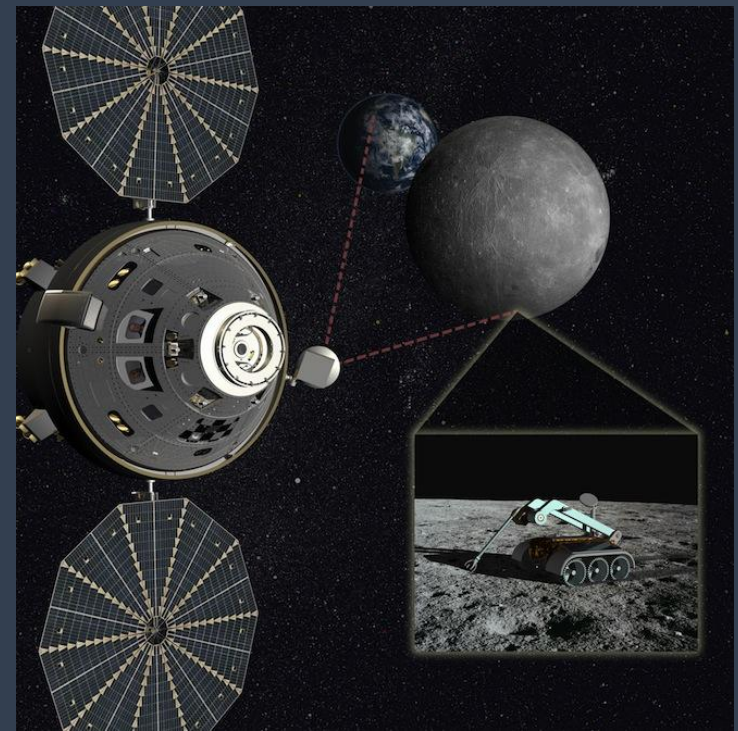


# NESS Telerobotic Experiment

An investigation of the minimum frame rate required for effective exploration via  
low-latency telerobotics

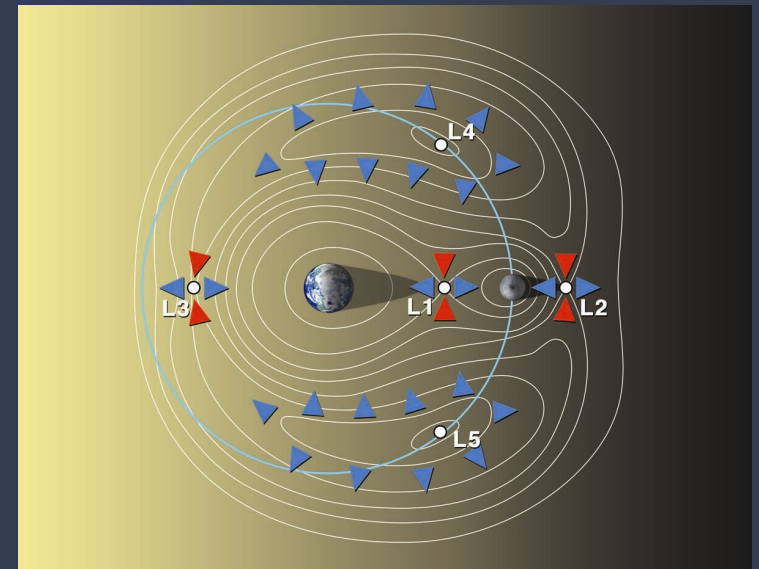
# Benefits of Low-Latency Surface Telerobotics

- Human/robotic partnership through low-latency telerobotics
  - Rapid scientific exploration and lower expense
  - Humans have cognitive threshold of approx. 0.3-0.4 seconds or less [D. Lester & H. Thronson, 2011]
- To meet the cognitive threshold, astronauts must be at most  $\sim 45,000$  to  $60,000$  km away



# Limitations of Low-Latency Surface Telerobotics

- We investigated reduced available bandwidth
  - Minimum frame rate
- Earth-Moon L2: maximum bandwidth is approx. 4 Mbps
  - Assuming 0.5 m Ka-band antenna on rover with 10 W output and 0.75 m antenna on crew habitat [T. Fong, M. Bualat, J. Burns, J. Hopkins, & W. Pratt, 2014]
- Bandwidth varies



## Research Statement

- Find the minimum operational frames per second (FPS) required for a human operator to successfully explore an unfamiliar environment using low-latency telerobotics

# Experimental Design/Procedure

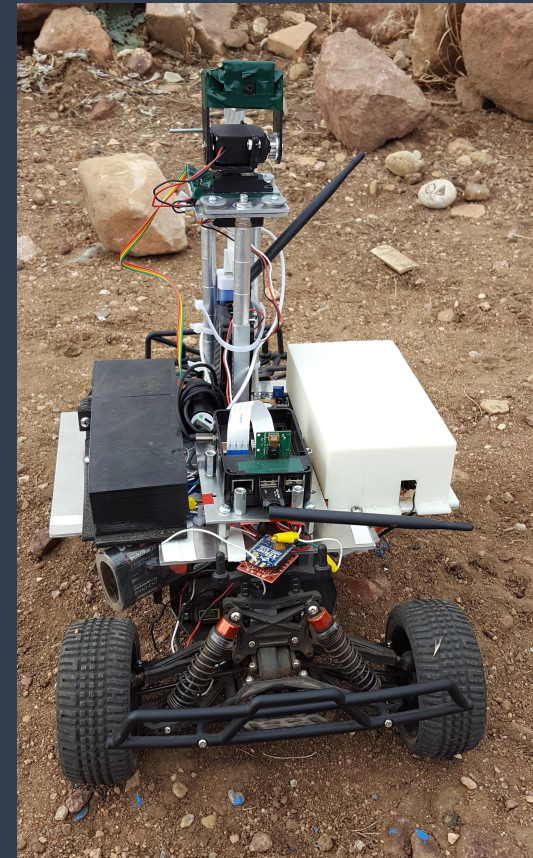
- Operator identified targets as frame rate varied each trial
  - Targets were painted rocks with a letter/shape written on surface
  - Possible frame rates: 4, 5, or 6 FPS
- Operators housed in an isolated tent and relied only on video feedback from Rover
- Used time to discovery as our metric for measuring “explorability”



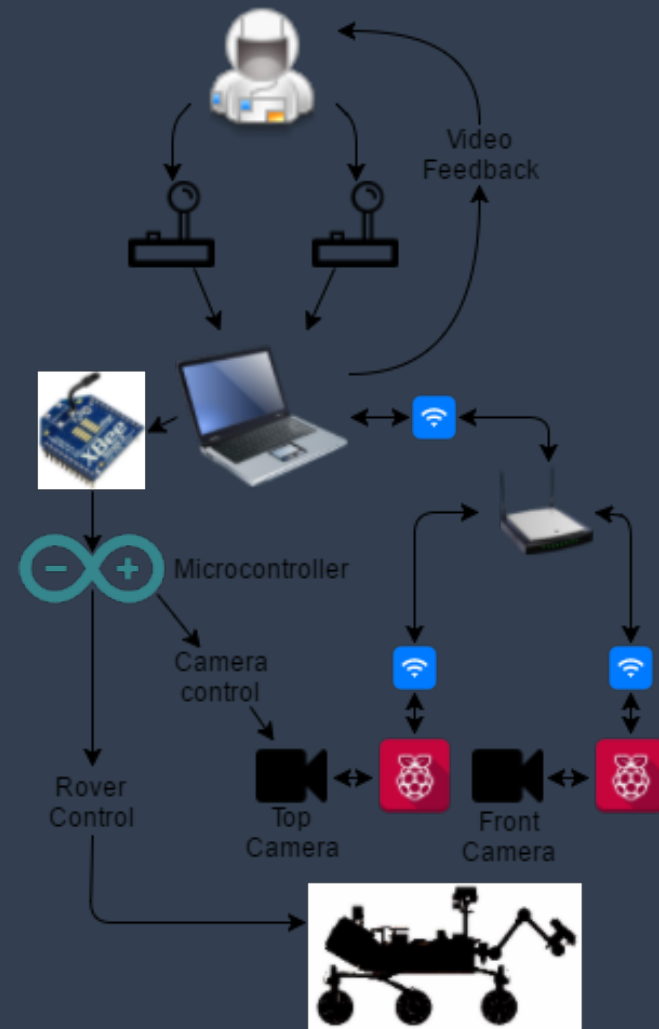


# ROVER: Remotely Operated Vehicle for Exploration Research

- Modified remote controlled car
- 2 separate video systems running on Raspberry Pi computers
  - Front camera is fixed
  - Top camera can rotate in pitch and yaw responding to user commands
- XBee RF modules used to send user commands
- Improved gear ratio for increased torque



# Control and Communication System



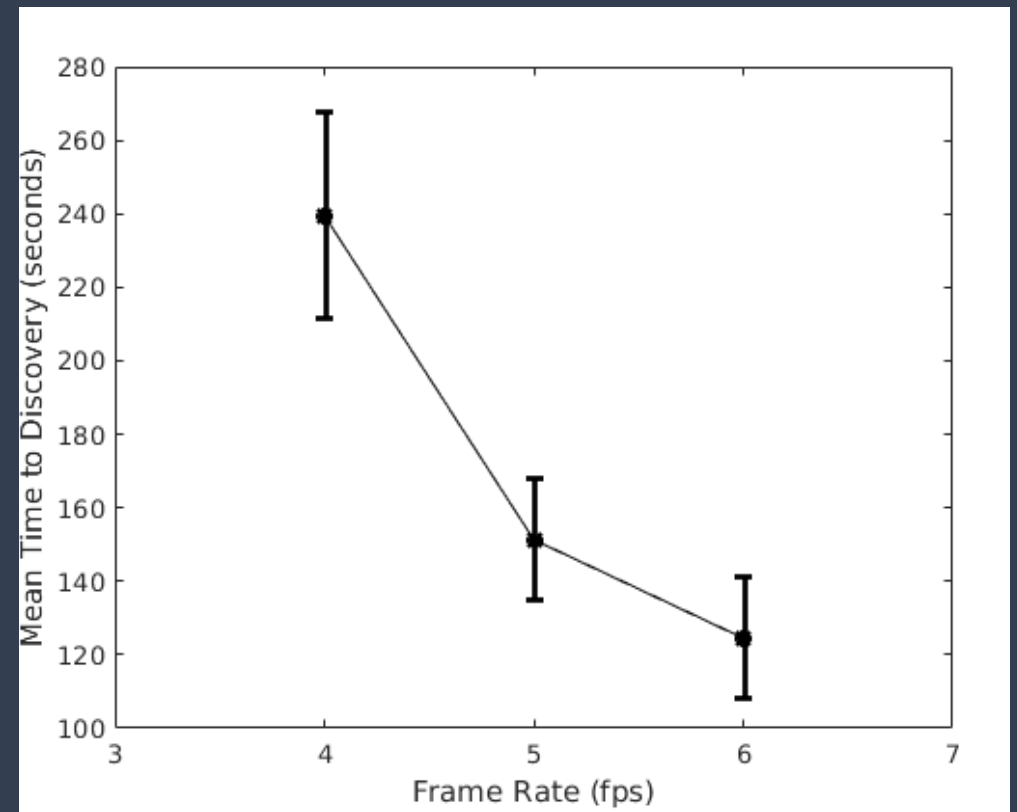






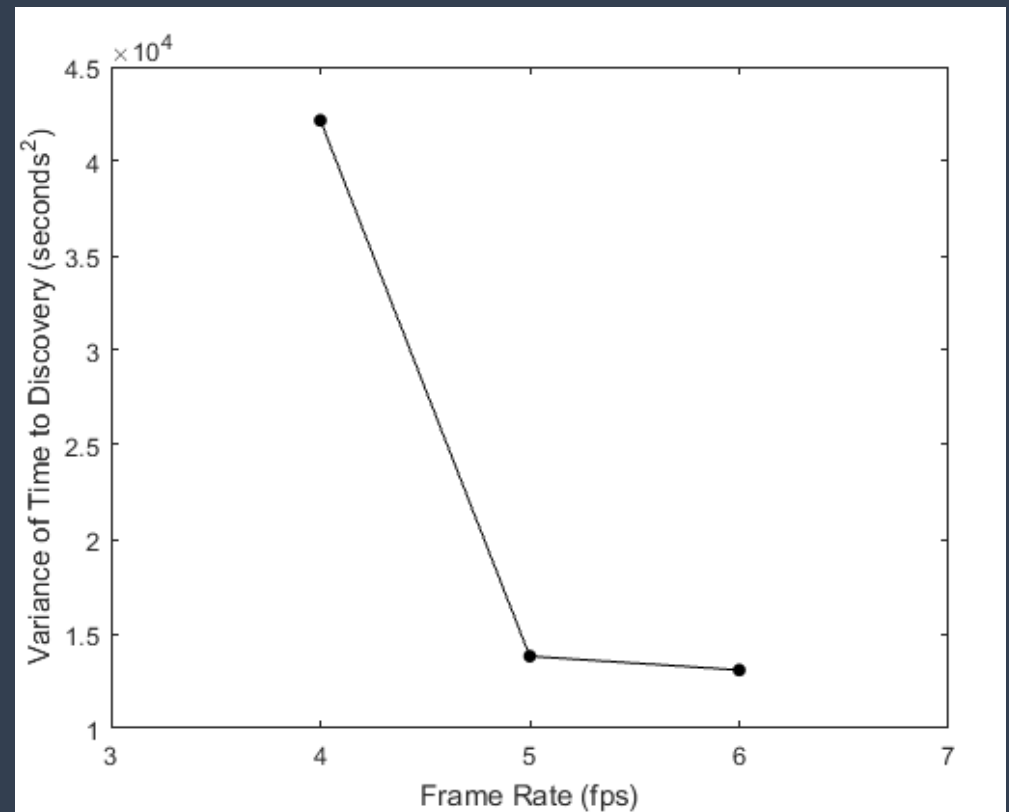
# Mean Time to Discovery

MTD at 4 FPS is significantly higher than 5 & 6 FPS at the 95% confidence level



# Variance of Time to Discovery

MTD at 4 FPS is significantly higher than 5 & 6 FPS at the 95% confidence level



# Conclusions

- A minimum frame rate exists in low-latency telerobotics
- Given our operation parameters, (rover speed, resolution, colorscale), 5 FPS is the minimum frame rate for effective low-latency telerobotic exploration



# References

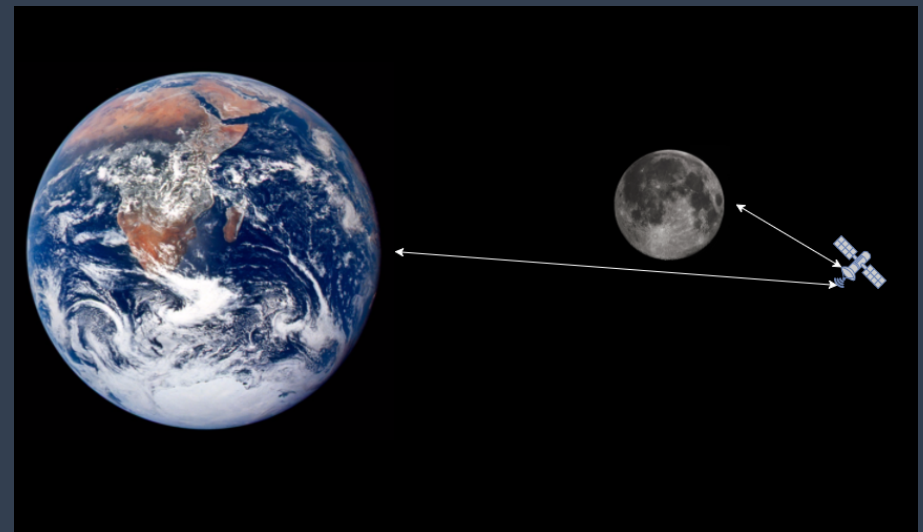
- [1] D. Lester, H. Thronson, Human space exploration and human spaceflight: Latency and the cognitive scale of the universe. *Space Policy* 27 (2) (2011) 89-93.
- [2] T. Fong, M. Bualat, J. Burns, J. Hopkins, W. Pratt, Testing astronaut-controlled telerobotic operation of rovers from the International Space Station as a precursor to lunar missions. 2014.

# NESS Telerobotic Draft Work Plan

Research Questions in Preparation for NASA Telerobotic Missions

# Introduced Latency Experiment: investigating 2.6 sec delay

- Round-trip latency between Earth and lunar far side is approx. 2.6 sec
  - How serious does this latency affect telerobotic exploration
- Quick follow-up experiment to investigate benefits of real-time teleoperations over delayed teleoperations
  - Compare MTD at 5 fps with 2.6 sec latency to MTD at 5 fps with  $\sim 0$  latency





# Effect of Rover Speed on the Minimum Frame Rate

- We have found the minimum frame rate given certain operating conditions
- Now we want to find the minimum frame rate given a particular speed of operation
- Useful for determining limitations on various telerobotic tasks



# Requirements for Augmented Reality in Exploration

- Mostly autonomous rovers are the future for telerobotic exploration
- Give power to scientists more likely find promising new discoveries
- Major value in finding effective ways of exploration and discovery by increasing situational awareness



## Effect of Task on the Minimum Frame Rate

- Telerobotics presents more opportunities besides exploration
- We hypothesis that the minimum frame rate will change depending on the task a user is performing

## Effect of Multiple Users on Minimum Frame Rate

- Our original experiment had operators controlling the rover, top camera, and exploring
- Splitting processing and/or control between two users should increase efficiency with good communication



# Time to Discovery

Long tails at each frame rate indicate non-normal distribution

