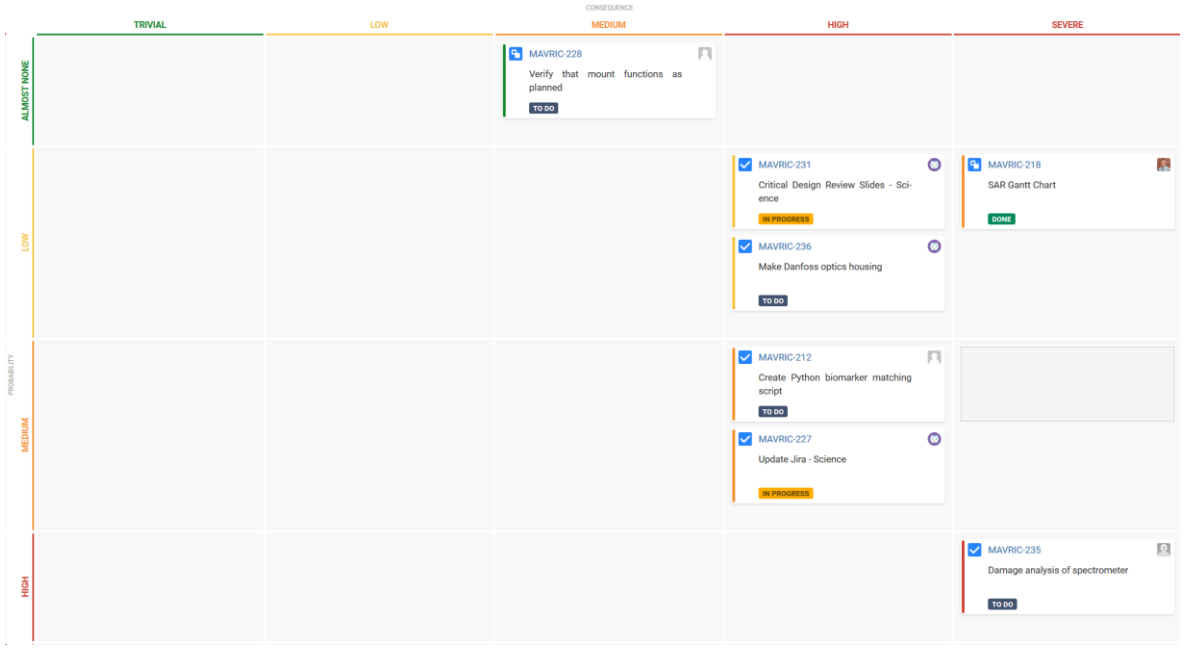
DESIGN RISKS - MECHANICAL

- Mechanical Team has some higher-risk items, mostly due to time constraints
- Most other items have already been completed or are low risk



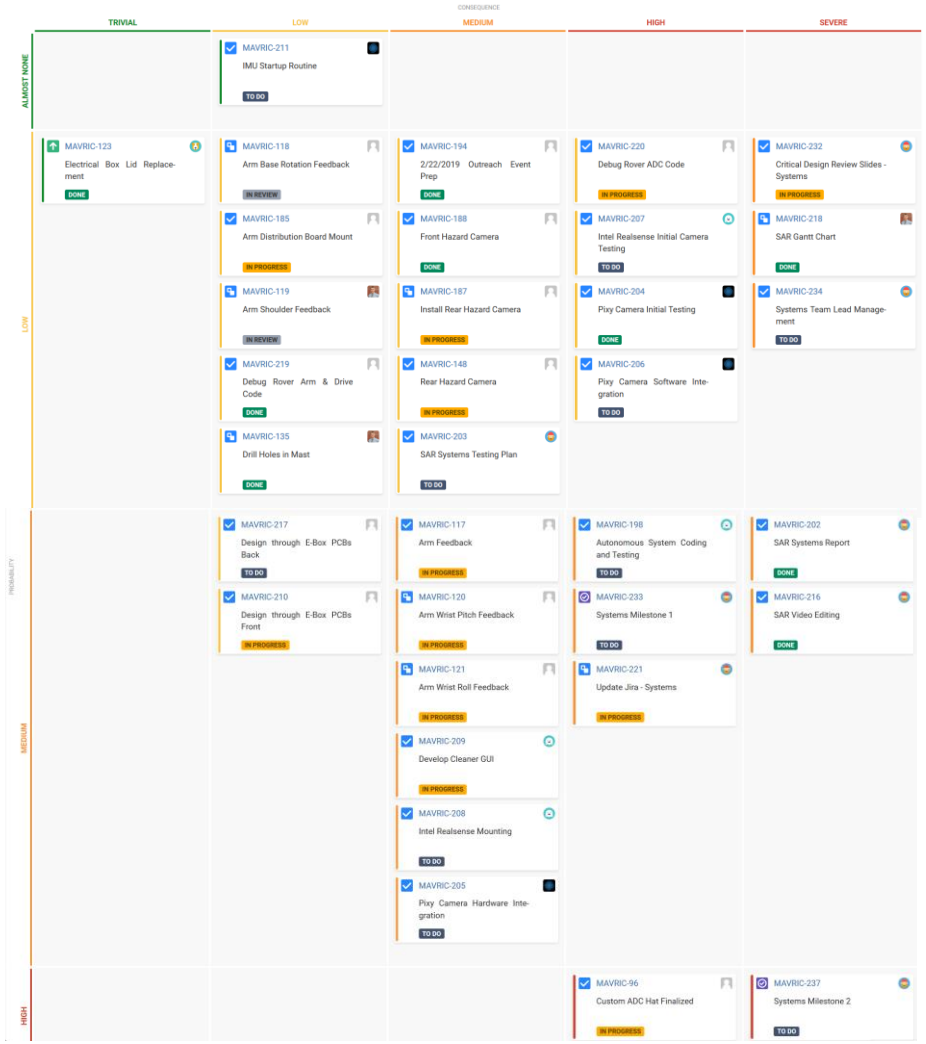
DESIGN RISKS - SCIENCE

- Notch filter problems
  - ID what is wrong
- Main concern is testing
  - Can we get accurate readings from biomarkers
- Python is secondary challenge
  - Must learn enough to graph and sort spectrometer data



DESIGN RISKS - SYSTEMS

- Mostly in the medium consequence / medium probability area
- Few high probability items
  - Intel Realsense testing
  - Custom ADC Hat finalization
- Some severe consequence items
  - Milestone 2 (Autonomous Systems)



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

BUDGET

Status and requests

BUDGET STATUS

Item (Expenses)	Amount
Travel	$3500
3D prints	$220
Science system	$1250
Arm components (Initial)	$1000
Arm components (Upgrades)	$450
Motor ESCs	$300
Computer vision	$400
Sector antenna	$170
Main mast camera	$180
Other expenses	~$1500
Remaining funds	~$825

Item (Income)	Amount
ISGC	$5000
M2I	$3000
Danfoss (Donated parts)	$150
Emerson (For arm only)	$1000
Protocase (Donated parts)	$2000

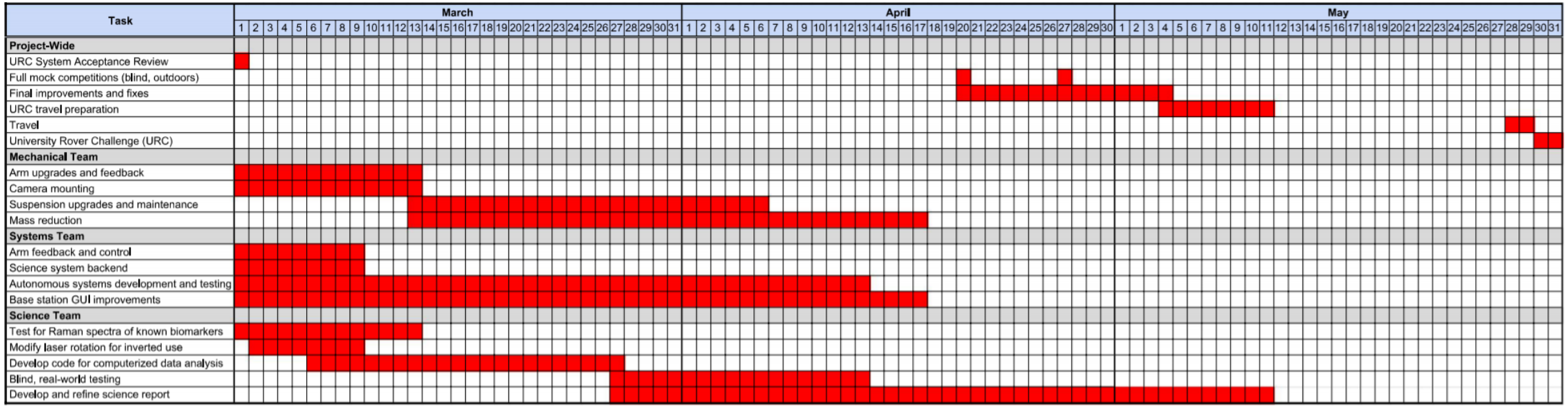
CONCLUSION

EXTRA SLIDES

EXTRA SLIDES - BUDGET

		MAVRIC PROJECT BUDGET	Acct. Number TBD				
Approved	Priority	Item	Notes	Req. Budget	Approved Budget	Spent	Difference
		− Total Project Budget		$8,000.00	$7,850.00	$3,179.24	$4,670.76
☐		− Equipment		$4,025.00	$4,025.00	$0.00	
☑		New Electronics box	Full budget breakdown for this item available on Box	$1,000.00	$1,000.00		$1,000.00
☑		New science sensors	Exact sensors TBD	$250.00	$250.00		$250.00
☑		Upgraded power distribution / spare motor controllers	Full budget breakdown for this item available on Box	$450.00	$450.00		$450.00
☑		Additional cameras		$200.00	$200.00		$200.00
☑		Base station / additional RF antennas		$500.00	$500.00		$500.00
☑		Arm refinements	Exact items TBD	$400.00	$400.00		$400.00
☑		Locker organization	Mostly plastic tote bins	$50.00	$50.00		$50.00
☑		Spare parts manufacturing		$250.00	$250.00		$250.00
☑		Science collection system		$750	$750.00		$750.00
☑		Specialized cables / connectors / other electronics		$175	$175.00		$175.00
☐					$0.00		$0.00
☐					$0.00		$0.00
☐					$0.00		$0.00
☐		− Travel		$3,575.00	$3,425.00	$0.00	$3,425.00
☑		Van rental	15 pass van, 7 days, 2350 miles	$1,150	$1,150.00		$1,150.00
☑		Trailer rental	7 days	$175	$175.00		$175.00
☑		Lodging	7 nights, 3 rooms per night	$2,100	$2,100.00		$2,100.00
☐		Food	mostly paid for by team members	$150			$0.00
☐		− Raw Supplies		$400.00	$400.00	$0.00	$100.00
☑		Assorted metal	mostly sheet metal for waterjet	$100	$100.00		$100.00
☑		Assorted 3D prints		$200	$200.00		
☑		Assorted other raw material		$100	$100.00		

EXTRA SLIDES – GANTT CHART

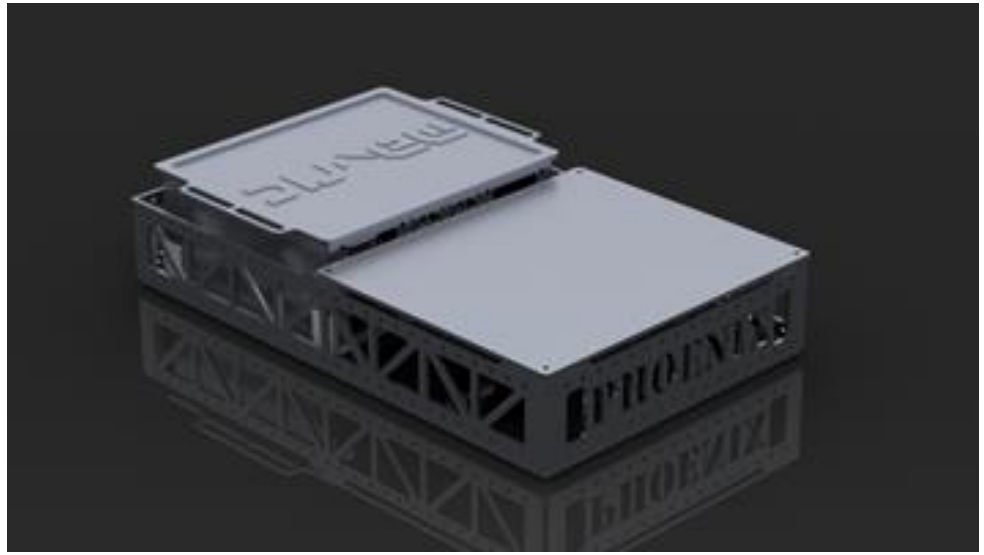


EXTRA SLIDES – WEIGHT REDUCTION

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

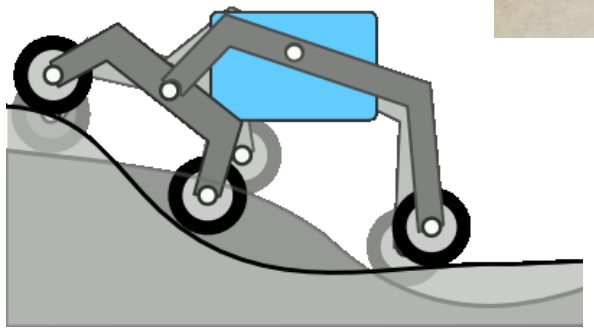
EXTRA SLIDES - CHASSIS

- 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



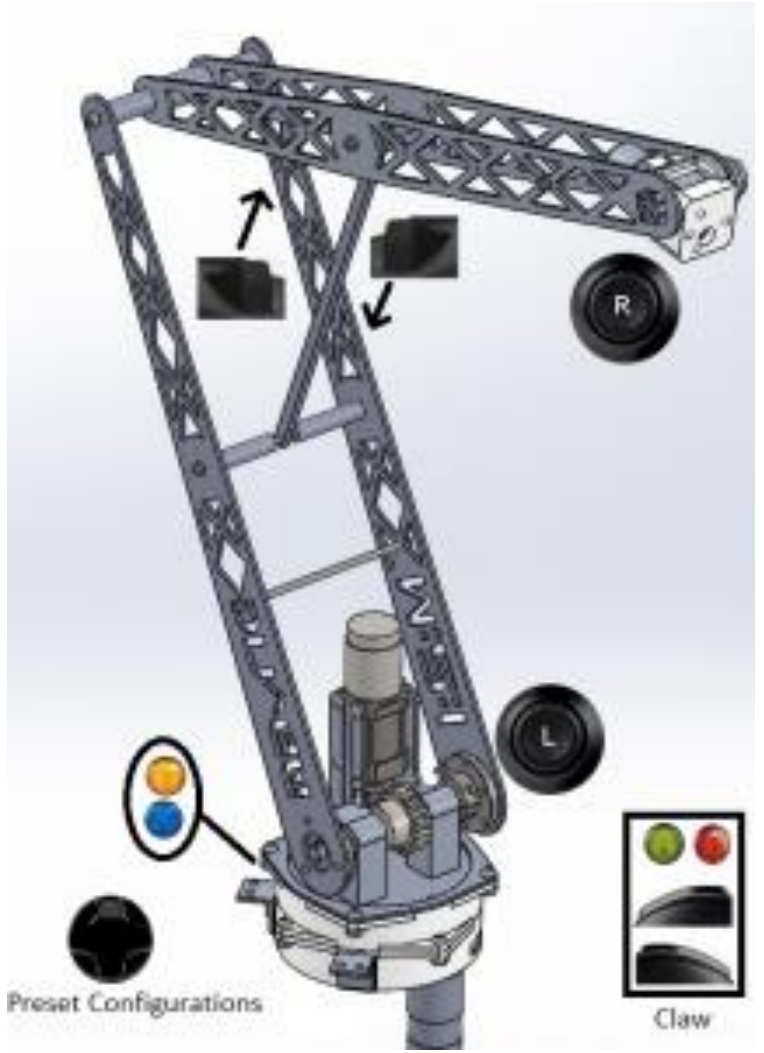
EXTRA SLIDES - SUSPENSION

- 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



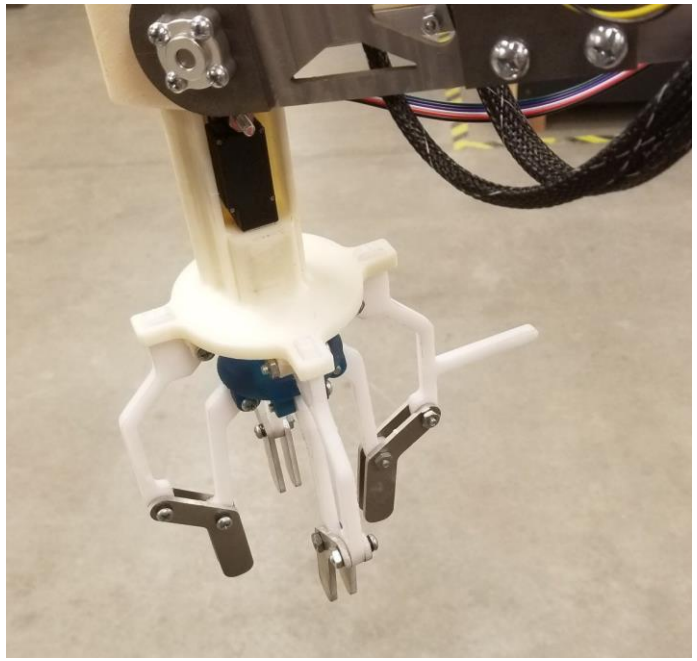
EXTRA SLIDES – ROBOTIC ARM

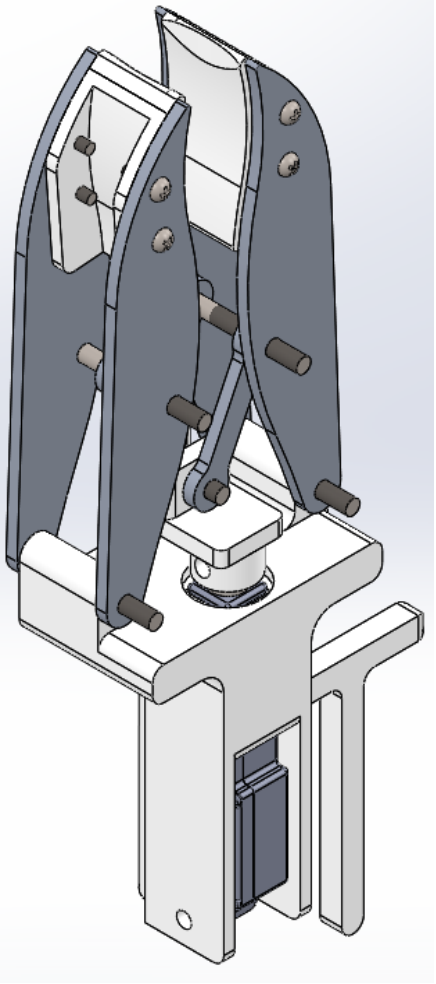
- Base rotation – motor and internal ring gear
- Shoulder – motor with worm drive
- Elbow – linear actuator
- Wrist – two direct-drive motors
- Arm control box attached beneath top plate
- Subsystem is easily removeable



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





EXTRA SLIDES – AUTONOMOUS

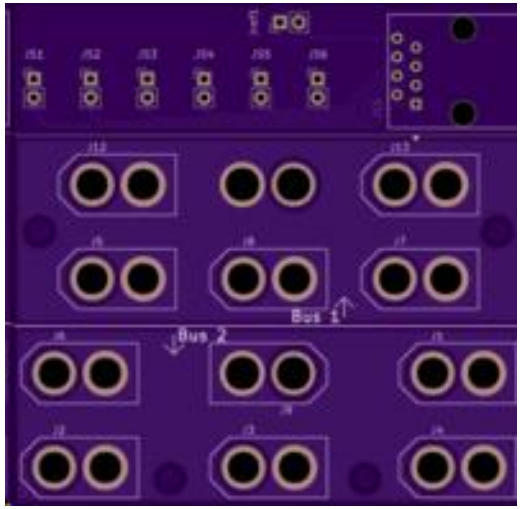
- Use GPS to navigate near the target (tested, working)
  - Use Intel RealSense to detect obstacles
  - Use IMU for compass heading

- 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

EXTRA SLIDES – PCB DESIGN

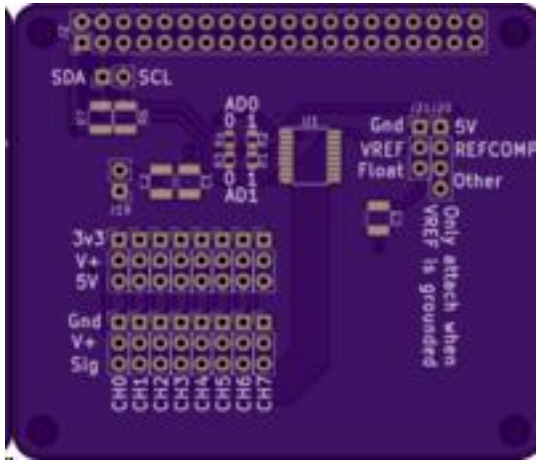
Arm Power/Signal Distribution

- XT-60 solder points
- Locking signal connectors
- 2 power busses

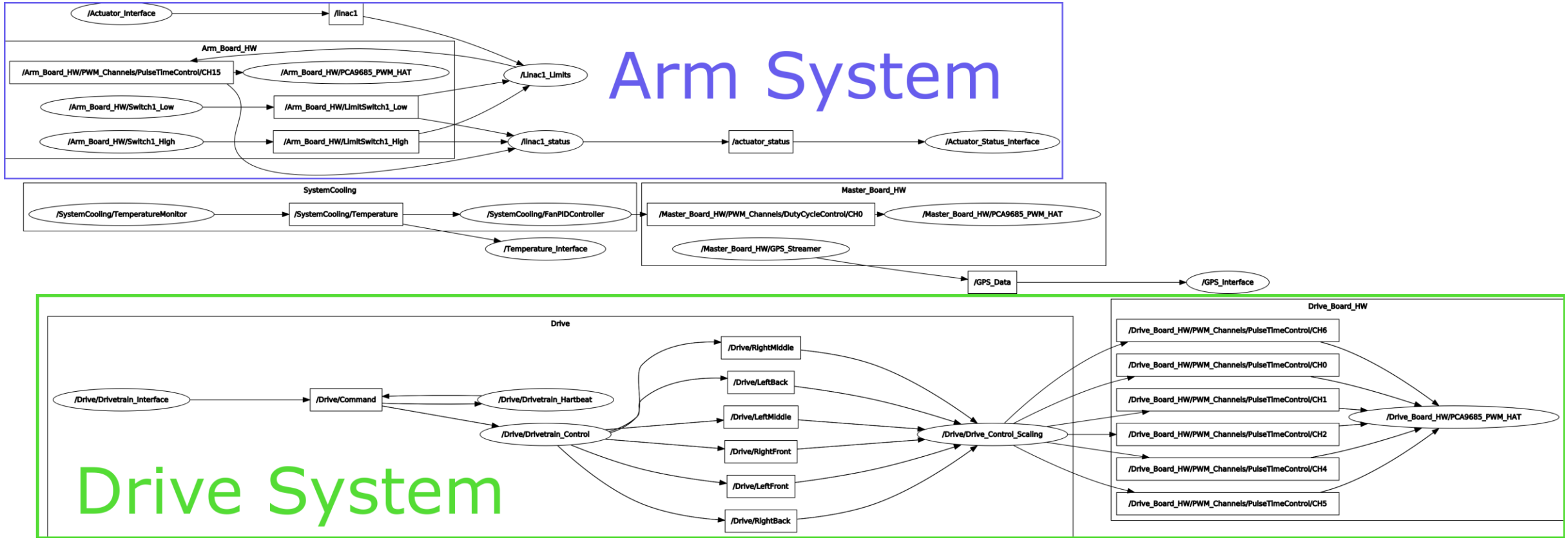


ADC HAT (Raspberry Pi Add-on board)

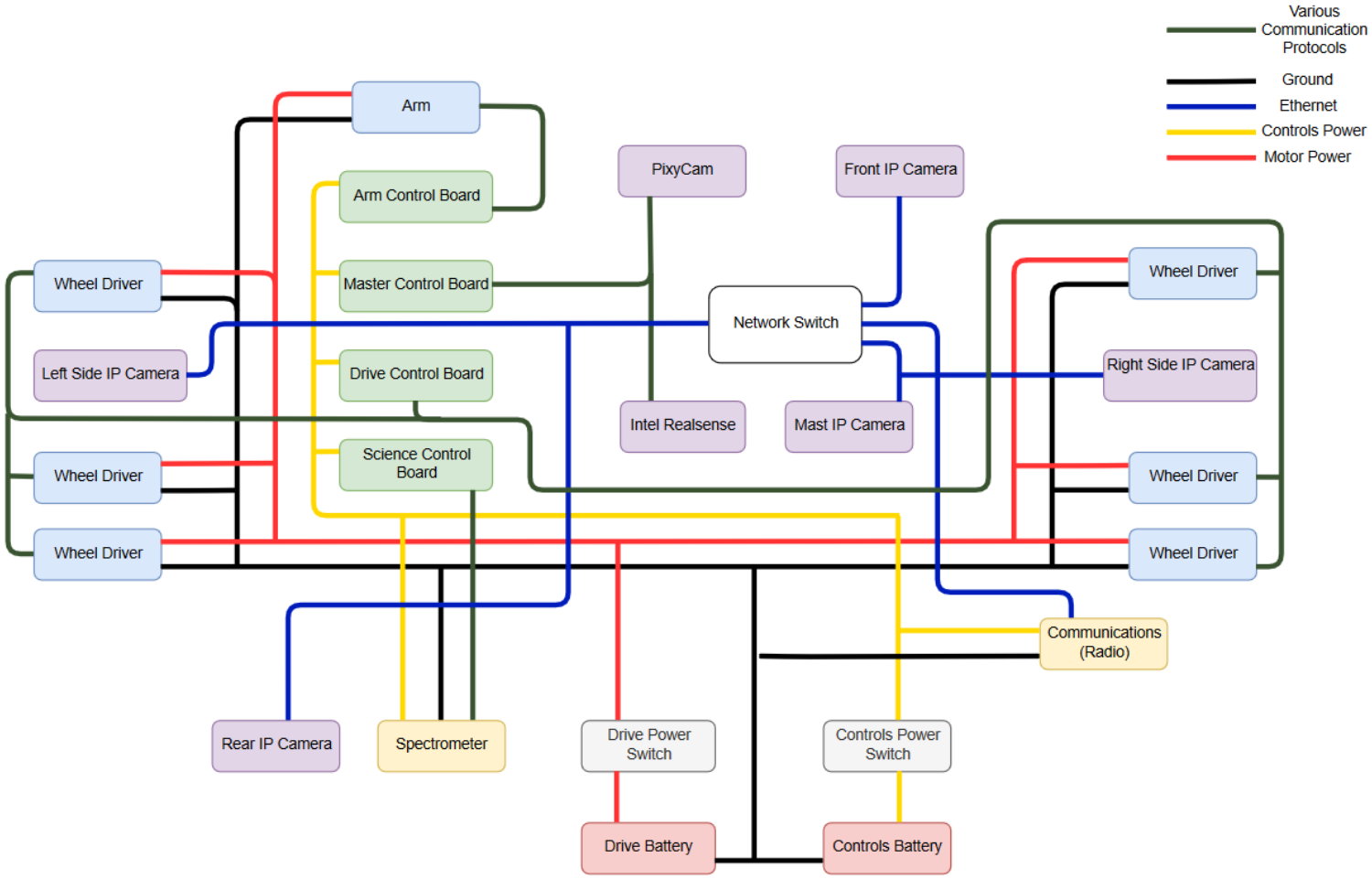
- Reads 8 analog sensors
- ~13 thousand samples/sec
- Selectable voltage reference
- Selectable voltage supply



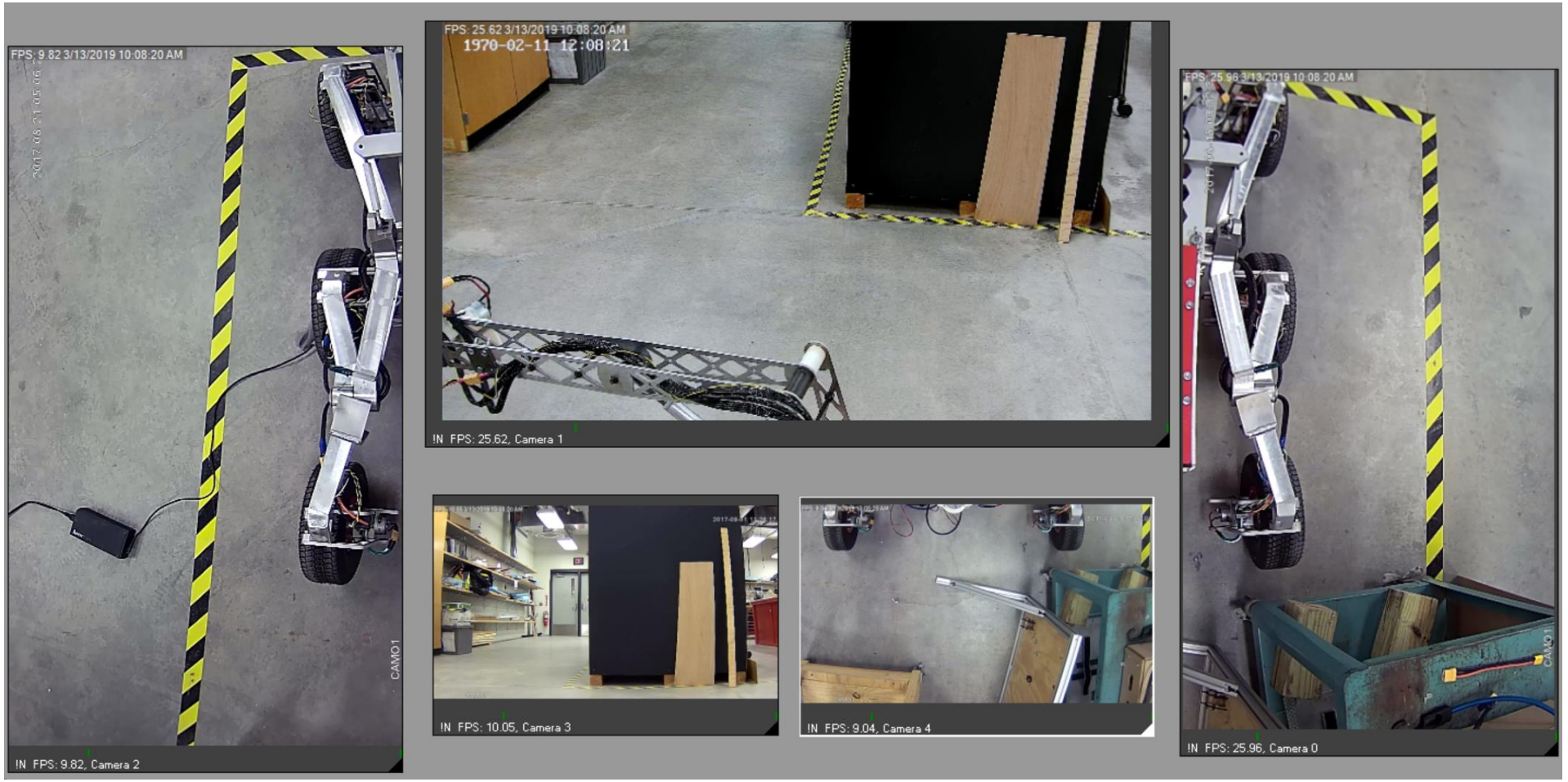
EXTRA SLIDES - ROS MAP



EXTRA SLIDES – BLOCK DIAGRAM



EXTRA SLIDES – CAMERA VIEW



EXTRA SLIDES – POWER BUDGET

ItemID	Peak % Capacity	Constant % Capacity	Battery Life (hrs)
Primary Battery Pack	36.67%	6.11%	1.09
E-Box Battery	10.42%	5.23%	1.27
Logic Supply	0.00%	0.00%	
Network Power	47.22%	22.22%	
Transceiver			
Network Switch			
Arm Power	0.00%	0.00%	
Drivetrain Power	16.50%	2.75%	
FrontRight ESC	16.67%	2.78%	
FrontRight Motor			
MidRight ESC	16.67%	2.78%	
MidRight Motor			
BackRight ESC	16.67%	2.78%	
BackRight Motor			
FrontLeft ESC	16.67%	2.78%	
FrontLeft Motor			
MidLeft ESC	16.67%	2.78%	
MidLeft Motor			
BackLeft ESC	16.67%	2.78%	
BackLeft Motor			
Cooling Fans Power	66.67%	35.00%	

Status:	GO
Battery Life:	01:05

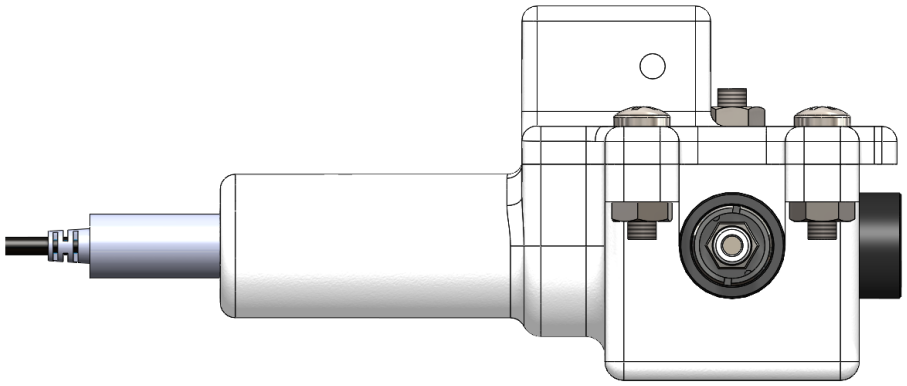
Power Rail	Voltage (V)	Current (A)	Peak Current (A)	Power (W)
Primary Battery Pack	22.20	11.00	66.00	1465.20
E-Box Battery	22.20	4.08	8.13	180.40

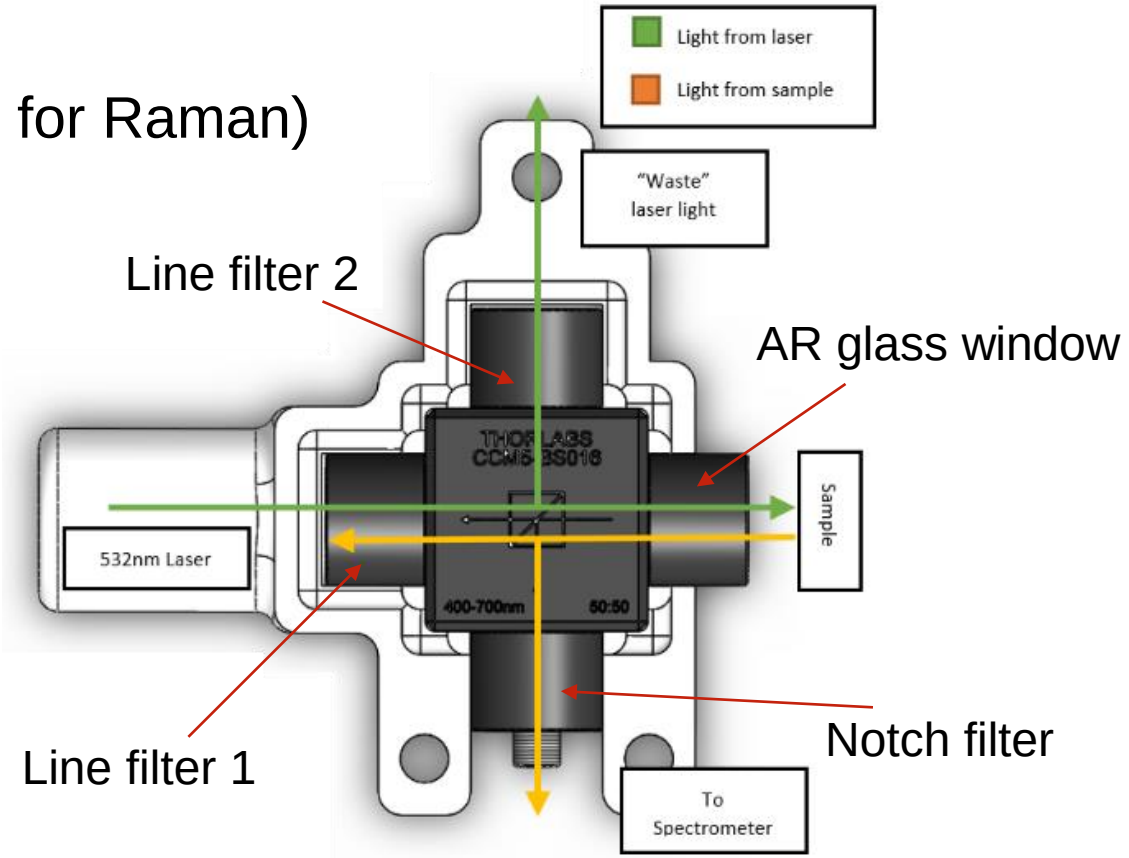
EXTRA SLIDES – PYTHON BIOMARKER IDENTIFICATION SCRIPT

- Still in early stages of development
- Steps to completion
  - Learn enough Python to complete this task
  - Create the convertPeaks() function
    - Converts the spectrometer wavelength data to Raman wavenumber data
  - Develop the findPeaks() function
    - Sorts through the spectra data and finds peaks that we can consider for biomarker assignment
  - Develop 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

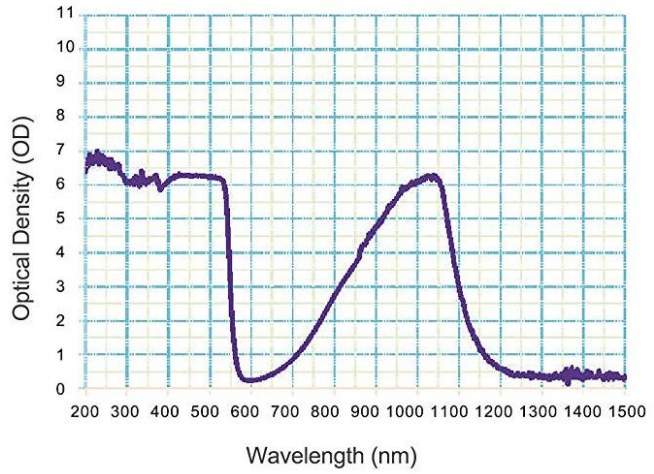
- Line filter has a range of ±2 nm
- Notch filter is OD6 (recommended for Raman)
- Laser has 532 nm wavelength





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



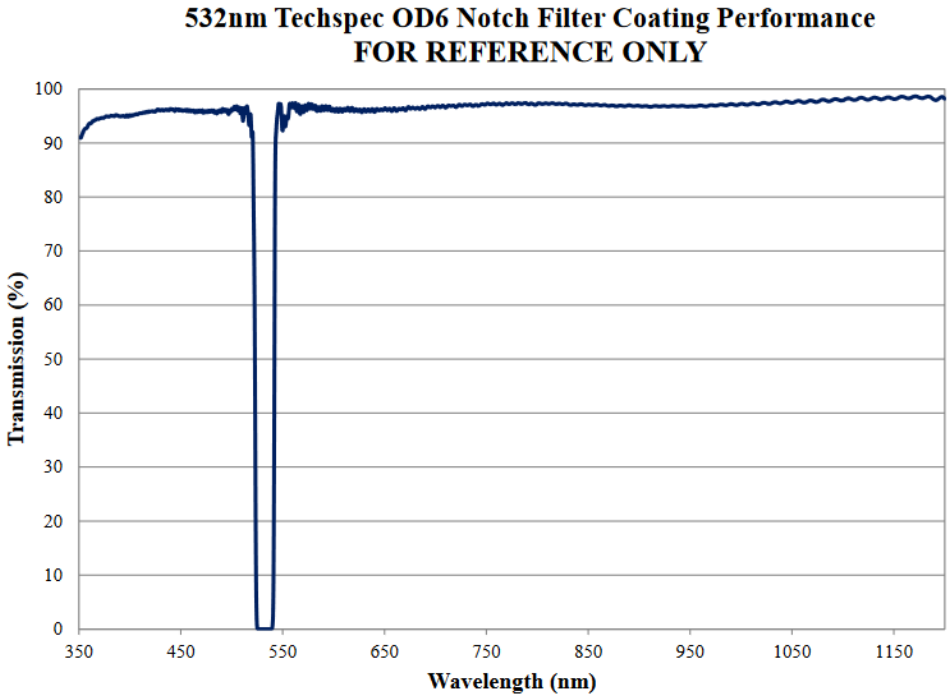
Unintentional or accidental exposure to direct or reflected beam has a low risk. Avoid intentional exposure to direct or reflected beam.

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

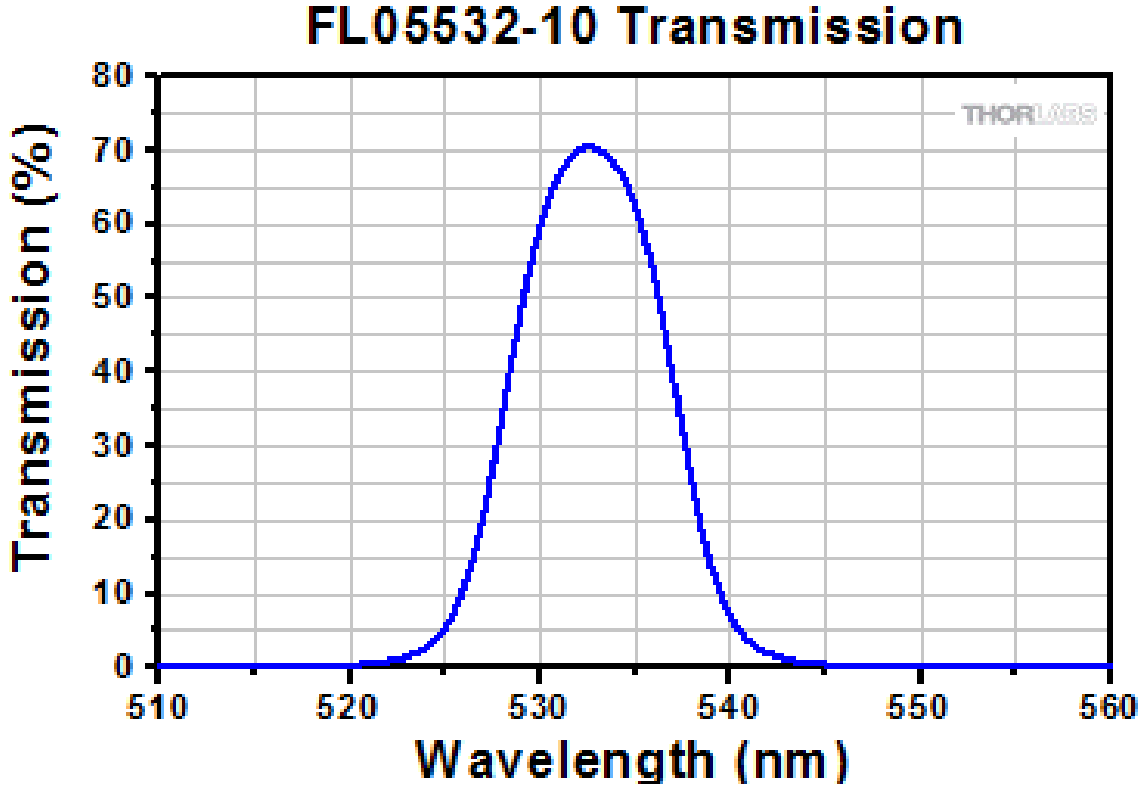
Regulatory Compliance

Reach 191:	Compliant



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

EXTRA SLIDES – LINE FILTER GRAPH



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

EXTRA SLIDES – LASER SPECS

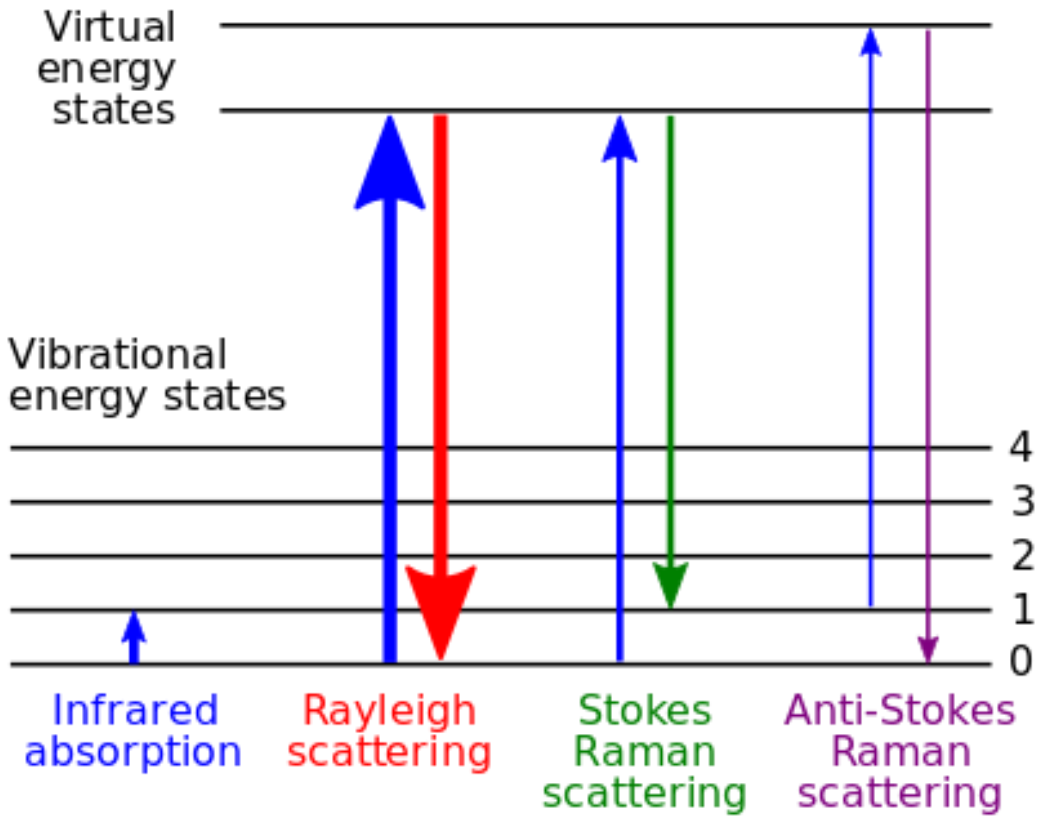
General Specifications	
Characteristic	
Housing Material	Aluminum
Housing Dimensions	Ø11.0 mm x 72.8 mm
Beam Size[a]	Round, Ø3.5 mm
Operating Temperature	10 to 40 °C
Storage Temperature	-30 to 70 °C
Operating Voltage (Nominal)	5 VDC
Laser Safety Class	3R

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[a]	-	-	5	mrad
Beam Divergence	-	-	0.5	mrad
Operating Current (CW)	-	250	-	mA

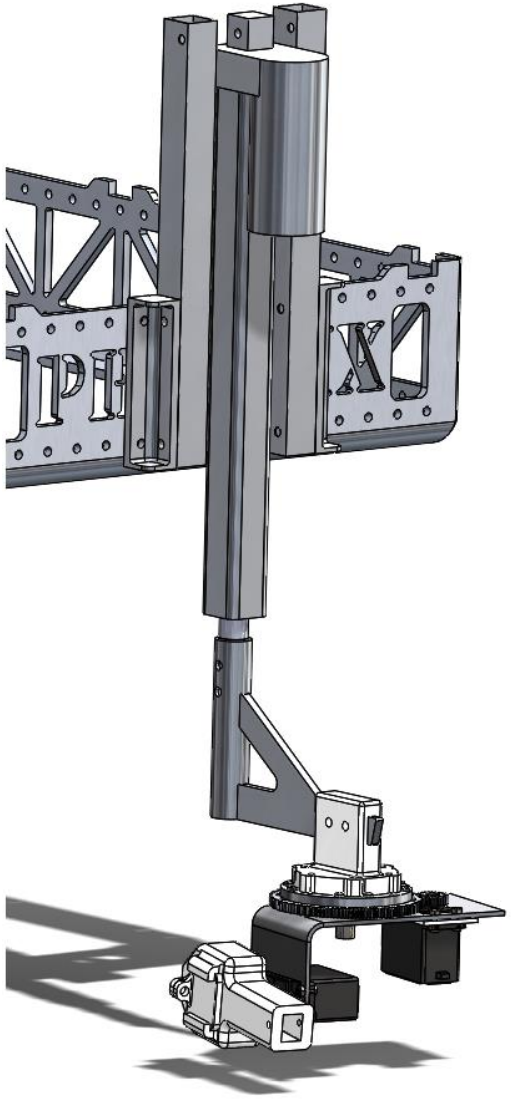
EXTRA SLIDES – RAMAN SPECTROSCOPY

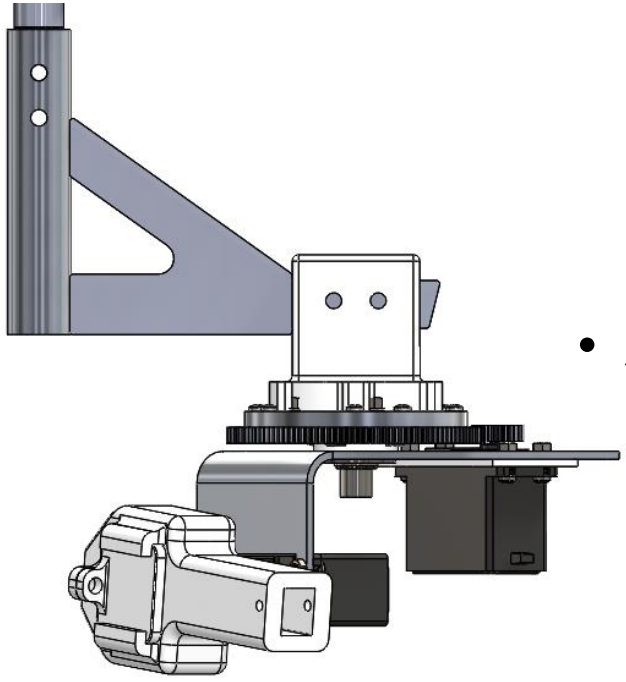
- Several different types of light return when a laser is incident to a surface
  - Rayleigh is easiest to see
  - Stokes and anti-Stokes are used for Raman spectroscopy

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



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