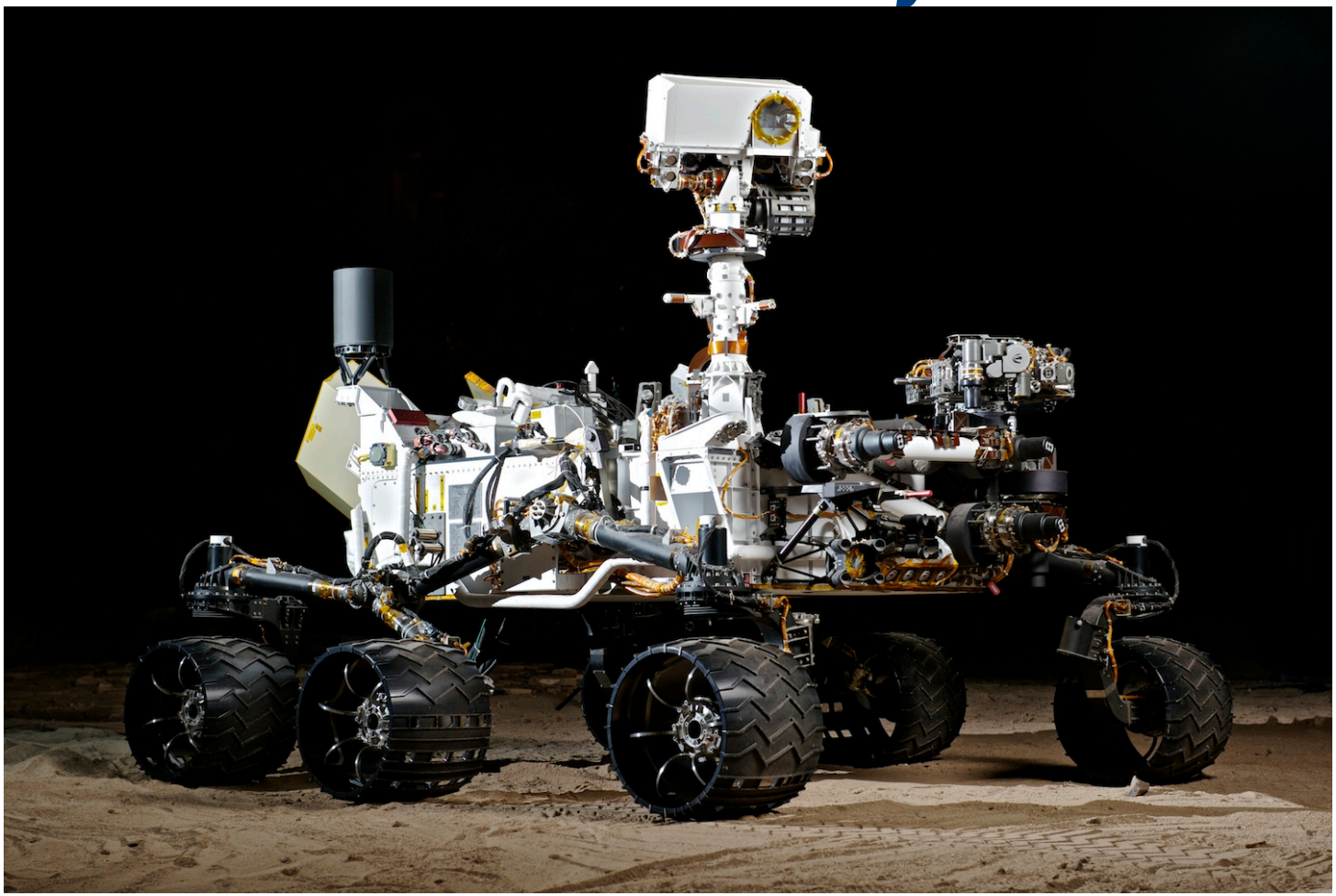
Introduction to Mobility for MSL

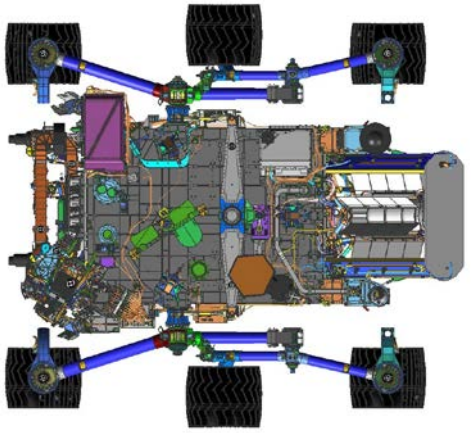


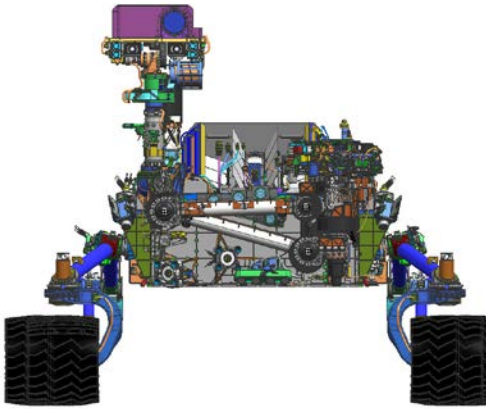
Agenda

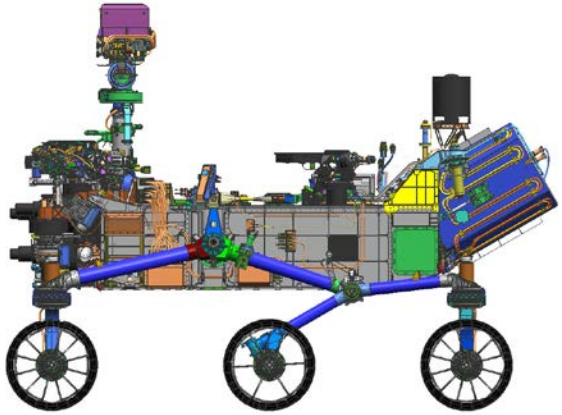
- Basics of the rover (rocker bogie suspension, ground pressure, etc.)
- Coordinate systems
- Motion primitives and blind driving behavior (arcs and turns)
- Basic reactive safety checks (tilt limit, suspension limits, motor current limits)
- Intro to autonomous behavior (visual odometry, autonav, visual target tracking)
- Observation tables
- RSVP and rover simulations

Rover Overview

- Six wheel drive
- Four wheel steer (corner wheels)
  - This means you can't "crab"







Fun Fact: Each drive actuator has enough torque to drive the rover straight up a wall on Mars

Suspension

- Passive suspension pivots
  - Rocker / differential (+/- 20 deg)
  - Bogies (+44 deg / -45 deg)
- The rover performs better bogie first, but drives rocker first to be able to “back” out of trouble

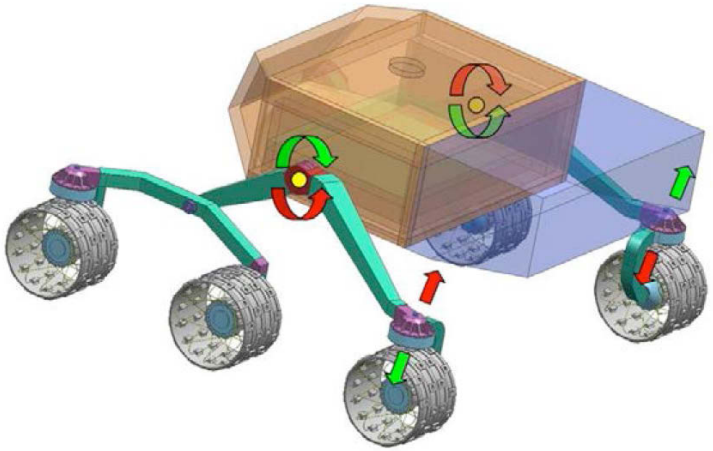
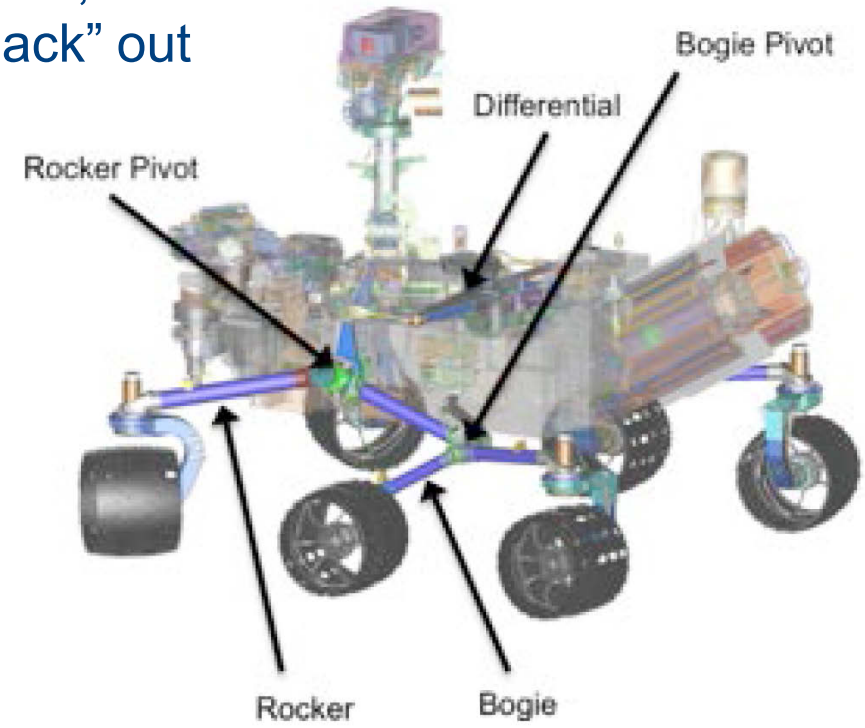
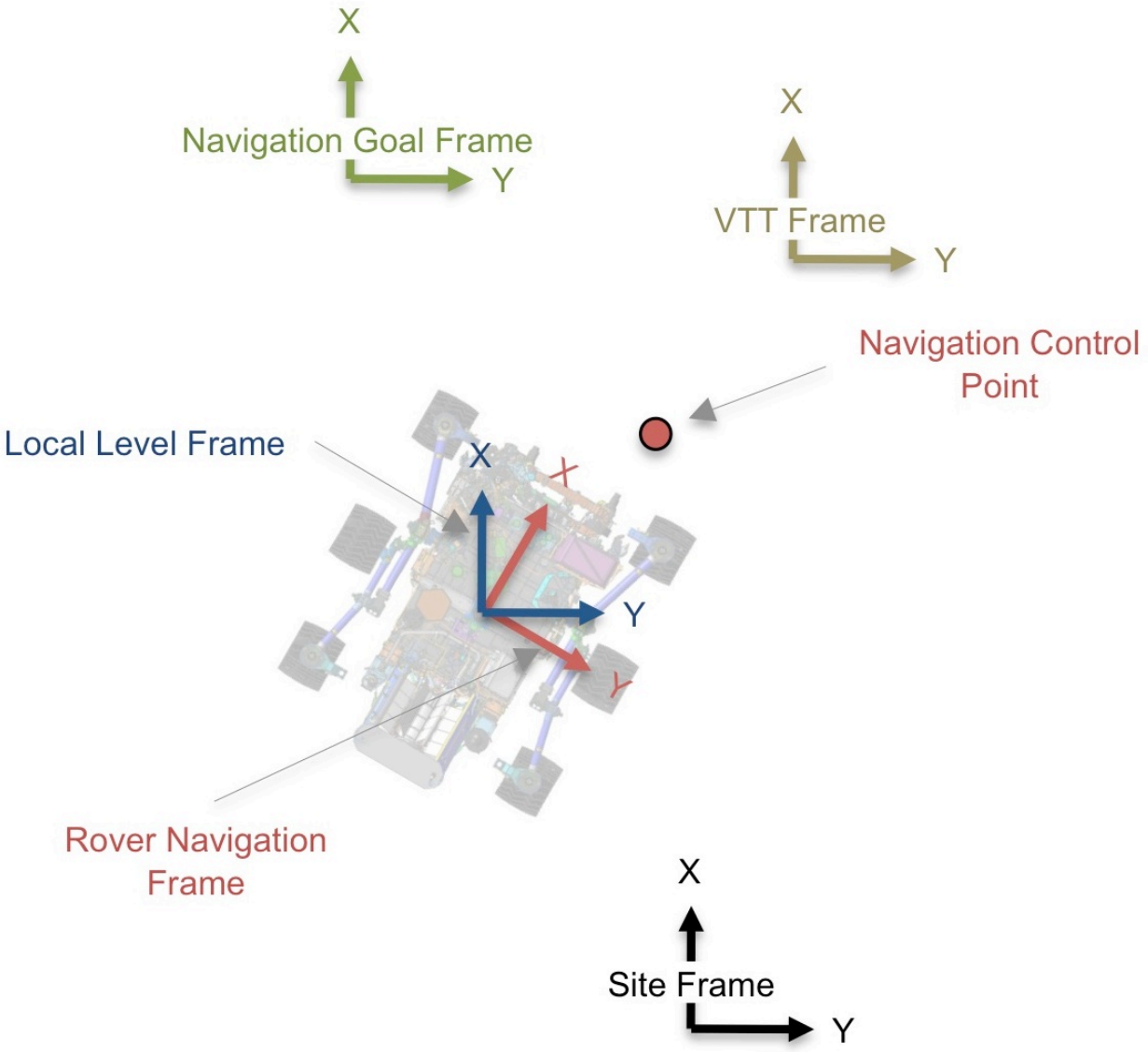


Illustration of rocker differential. As one rocker arm moves up, the other rocker arm moves down

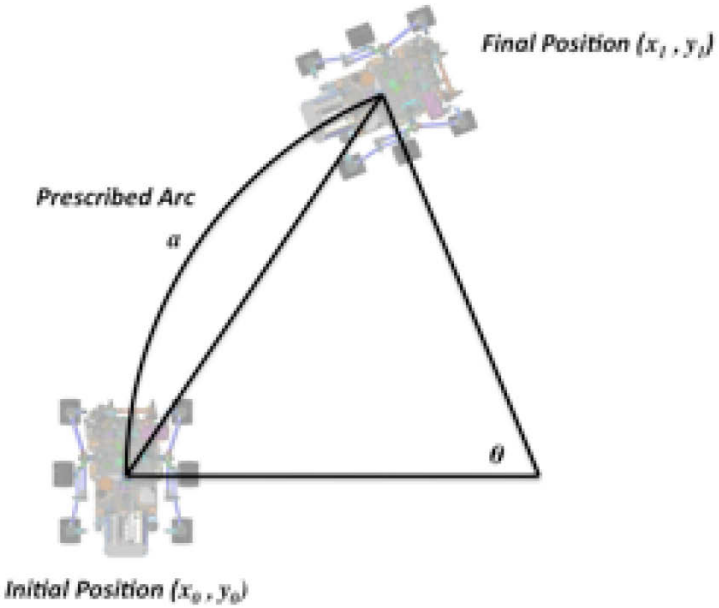


Mobility Coordinate Systems



Motion Primitives

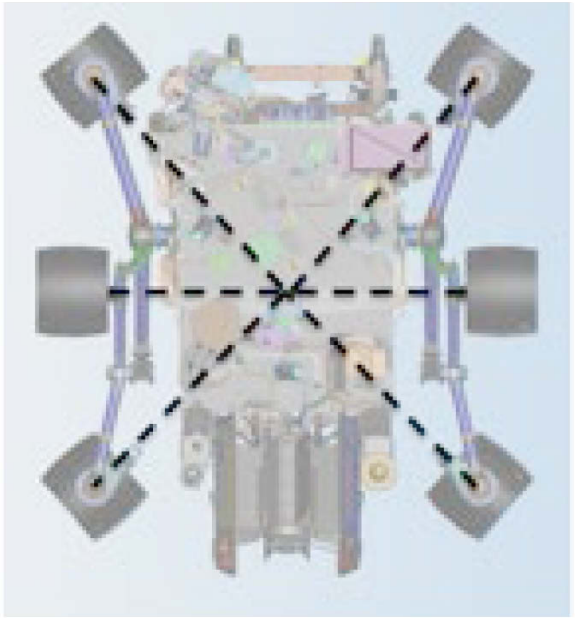
- Mobility motions are comprised of steering and then driving
- Actuators are steered for Ackerman steering so axis of rotation for all drive actuators intersect at a common point
- Individual drive actuator rates are scaled for zero slip (outside wheels move faster than inside wheels)



- The rover cannot drive and steer at the same time, therefore we can only take constant curvature arcs

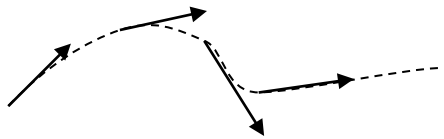
Turn-In-Place

- A turn-in-place is a special case of an arc with no change in position, only a change in heading
- A turn is fundamentally different than an arc because it is closed loop on rover heading reported by the Inertial Measurement Unit (IMU)



Keeping Track of the Rover

- A module called the Surface Attitude Positioning and Pointing (SAPP) keeps track of the rover
- The rover's orientation (roll and pitch) are instantaneously measured with an accelerometer
- The rover's heading is measured by integrating gyros as the rover moves
  - This method of tracking heading fundamentally has "drift". Every once and a while we perform a sunfind to remove the error
- The rover's position is tracked by integrating commanded motion along the heading vector



Rover Safety

- There are two types of safety checks for the rover
  - Proactive safety checks keep the rover from doing something dangerous
  - Reactive safety checks mean something considered dangerous **HAS** happened

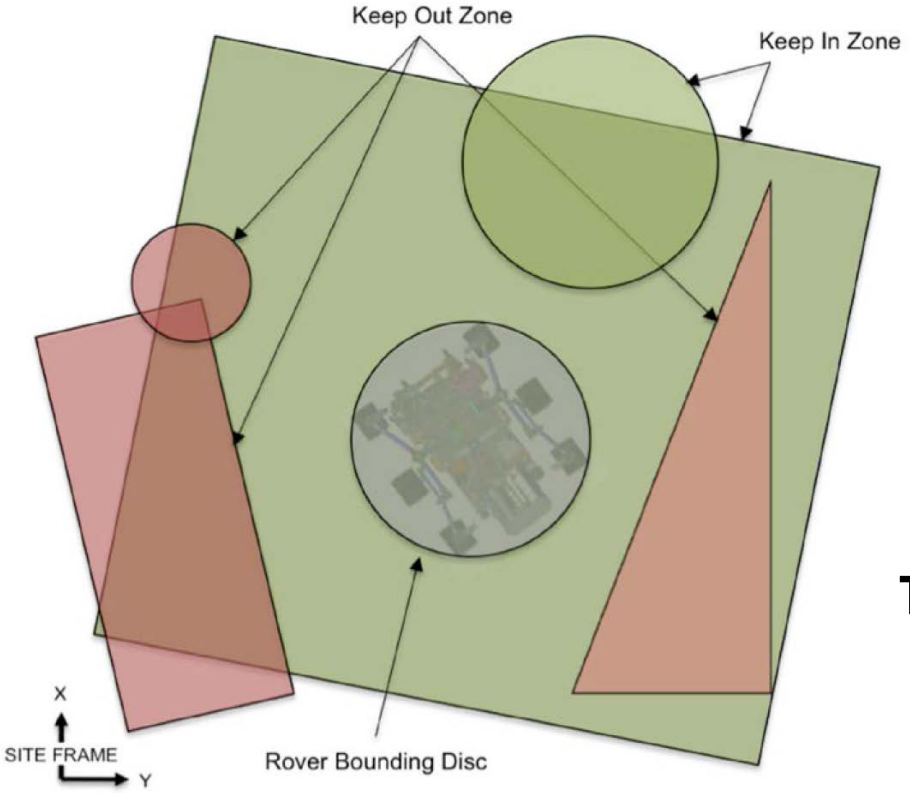
Reactive Safety Checks

- **Motor faults**: current limits, stalls, etc.
- **Tilt limit**: min and max tilt. Also roll and pitch limits
- **Suspension limits**: min and max for rocker and bogie angles
- **Yaw limit**: Rover heading is outside expected bounds
- **Yawrate**: While turning, the rover is not making the expected progress
- **Actuator backdriving**: Non-driven actuators are monitored for backdriving which would indicate the motor brake is not functioning
- **Thermal limits**: Actuator temperatures are measured
- **Nadir miscompare**: The measured gravity vector is too far off from the gyro integrated gravity vector
- **Average current**: High average current on all drive actuators indicated embedding
- **High slip**: Detected through visual odometry
- **ChemCam**: ChemCam is warm and not sun safe (note only sets goal error)

These faults set mobility goal and motion errors

Proactive Safety Checks

- Terrain is untraversable
- Commanded motion would drive into a keepout zone



These faults set only a mobility goal error

Driving Modes

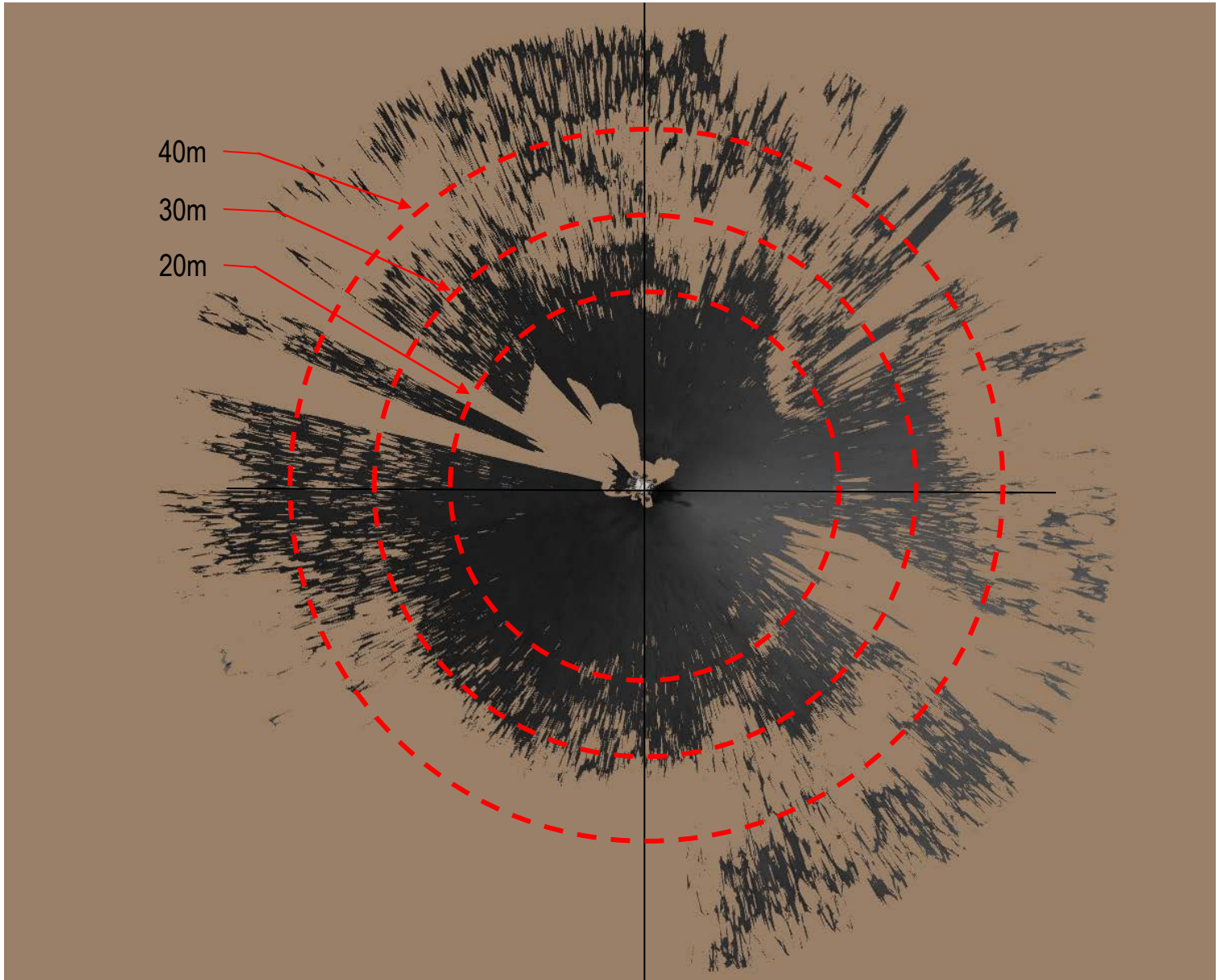
- Blind driving
- Autonav
- Visual Odometry
- Visual Target Tracking

Blind Driving

- Rover turns its wheels the commanded distance
  - No stopping to evaluate terrain hazard
  - No Visual Odometry to measure actual distance travelled (slip)

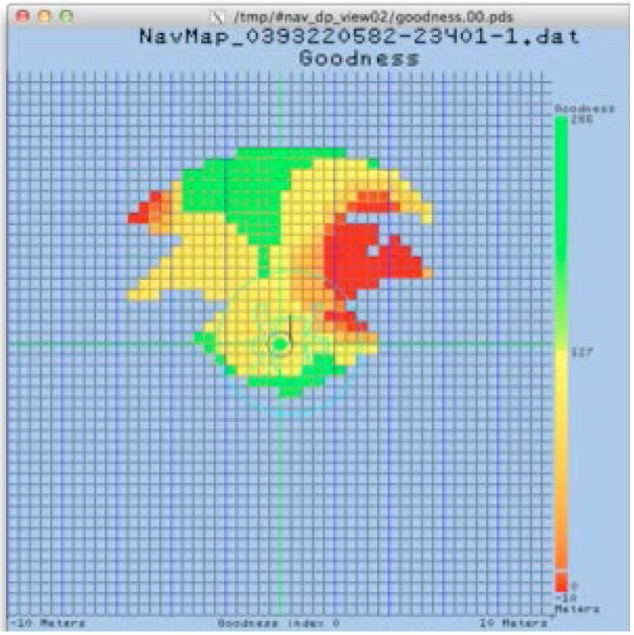
- This is typically used for the first portion of a driving day since it is significantly faster than other driving modes
- Terrain must be confirmed to be safe and free from hazards based on imaging
- ~40m limit based on Navcam terrain mesh

Terrain Mesh Horizon



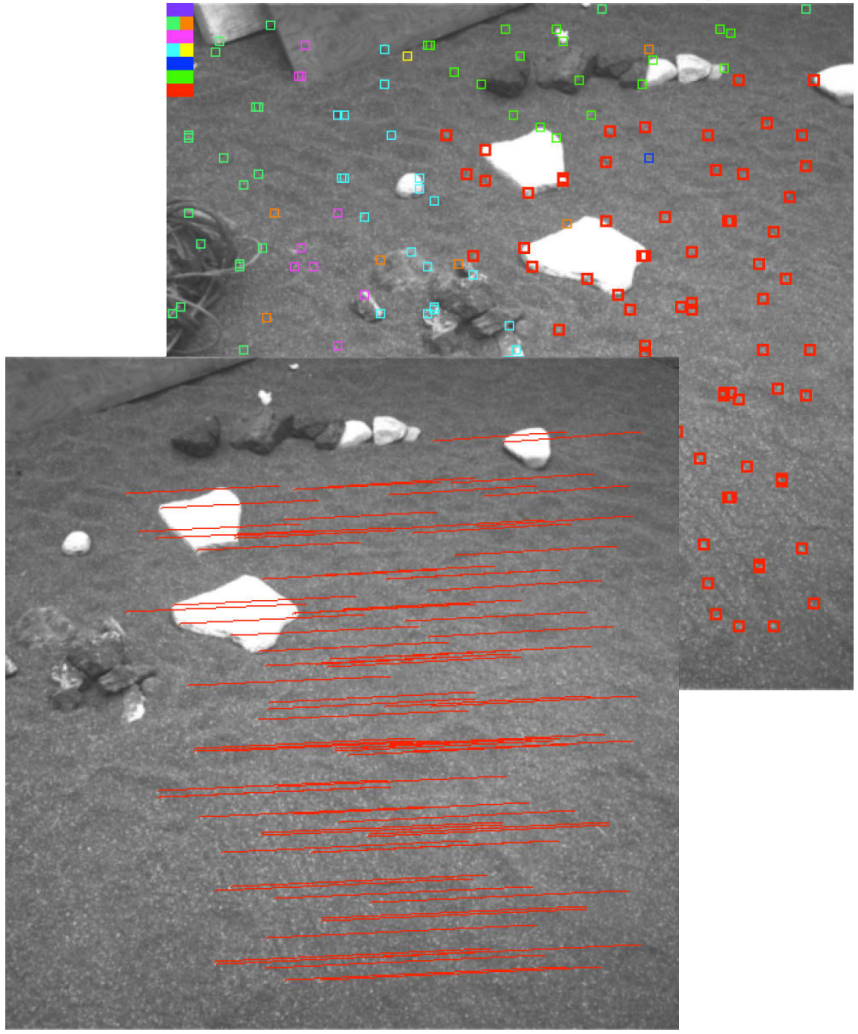
Terrain Assessment

- Rover images the terrain and assesses the safety of a given path based upon
  - Roughness
  - Slope
  - Obstacle height
- GUARDED mode will only drive the specified arc if it is safe
- Autonav mode will choose the best path to get you to your goal



Visual Odometry

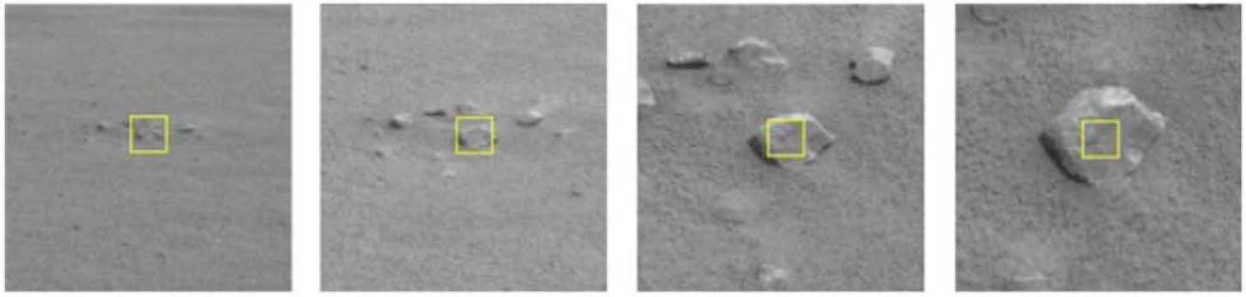
- Visual Odometry (VO) uses stereo images at two rover locations to track true rover motion
- VO helps to
  - Localize the rover for precision drives
  - Detect slip and embedding
- VO is accurate to ~3% of the traverse distance between the VO updates



NOTE: Slip checks are a special case of VO where the rover does a VO update, drives a short distance and does another VO update. It uses the slip during this slip check to verify the rover is not getting stuck. This is typically sequenced as: 20m blind -> slip check -> 20m blind -> slip check -> etc.

Visual Target Tracking

- Visual Target Tracking (VTT) uses visual servoing to drive the rover to a specified target
  - An image of an object is used as a template
  - As the rover drives it attempts to match the template to track the target
- VTT is different than VO because
  - VTT tracks relative position to a target
  - VO tracks rover's position in absolute space
- VO and VTT are not mutually exclusive, but it is not typically necessary to use both



Drive Rates

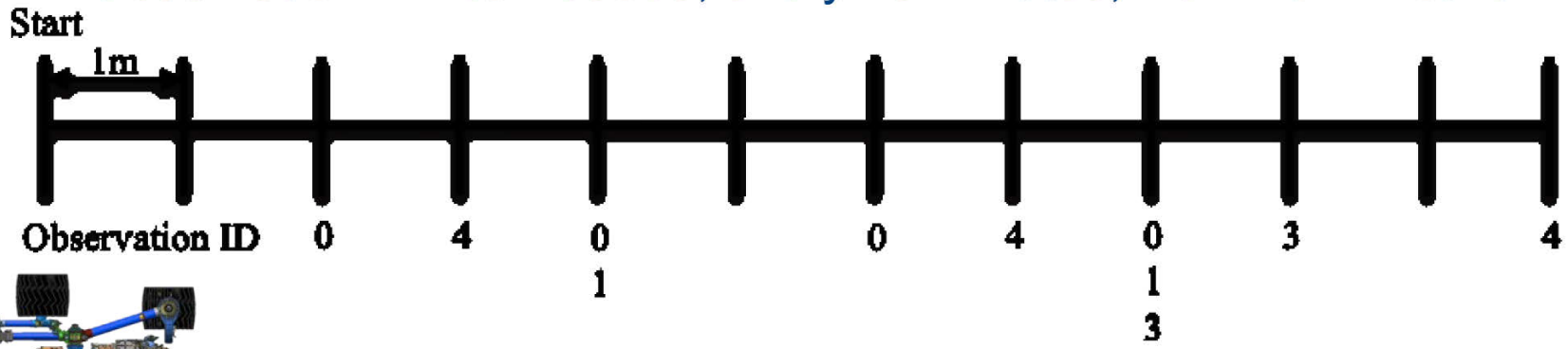
Drive Rates	m/hour	Notes
Absolute top speed	151.2	Absolute top speed on rigid terrain with zero slip
Blind drive	139.5	Top speed for straight driving with pause between steps
Blind drive with slip checks	116	Averaged over a significant number of slip checks
VO	64.5	VO at every step
Autonav	40.1	Assumes the number of steps skipped and number of images taken at each step as described in the assumptions below
Autonav with slip checks	38.5	Assumes the same rate as above for autonav
Autonav with VO	30.0	Assumes VO driving rate with additional time for map imaging at the appropriate spacing

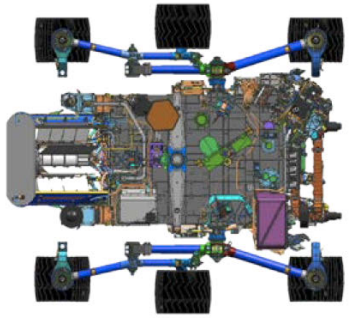
Observation Tables

- The mobility observation table is a table of sequences that is called at various intervals during a drive.
  - The sequences can contain any command (with a few exceptions)
  - The sequences are delivered by the subsystem
  - The sequences can be called at intervals of
    - Absolute time
    - Relative time
    - Distance
    - Steps

Observation Table Example

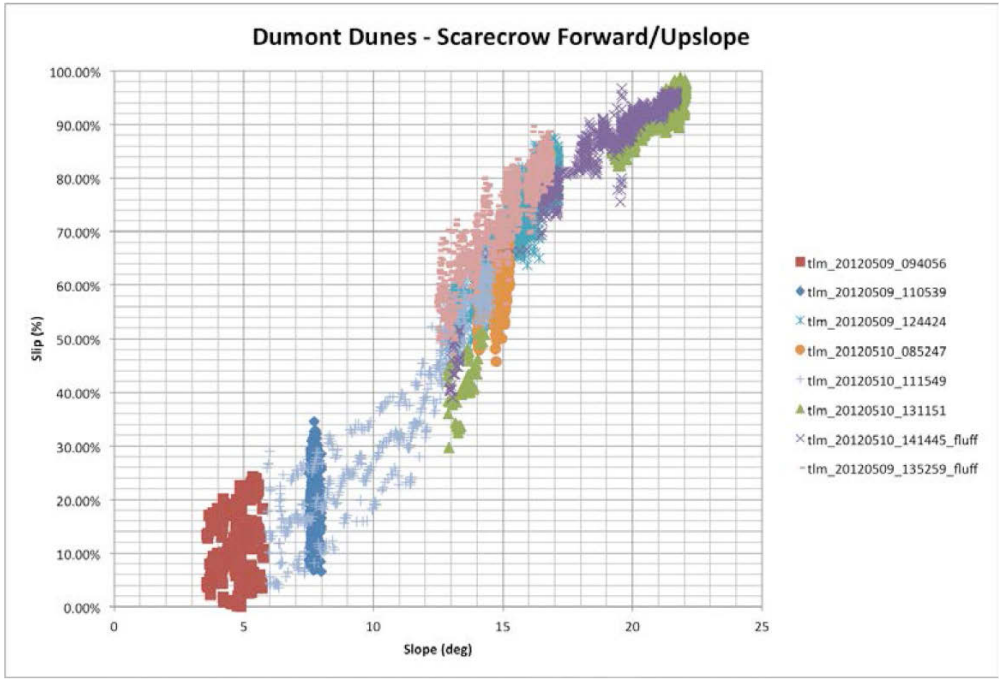
- Observation 0: mcam00010, every 2 steps, maximum 4 calls
- Observation 1: dan_01234, every 3.5 meters, maximum 100 calls
- Observation 3: ncam00000, after sclk 307512588, maximum 2 calls
- Observation 4: ncam00030, every 10 minutes, maximum 4 calls





Physical Hazards for the Rover

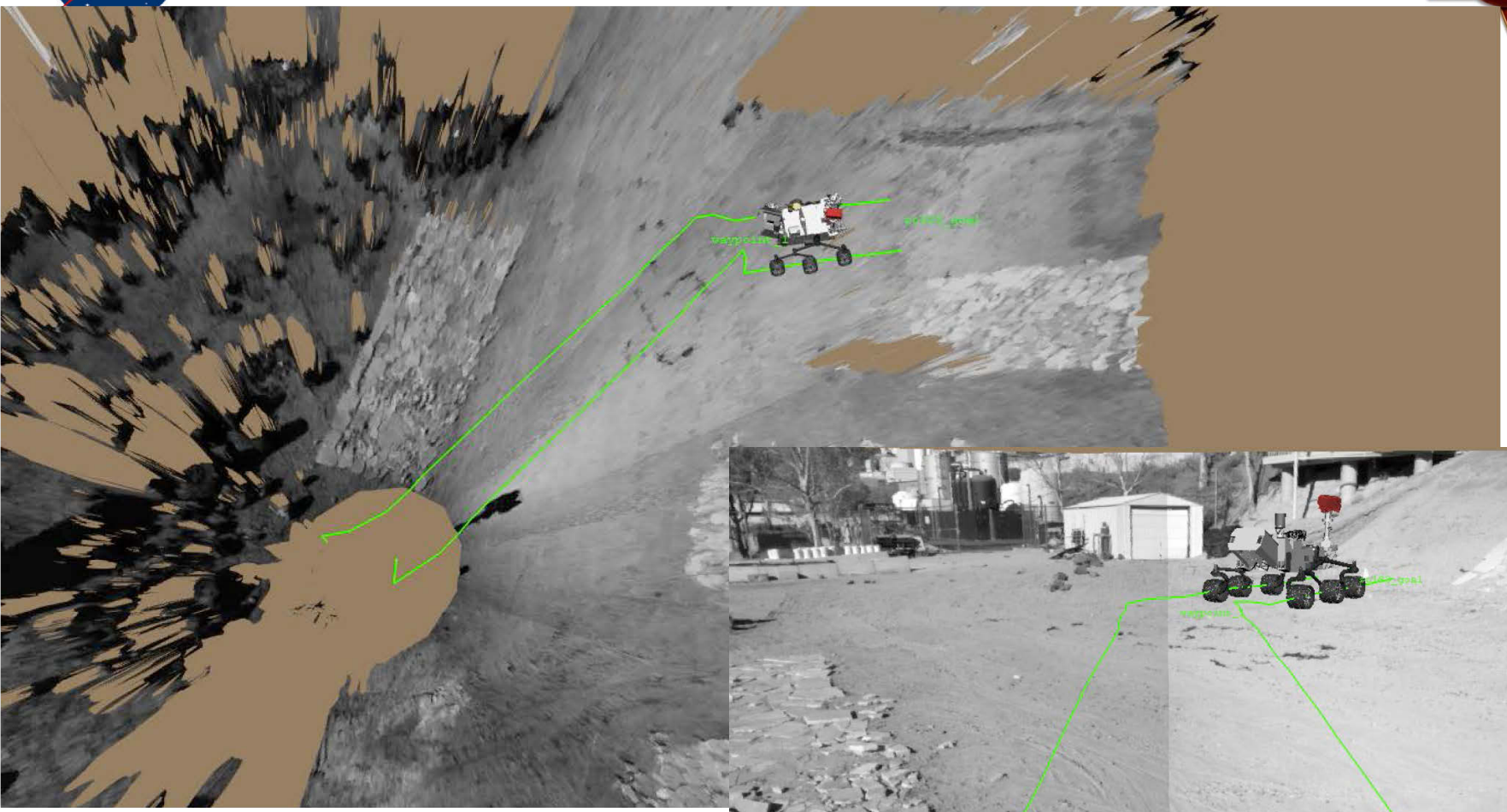
- Traversable Slopes
  - < ~12.5 deg on sand
  - < ~25 deg on bedrock
- Rocks
  - < 25cm not hazard
  - > 50cm hazard



Slip vs Slope curve for Scarecrow rover on wind blown sand

NOTE: 50 cm is the wheel diameter

Rover Simulation



Drive sequences developed in the Rover Sequencing & Visualization Program (**RSVP**)

Backup

Achilles Rocks

- Rocks that fit roughly between the wheels can cause wheel damage.
  - Rocks 60-90cm wide and 25cm tall or taller can get caught “between the wheels”
  - As one wheel rolls up one side of the rock, the other wheel rolls down the other. This wedges the rock between the wheels and can cause punctures