# CS/EE/ME 75(a)

Oct. 9, 2019

Today:

- SubT Review
- Systems Architecture: Physical, Software
- Strategy/”ConOps”
- First Look at Projects
- Teaming
- Tentative Schedule:

# The DARPA challenges

DARPA = Defense Advanced Research Project Agency

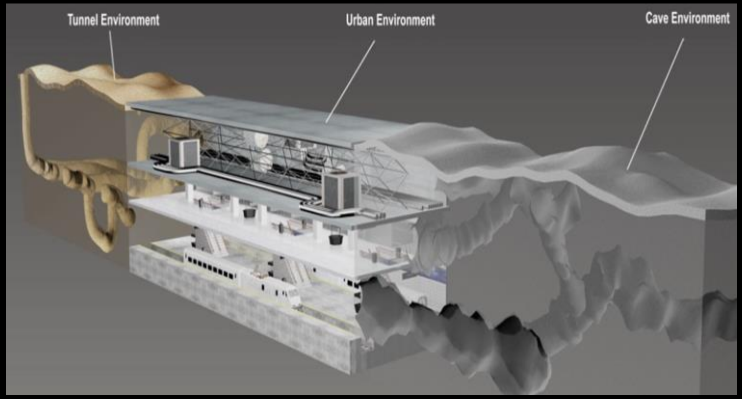
- Setting ambitious goals, making way for novel approaches that might otherwise seem too risky to pursue. [from DARPA website]
  - Realize advanced cutting-edge technologies
  - Address systems-level integration problems

- Have catalyzed advances in autonomy and changed the course of U.S. research/funding (for driving, robotics, manipulation).

2003-2007

2012-2015

2019-2021





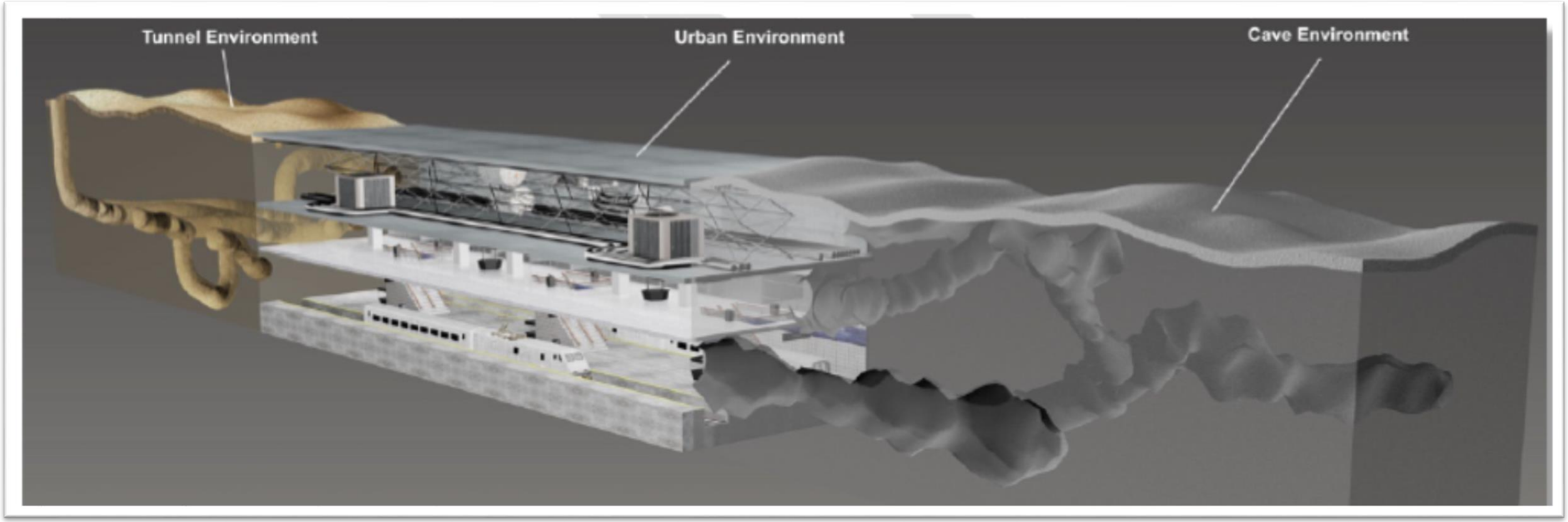

# The DARPA Subterranean Challenge

(www.Subtchallenge.com)

**Objective:** Revolutionize autonomy/technologies needed for exploring extreme environments (tunnel, cave, lava tubes, pit craters, etc.) using robot teams.

**Scope:** 6 teams selected worldwide (DARPA awarded each ~$4.5M/3yrs).

**Duration:** 3 years with 4 competitions and practice events.



# Scoring/metrics

## Goals:

- Find and identify ~30 objects
- Geo-locate objects (1m error in 1Km)
- Time to detection is scored
- Map the environment (10cm resolution)
- Endurance (eventually up to 5 hours)

## Constraints

- One Human operator (high autonomy)
- No power, lighting, communications provided
- No prior map

# Rules/details

- Entrance/exit is known
- No humans can enter the tunnel
- One human operator.
- The size of the underground space, size and types of obstacles will be announced ahead of the competition.
- Narrow passages: different sizes – minimum human crawlable
  - Hvac vents
  - Storm drain
  - Sewer system
  - Water tunnels

# CoSTAR-bots:
## Collaborative SubTerranean Autonomous Resilient Robots to Explore Subterranean Environments


Jet Propulsion Laboratory
California Institute of Technology

NASA's JPL
POC: Dr. Ali Agha (PI)

California Institute of Technology
POC: Dr. Joel Burdick

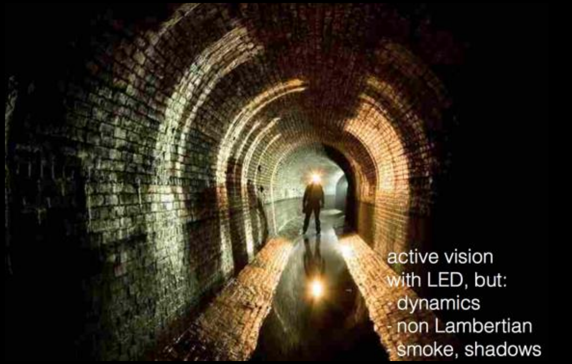
Massachusetts Institute of Technology
POC: Dr. Luca Carlone

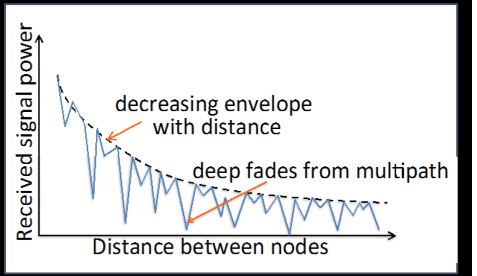
# General Challenges in SubT Environments

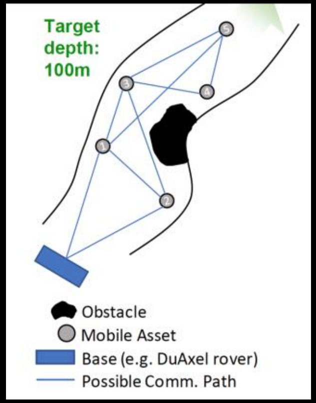
- Mobility
  - Narrow passages
  - Climbs and drops
  - Unpredictable terrain
  - Dust, debris
- Perception
  - Bandwidth constraints
  - Darkness/energy constraints
  - Dust/debris
  - Perceptual aliasing and high outlier rate
  - Automated or human-guided recognition?
- Localization
  - No GPS underground
  - Limited communication between vehicles
  - Multi-vehicle aspect.







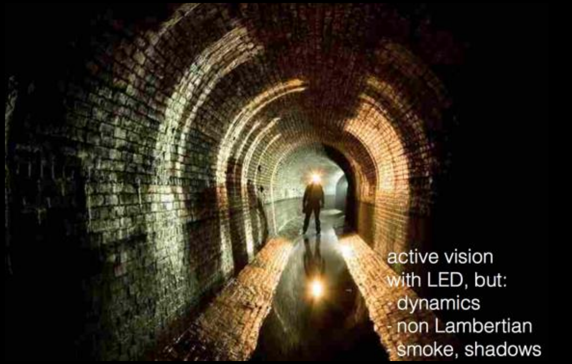





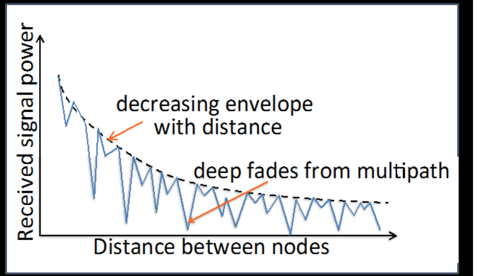
# General Challenges in SubT Environments

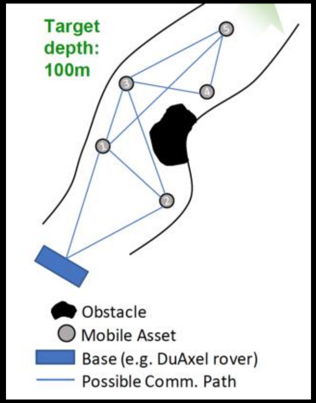


- Communication
  - Latency constraints
  - Requires daisy-chain operation
  - Multipath environment can generate unpredictable link qualities
  - Rock/soil is poor transmission medium
  - Need to model, validate, and mitigate uncertainties in data links between nodes in SubT environment
  - Data drop out





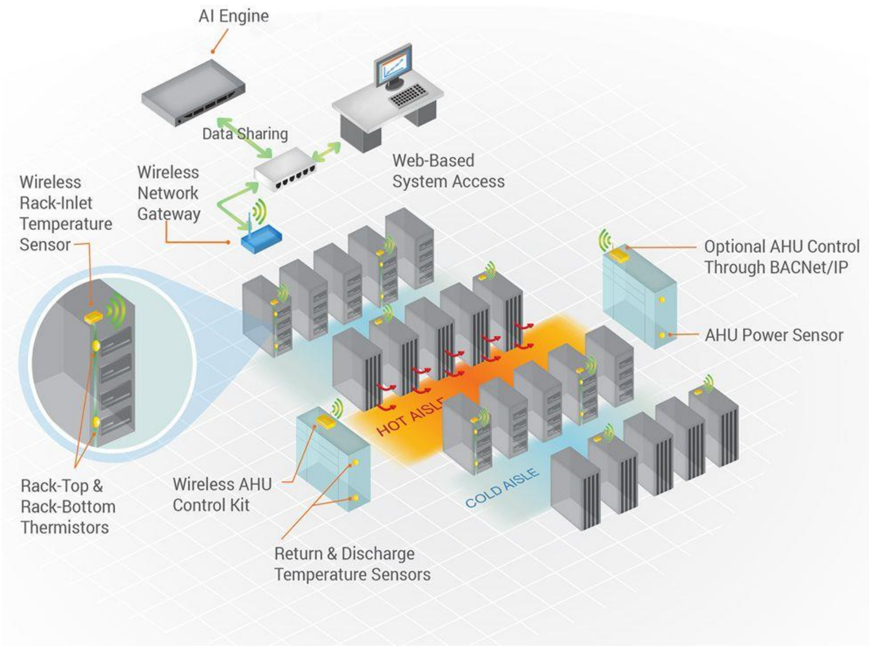
# System Architecture

## Some Definitions:

- A representation of an existing or future system that describes (at a “high level” of organization) the functional organization of the system components and their interactions.  The architecture can be progressively refined to more detailed and concrete descriptions.
- The fundamental organization of a system, embodied in its components, their relationships to each other and to the environment, and the principles governing its design and evolution.
- A formal description of a system, or a detailed plan of the system at component level to guide its implementation.

## Characteristics

- A system architecture should display the internal interfaces among the system’s components or subsystems, as well as the interface(s) between the systems and its environment and users.
- Usually represented as a diagram



# CoSTAR-bots

Collaborative
SubTerranean
Autonomous
Resilient robots

## Mobility

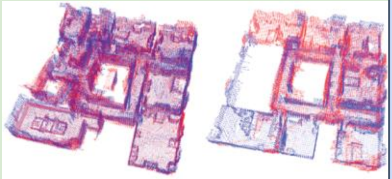
Long-endurance all-terrain mobility platform.

## Localization

Onboard localization + Magneto-quasi-static-based resilient localization system.

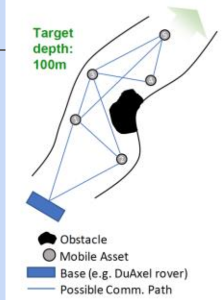

## Distributed Perception

Robust distributed perception under uncertainty using DGPO.



## Communication

Disruption-Tolerant Networking.

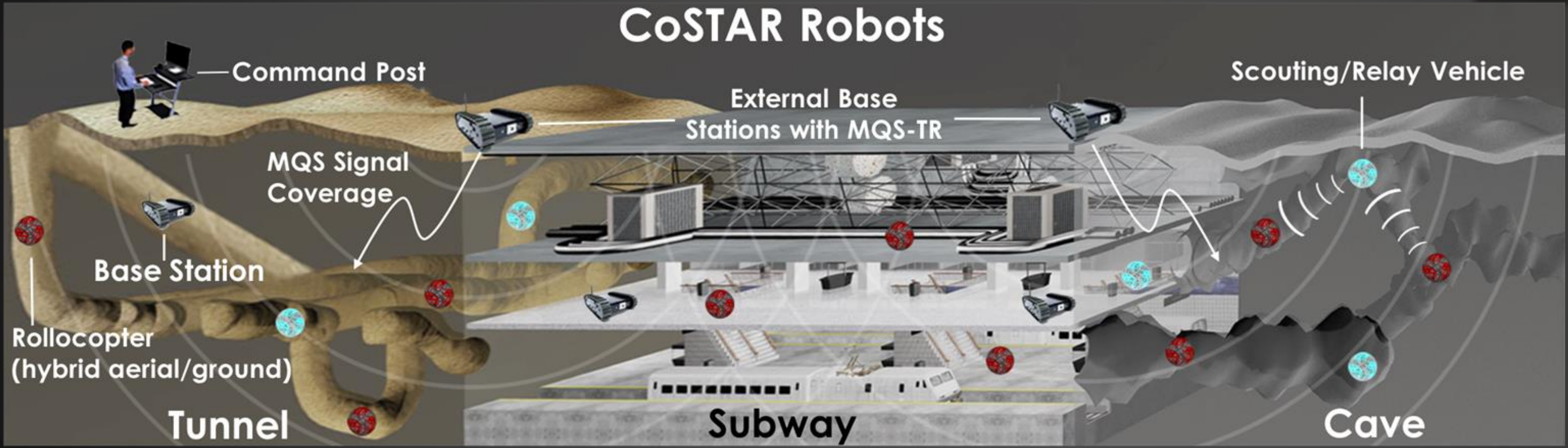


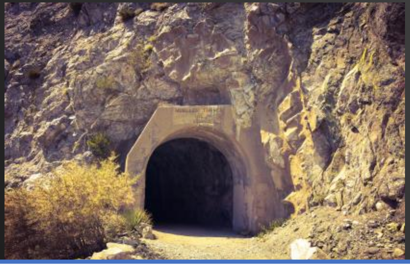

## Autonomy

Risk-aware belief space autonomy using feedback-based information roadmaps.

## Mapping

High-resolution and consistent representation using Confidence-rich grid mapping.

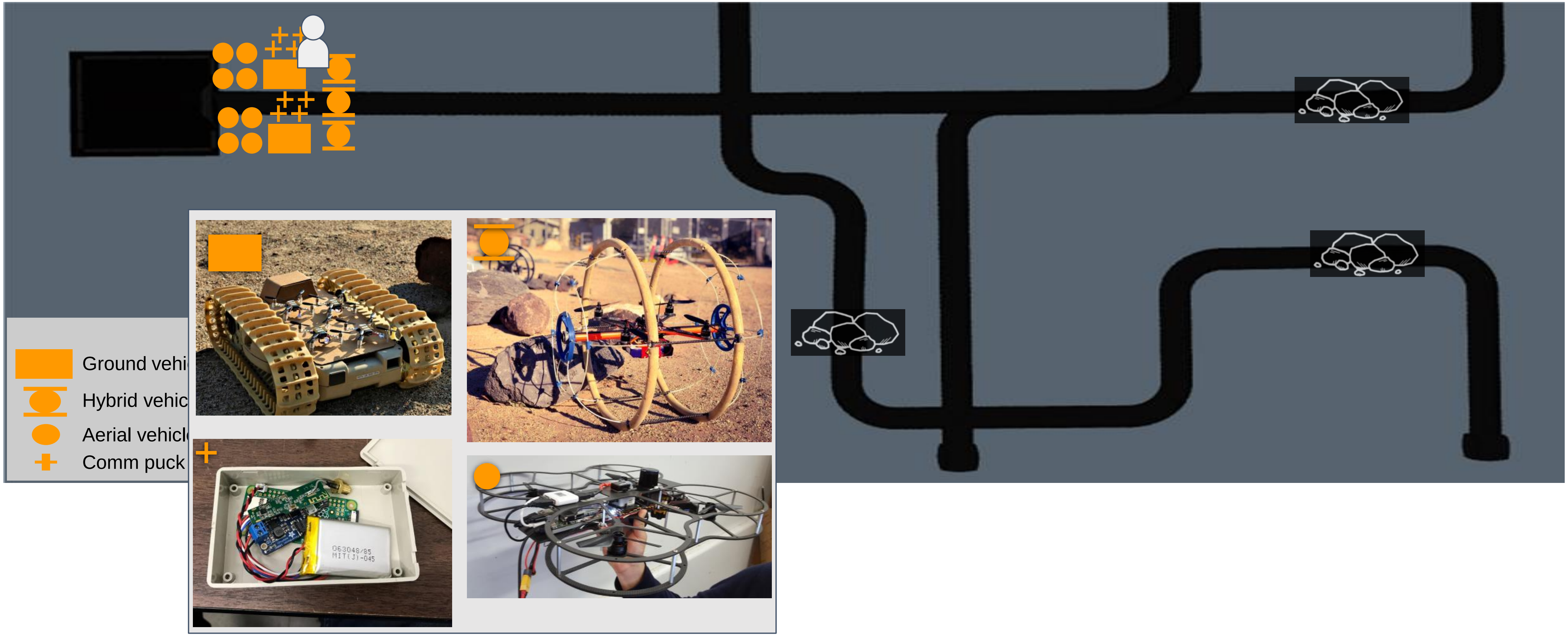



**Testing facility**: Caltech's center for Autonomous Systems and Technologies (CAST), JPL's large Mars Yard, Mueller Tunnel, Bronson/Pisgah/Big-Skylight caves, Galvez tunnel, and potentially abandoned LA railway tunnels

# System Design Overview

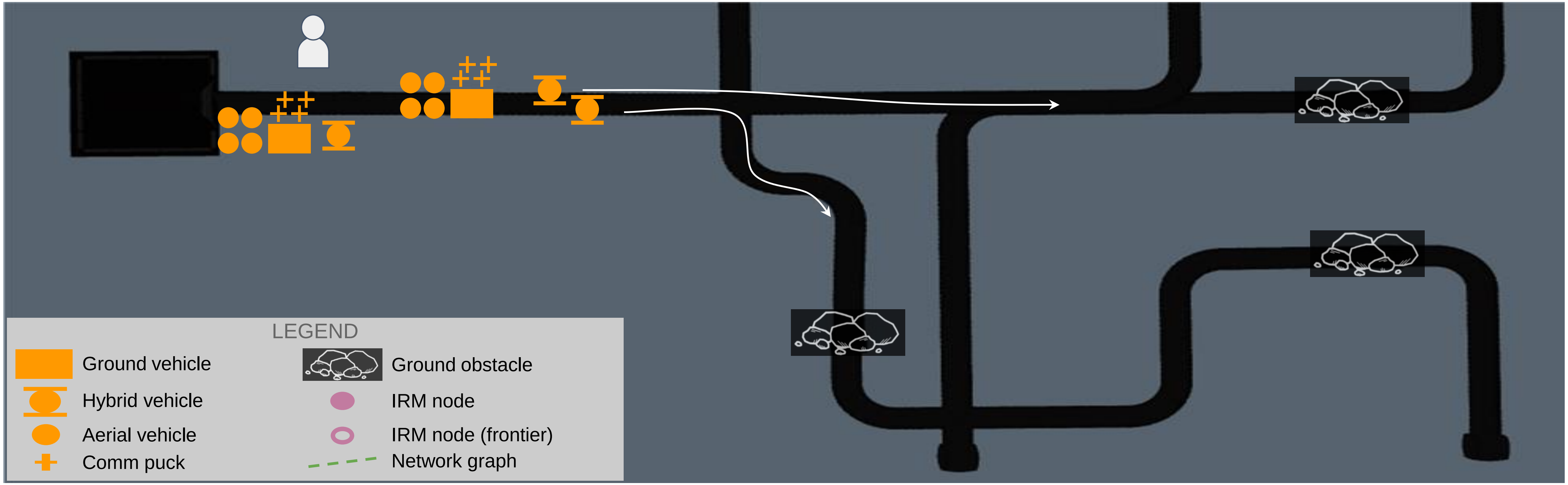
## Simplified CONOPS (Concept of Operations)




Begin with a heterogeneous set of platforms at the base station

# System Design Overview

## Simplified CONOPS

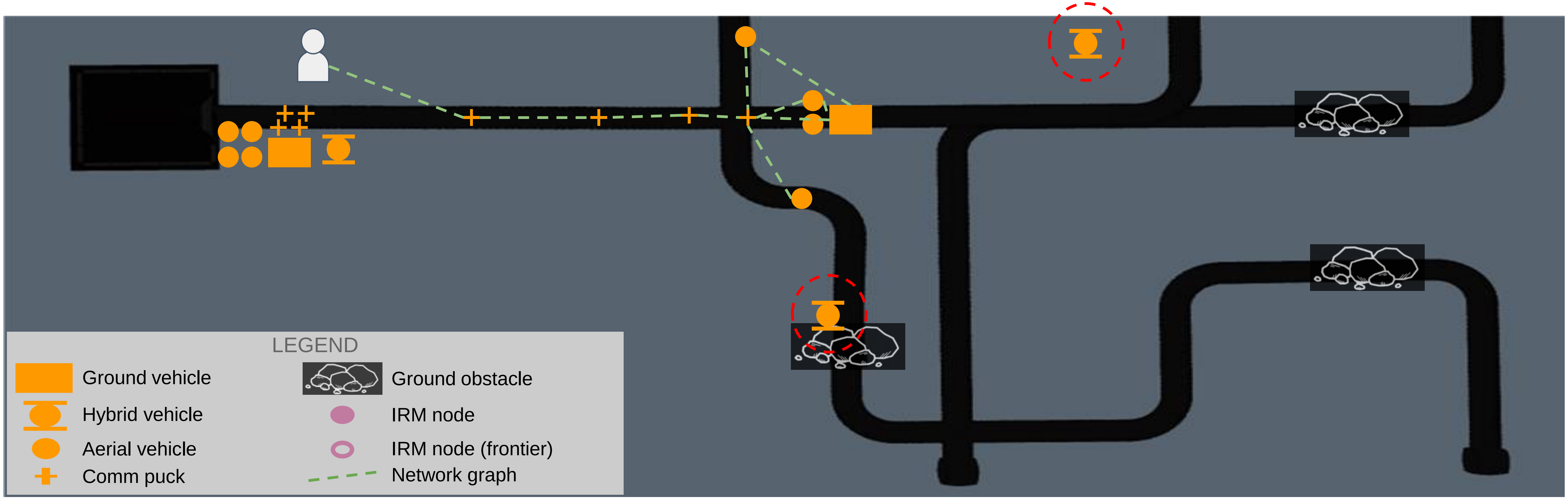



Thrust 1: *Explore the frontier* with a **vanguard** of hybrid ground/air vehicles with highly capable sensing for mapping and artifact detection.

Also: Ground vehicle carries in smaller platforms for future use.

# System Design Overview

## Simplified CONOPS

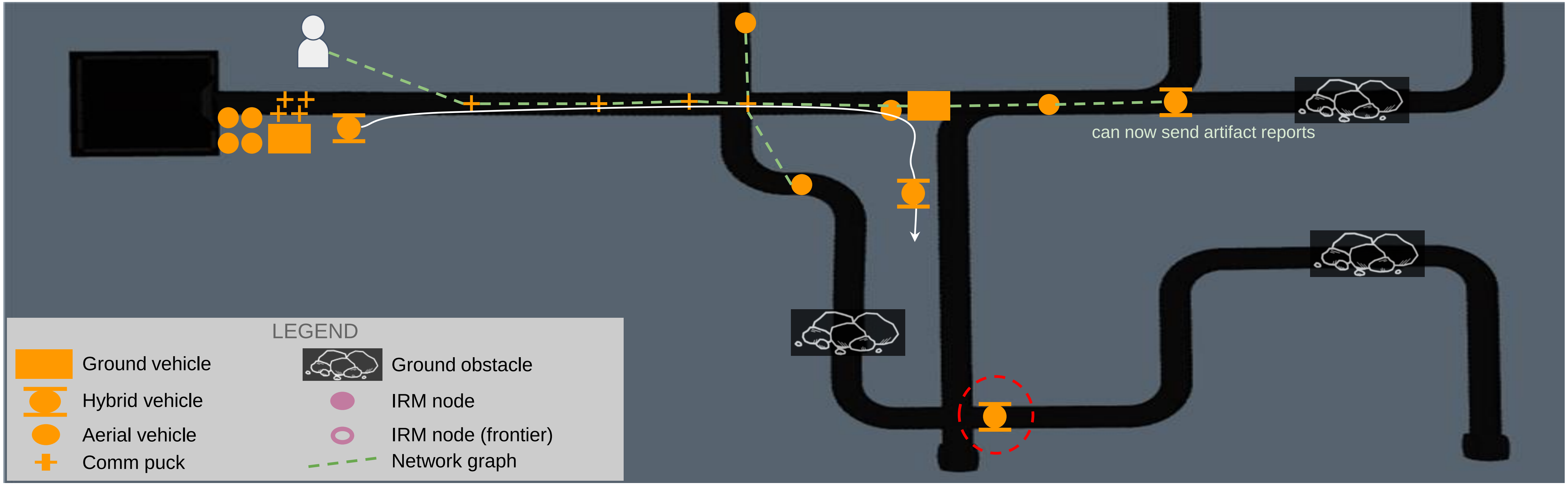



Thrust 2: *Extend the reach of the human supervisor* by tasking robots to create and propagate a **mesh** network for communications.

Ground robot deploys communication pucks, and aerial scouts can self-deploy for either comms relays or added sensing—as directed by either Supervisor or Autonomy.

# System Design Overview

## Simplified CONOPS



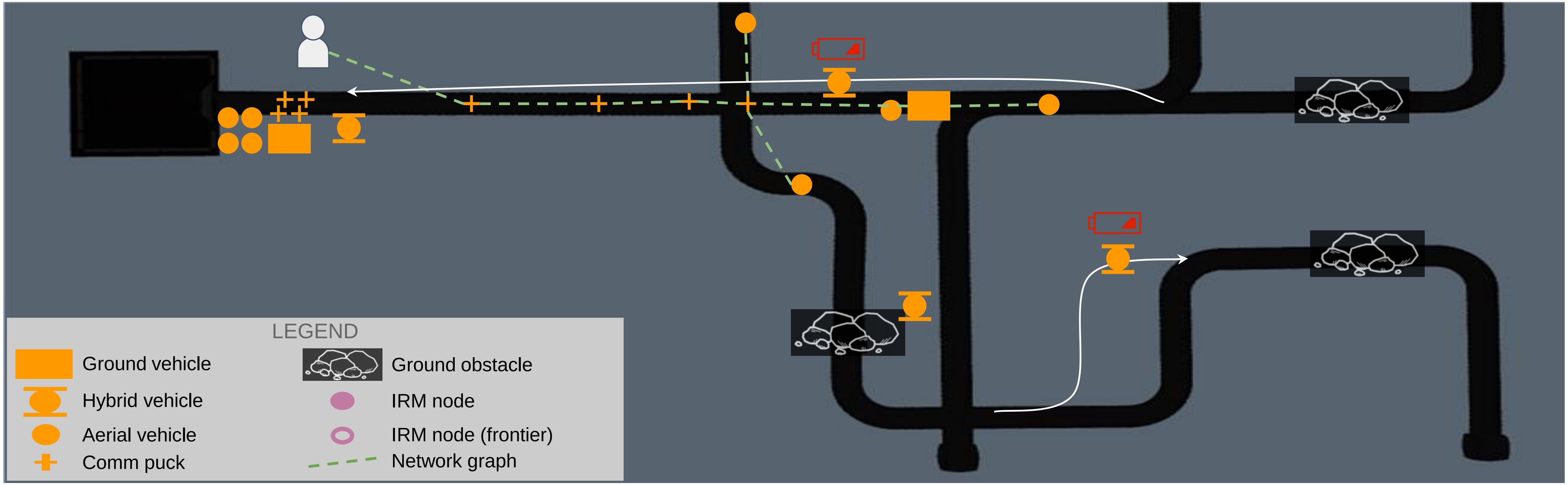

Continue simultaneous frontier exploration and mesh building.

Deploy further vehicles at the discretion of Supervisor.

Supervisor can re-task or re-position any vehicle in the mesh network.

# System Design Overview

## Simplified CONOPS

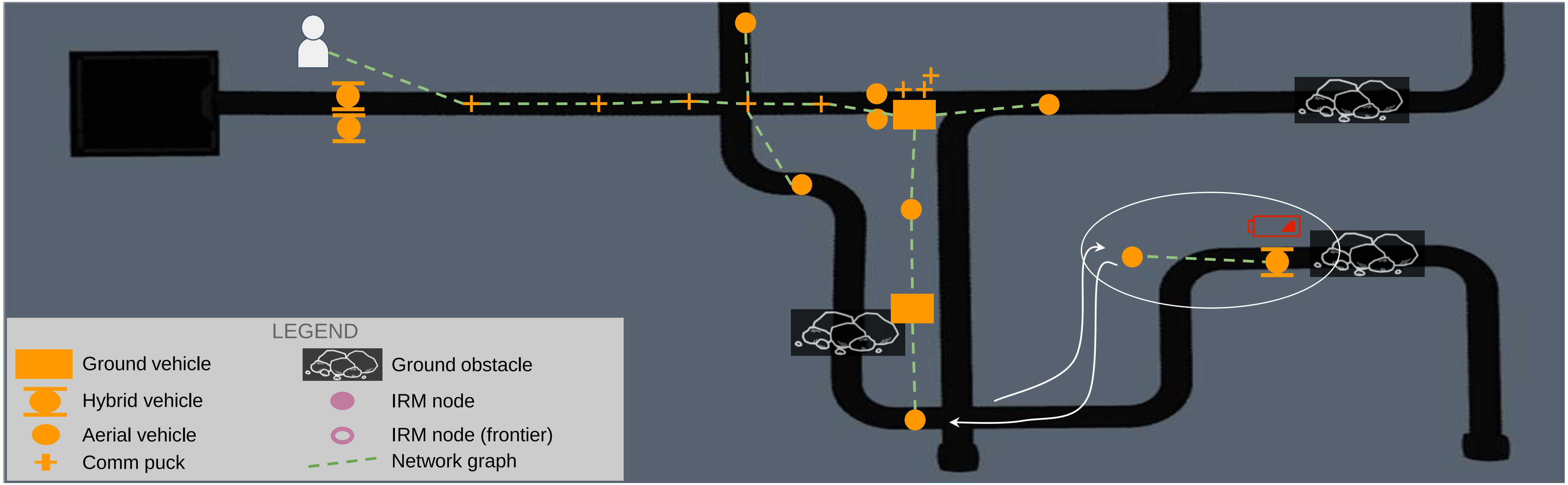



Vehicles can be configured (by Supervisor or Autonomy) for one of the following behaviors near battery depletion:

1. Return to Base—battery swap possible at base
2. Return to Mesh—ensure the data are exfiltrated, then continue
3. Explore Frontier—continue as is, aggressively prioritizing coverage

# System Design Overview

## Simplified CONOPS

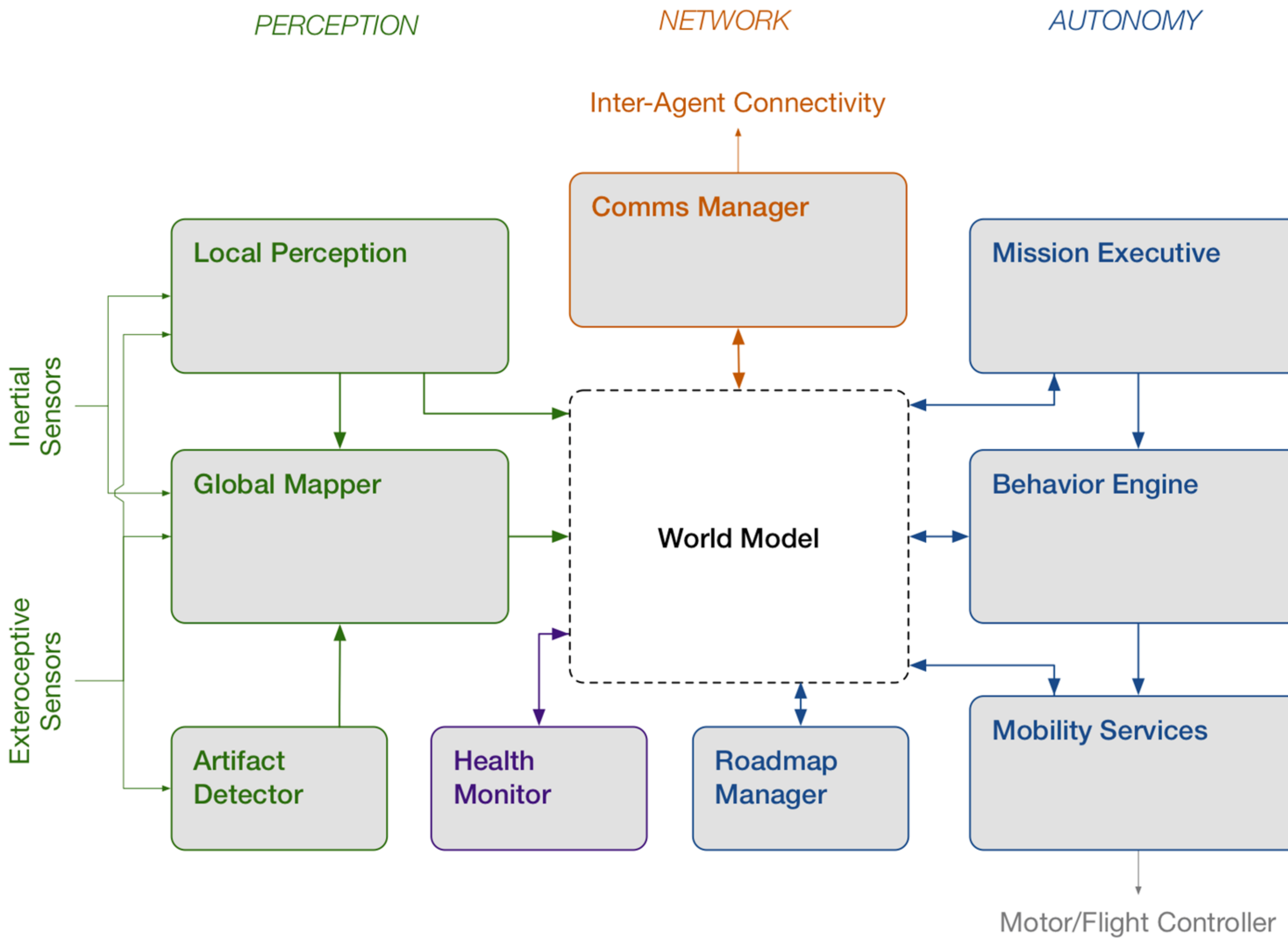



To enable vehicles to continue exploration beyond communication range, agents may be assigned to serve as **data mules**.

These behaviors continue until the entire course is explored.

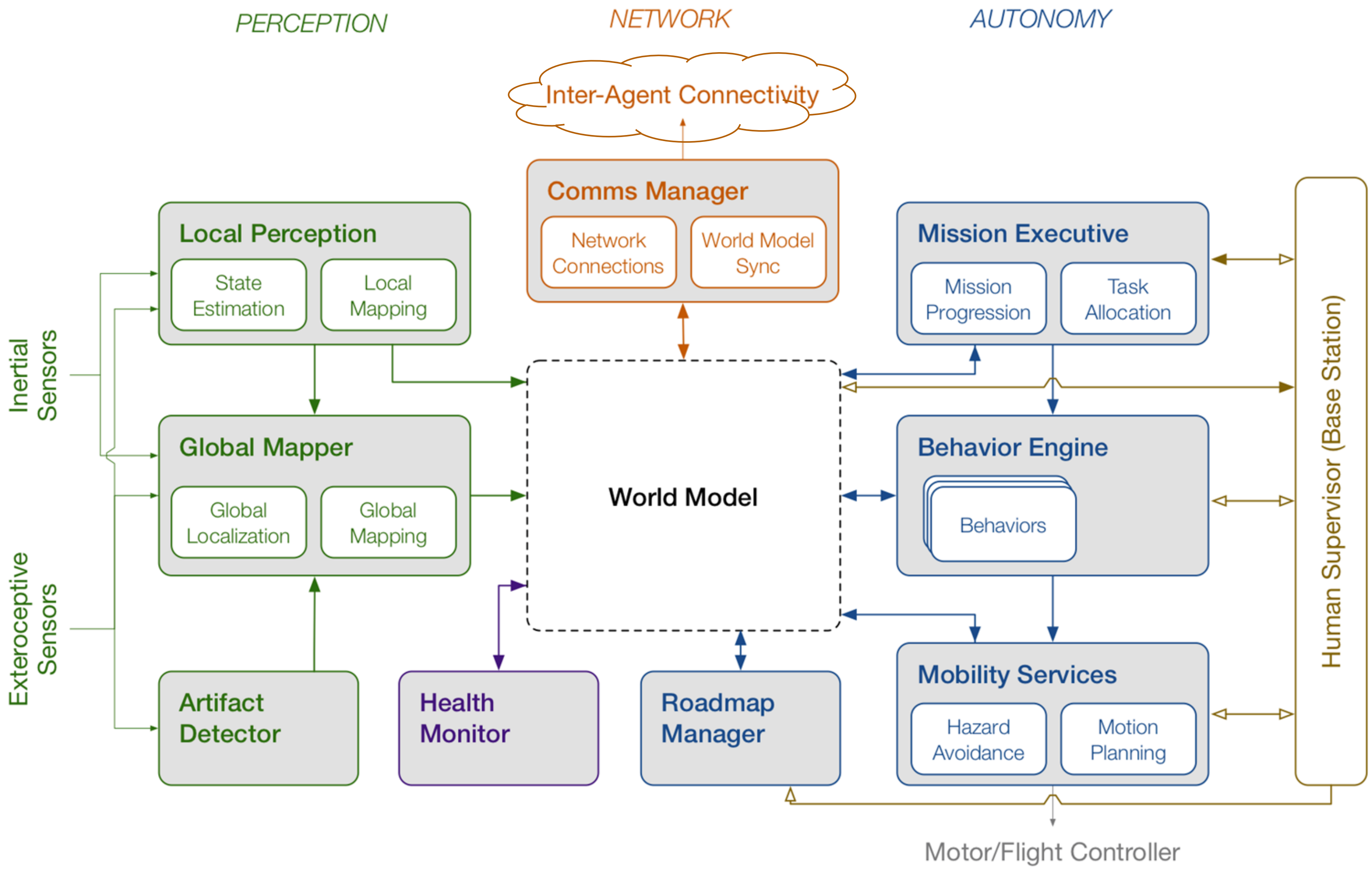
# System Design Overview

## Software: Functional Architecture (single agent)

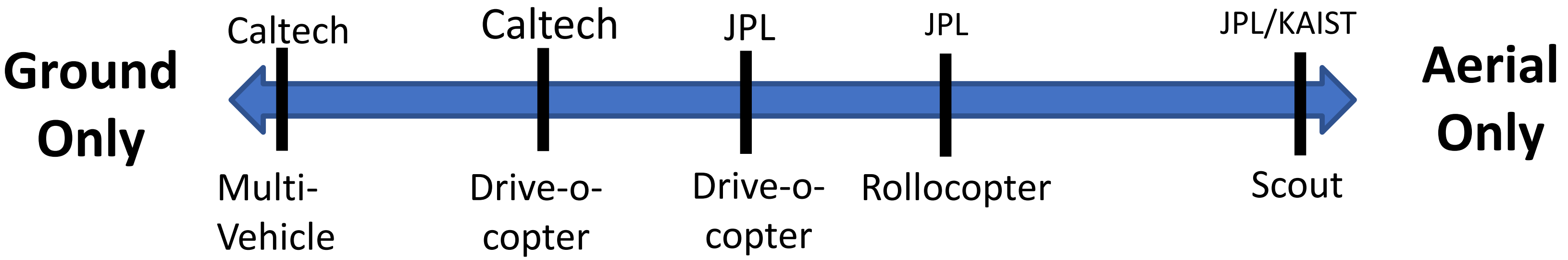


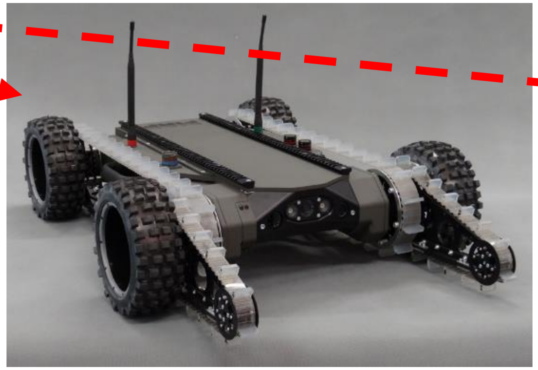
# System Design Overview

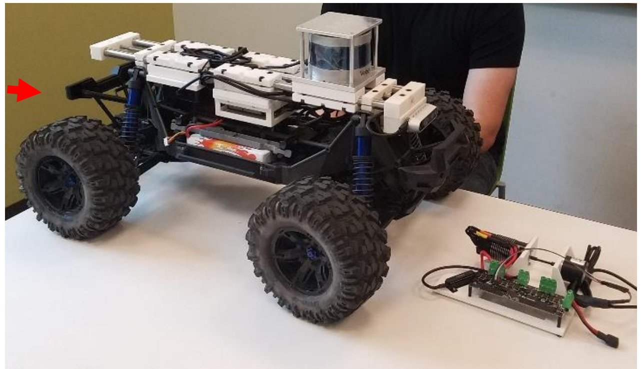
## Software: Functional Architecture



# Cross-Domain Mobility





**Mobility:** 4-wheel Skid Steer
- Not good in sandy terrains
- Poor on stairs

**Roles:**
- Towing vehicle
- compute node
- MQS/IMU node

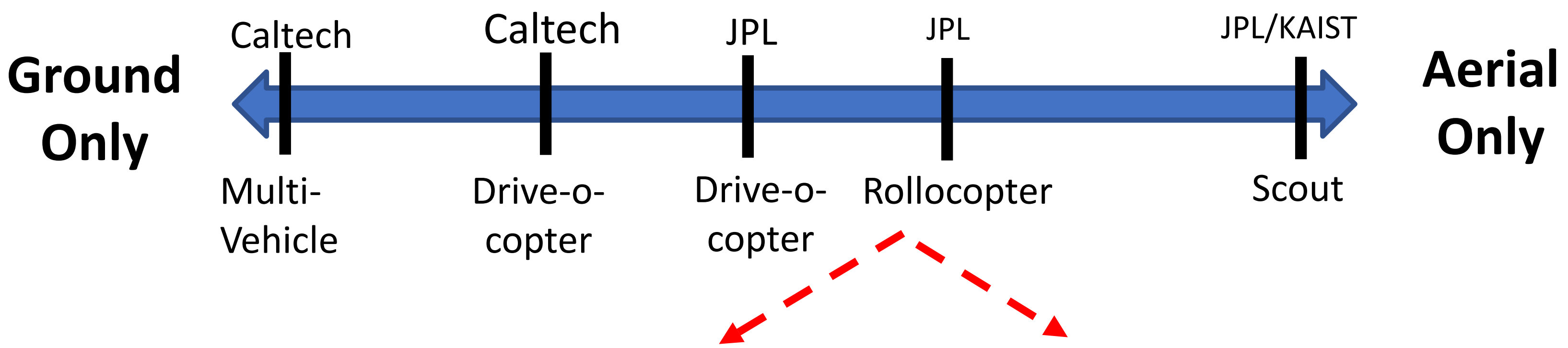
**Mobility:** Tracks
- Stairs
- Handles poor terrain

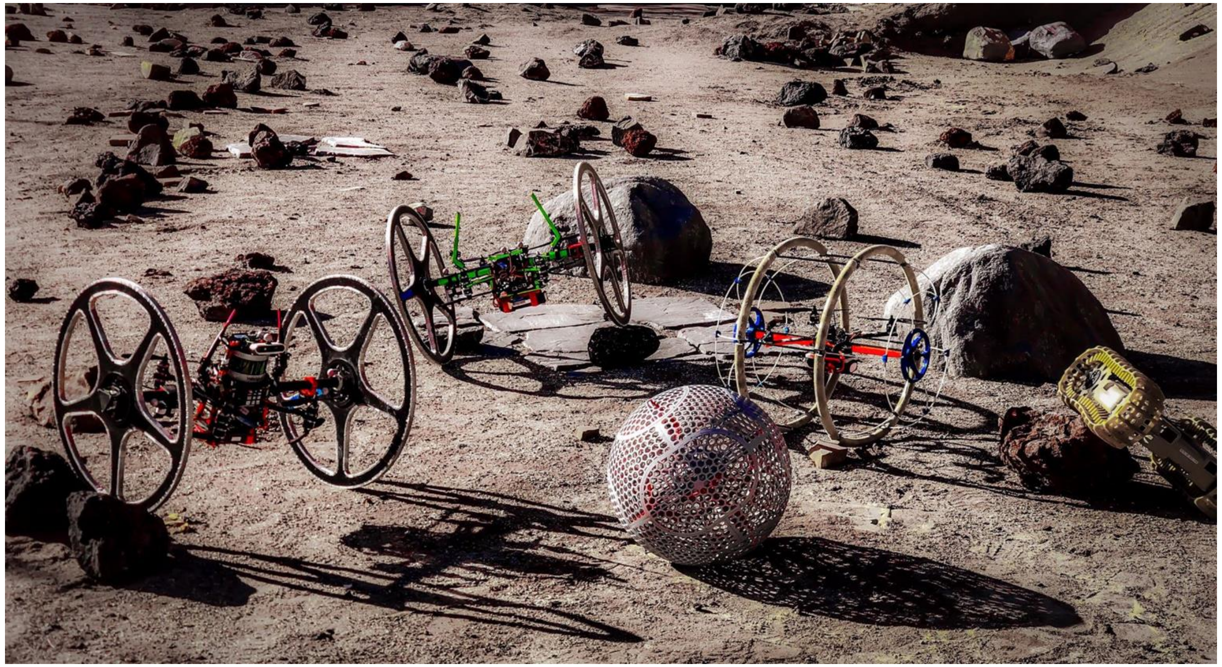
**Roles:**
- Light towing vehicle
- Mapper
- Stair Access

**Mobility:** Ackerman 4WD
- tunnels, urban circuit

**Roles:**
- “Scout-like” exploring vehicle
- Mapping/Detection
- Fast vehicle on moderate terrain

# Cross-Domain Mobility



# Approach

## Rollocopter Spec.s

**Flight system**

- Coax Quadcopter,  9.5”x4.7” propellers

**Physical properties:**

- Total weight: 4 kg

**Battery**

- 10Ah 4S Lipo

**Endurance:**

- Rolling: ~40min
- Hopping, bouncing, and flying: ~8 min

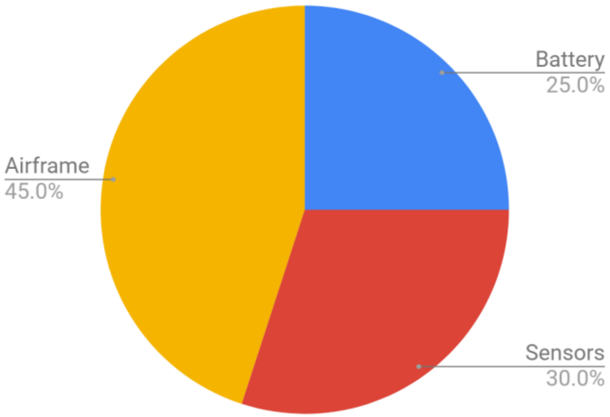
**Sensors**

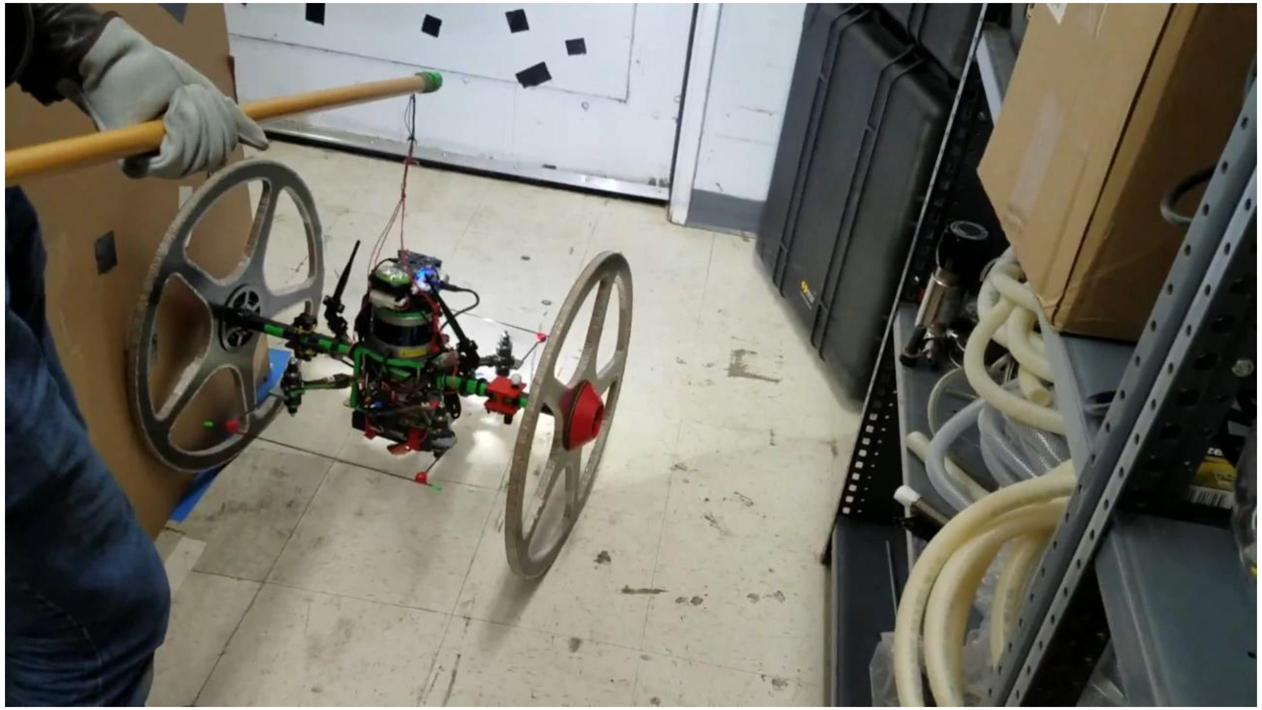
3D Lidar: (VLP-16 Lite) 

RGB-D Camera: (Intel Realsense) 

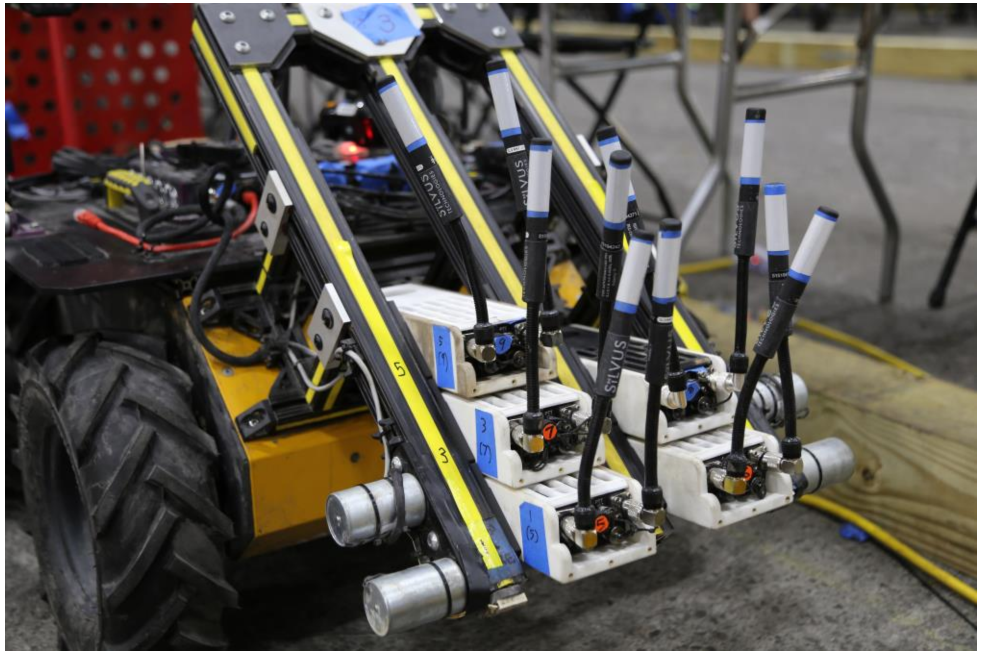
IMU: (VectorNav VN100) 

1D Lidar: (Garmin) 



# What Actually Got Deployed?




# Videos from “Tunnel Circuit”

**Videos of all scoring runs**

https://www.youtube.com/playlist?list=PL6wMum5UsYvYqHMxOkZuopRMqVxm9MtAJ

**Video of CoSTAR Final Run**

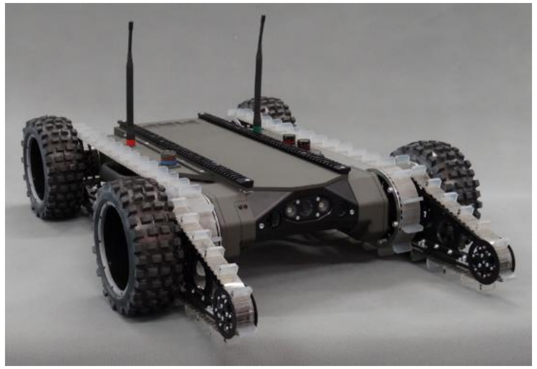
https://www.youtube.com/watch?v=QpkZIaLdrlk&list=PL6wMum5UsYvYqHMxOkZuopRMqVxm9MtAJ&index=27&t=0s

**Video “Fly-through” of Tunnel Circuit**

https://www.youtube.com/watch?v=-qqD243S6RM

# What will get deployed in Tunnel Circuit?

Two Huskies
(for ground floor)



Two Stair-Climbers
(for upper floors)

Baseline System

Stretch Options

# Project Ideas

## Well-defined Near Term & Long Term Projects

- Automated RC Car
  - Improved Mechanical Design
  - Added sensors, Improved State Estimation
  - Improved Steering Control
- Drive-o-copter
  - New Mechanical Design
  - Ground-up implementation of Autonomy, Hybrid mobility planning
  - Improved Sensor Suite

## Less well-defined, but important Near Term Projects

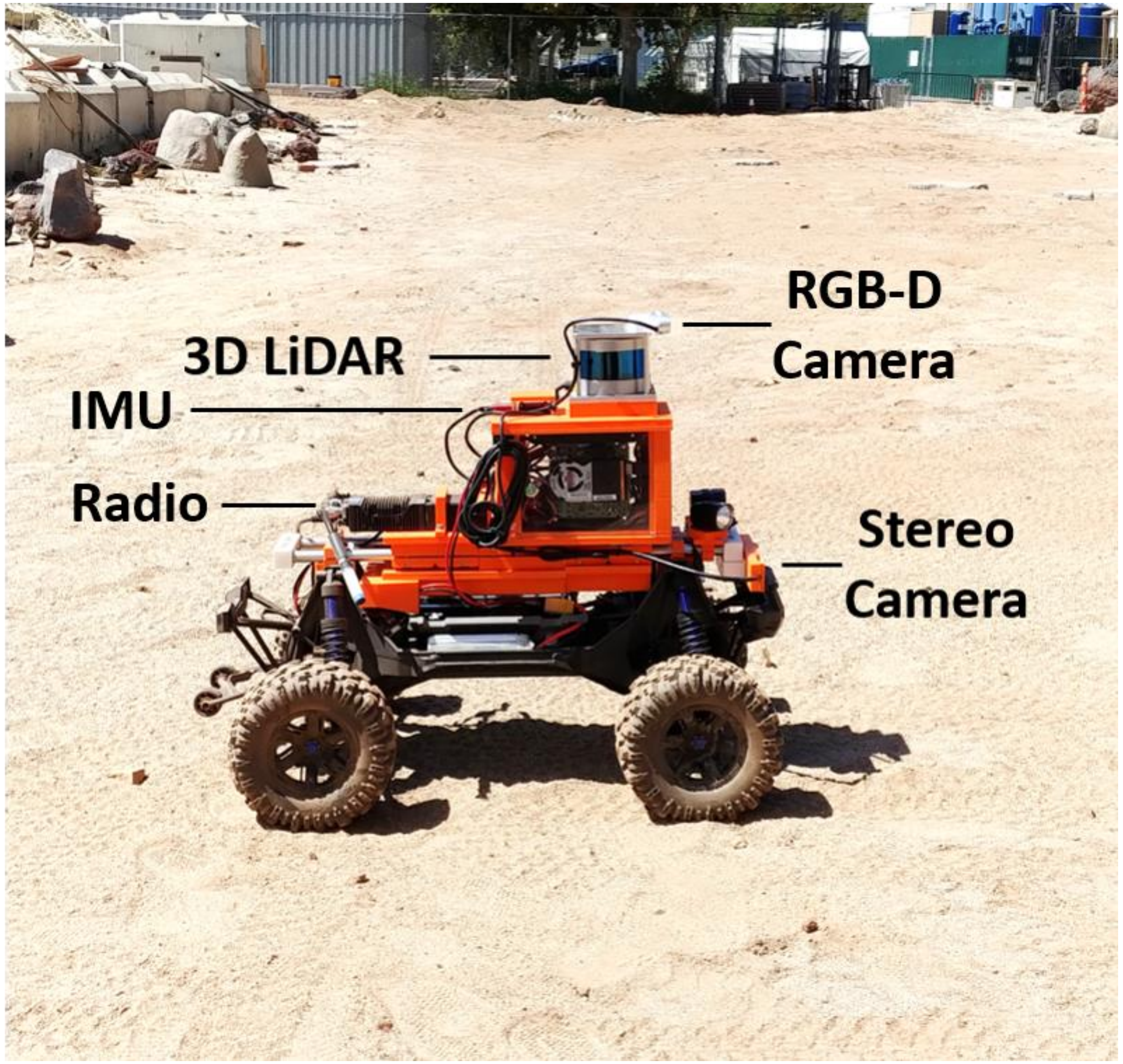
- Tracked Vehicle Stair Climbing

## Important Long Term Projects

- Long Flying Duration (diesel or electric) drone

## Blue Sky, but very important Projects

- Deployable, robotic Total Station

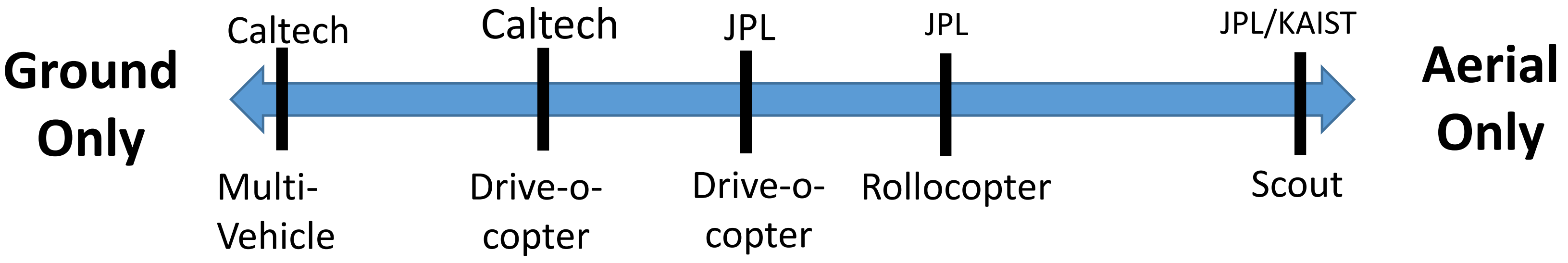

RGB-D
Camera
3D LiDAR
IMU
Radio
Stereo
Camera

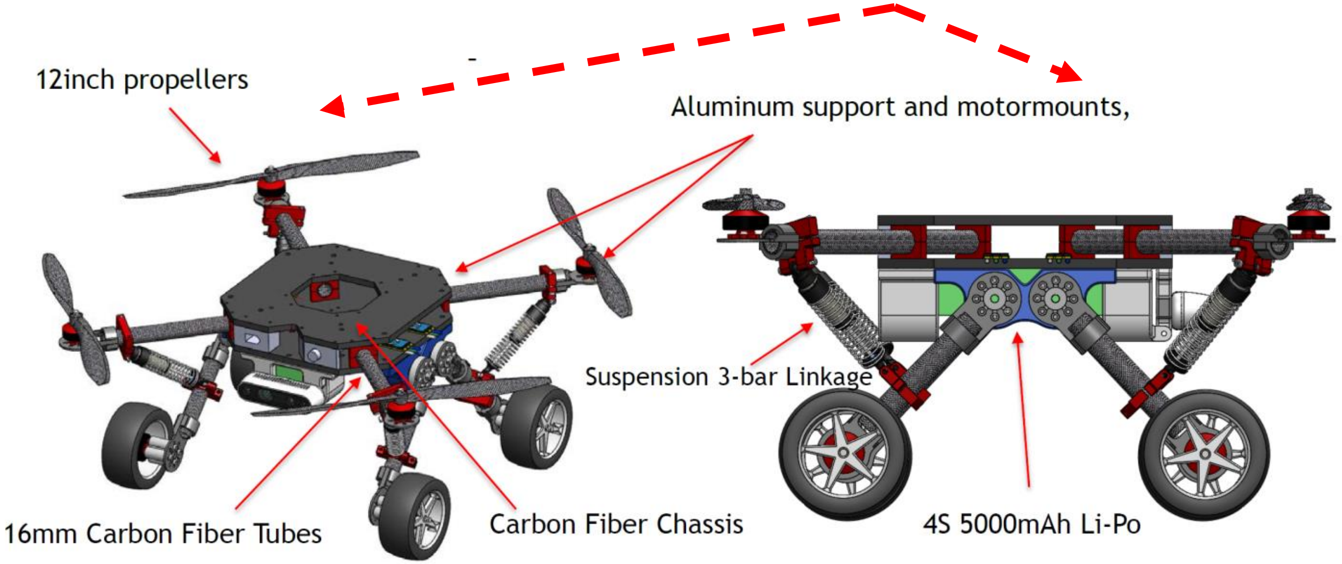
# Automated RC Car Project Goals

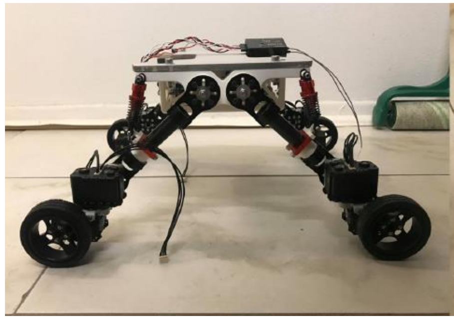
1. Redesign Super-structure so that it is less top heavy
2. Add Sensors to wheels for “odometry”
3. Build 2nd car copy)
4. Develop odometry estimate using the wheel sensors
5. Improve steering control at high speeds and during backup
6. Stretch goals
    - Add sensor to suspension
    - Develop whole body estimator
    - Develop high speed navigation based on “perception aware” planning principles

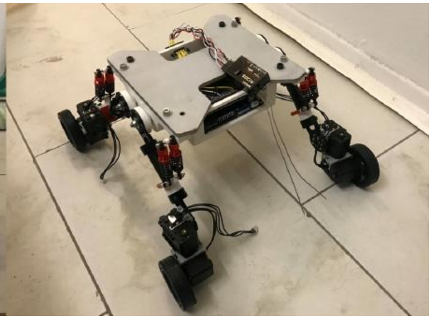
Resources: Jake Ketchum (*jketchum@caltech.edu*) , Anushri Dixit (*adixit@Caltech.edu*), Nikhilesh Alatur (*nikhilesh.alatur@jpl.nasa.gov*)

# Cross-Domain Mobility





**Principle:** primarily a driving machine which can "hop" or fly up stairs as needed.

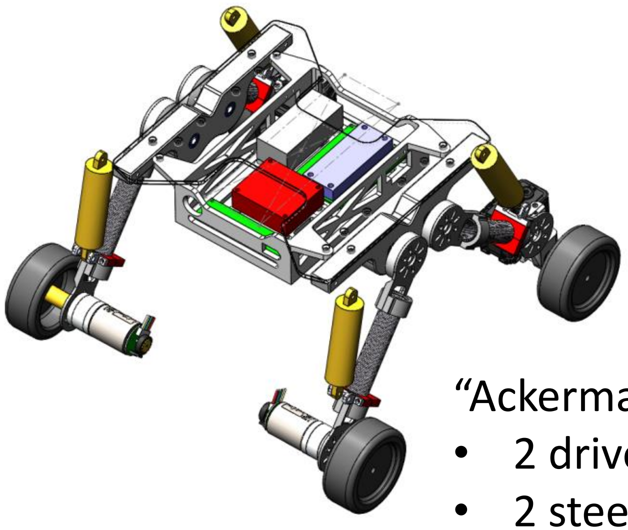
- Multiple drive configurations
- "Easy-Swap" chasses



"Swerve Steer"
- 4 drive motors
- 4 steer motors

**Driving Performance:**

1. 65kJ spent for 951m of driving
2. 21% battery spent
3. Expected Driving Range: ~ 4.5km
4. COT of 2.0, close to humans
5. Average Speed: ~1m/s



"Ackerman Steer"
- 2 drive motors
- 2 steer motors

**Driving Performance:**

1. Expected Driving Range: ~ 35 km
2. COT of 0.4, better than humans
3. Average Speed: ~1.5 m/s

# Drive-o-Copter Project Goals

1. Design/Build specialized Urban Circuit Design
2. Finalize Sensor Suite
3. Bring up JPL autonomy package on Drive-o-Copter
4. Take-off and landing control
5. Test Extensively
6. Stretch goals
    - Hybrid Locomotion Planning

Resources: Drew Singletary (*asinglet@caltech.edu*), Anushri Dixit (*adixit@caltech.edu*) , Amanda Bouman (*abouman@caltech.edu*)

Rover Robotics “Flipper”

Rover Robotics “Flipper”


Spin-off of RoboteX
“Emergency Response” Rovers

# Stair Climbing Project Goals

1. "Centering control" while stair climbing
2. How to use autonomously use "arms" to facilitate climbs on complex stairs
   - Disaster recovery?
3. Estimate "Slip" during motion, particularly on stairs.
4. Stretch goals
   - Develop perception for stair climbing

Resources: Anushri Dixit *(adixit@caltech.edu)*, Nikhilesh Alatur (*nikhilesh.alatur@jpl.nasa.gov*), Rohan Thakoor (JPL)

# Long Flight Duration Drone

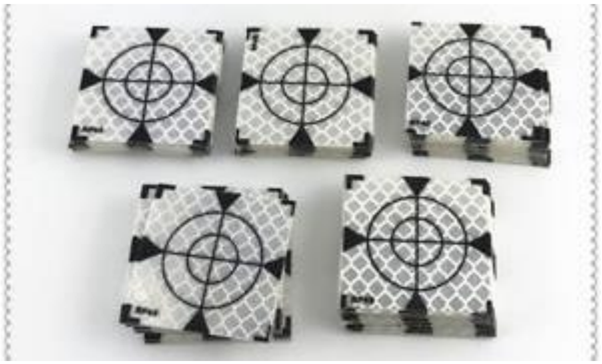
(mainly for cave circuit & beyond)

1. Investigate at least 2 strategies
    - diesel power (no gasoline allowed) & collective pitch
    - Battery Power
2. Design/build prototype
3. Demonstrate autonomy

Resources: Luis Pabon (*lpabonma@caltech.edu*), Malcom Tisdale (mtisdale@caltech.edu) , Drew Singletary (*asinglet@caltech.edu)*

# Blue Sky: robotic, multi-leg Total Station

1. Investigate:
   - Can we make a multi-leg total station
   - How accurate
   - How to automate
   - How to deliver
2. If feasible, Design/build prototype
3. Demonstrate



Resources: Joel

# Homework

- Build a team of 3-6 people
- Select a project
- Prepare a “GoTChA” chart