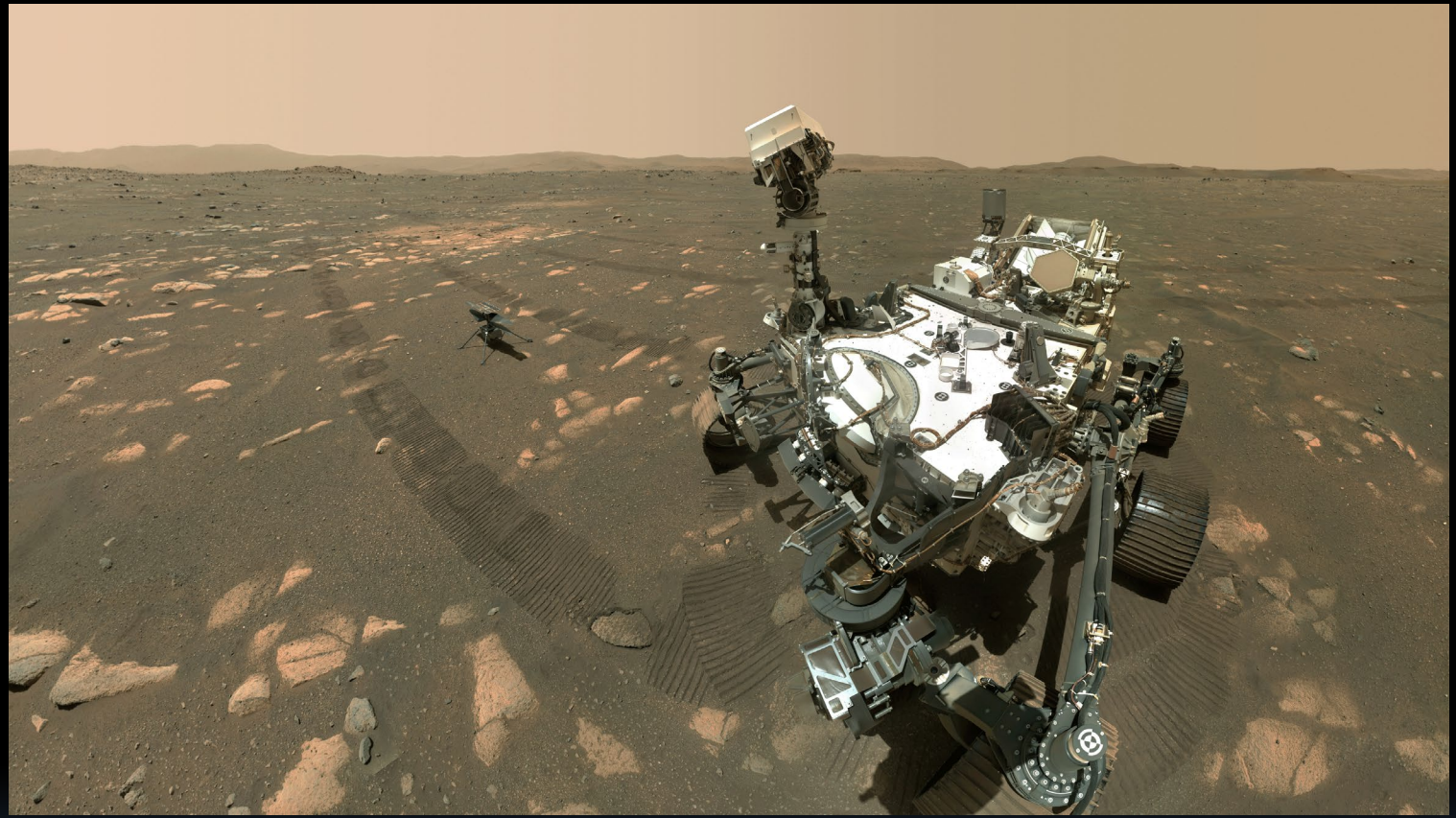
The Challenges of Operating Rovers and Helicopters on Mars

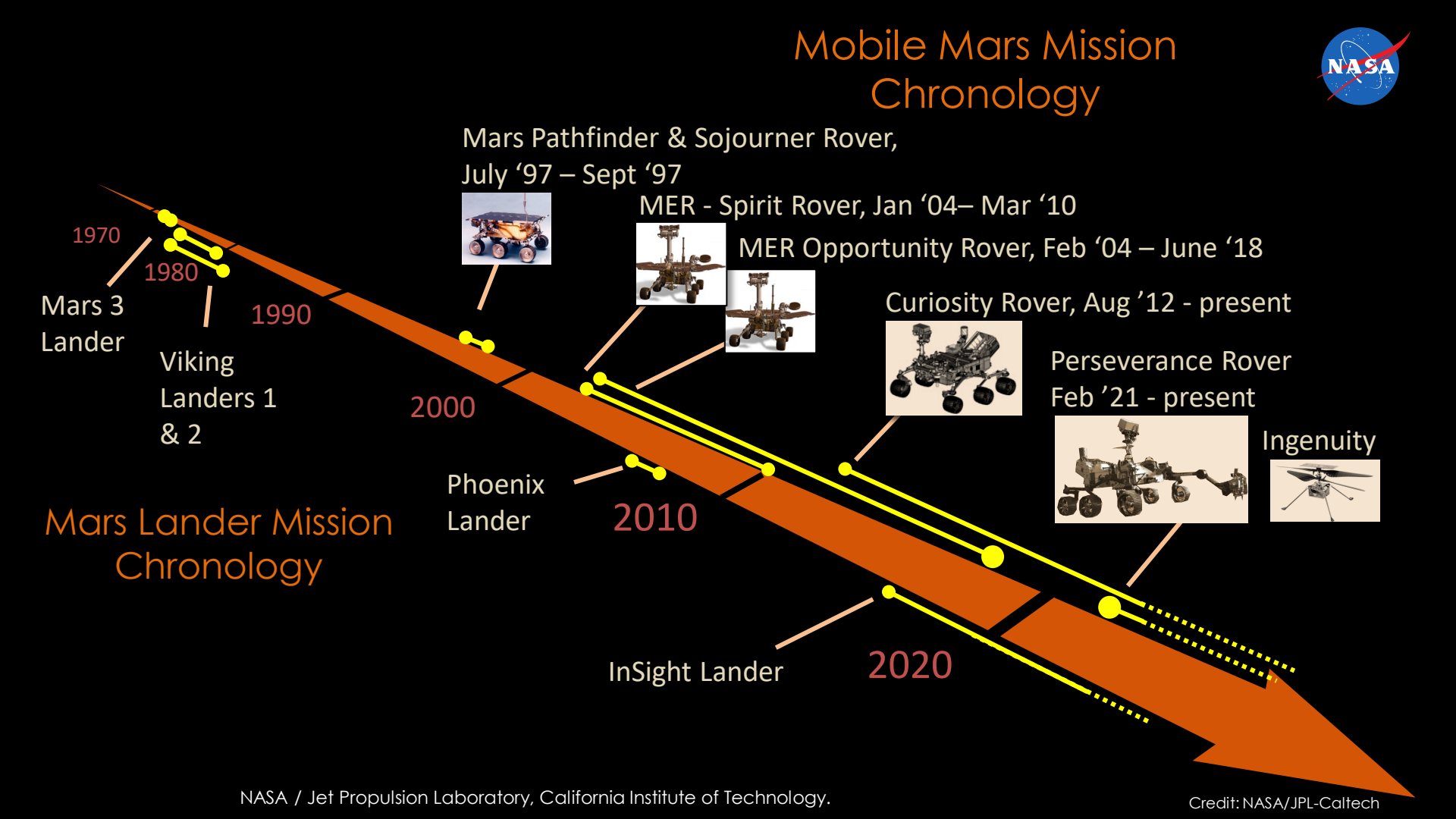


Rob Manning
NASA/JPL

Space Power Workshop
April 2021

Image courtesy NASA/JPL

Mobile Mars Mission Chronology



NASA / Jet Propulsion Laboratory, California Institute of Technology.

Credit: NASA/JPL-Caltech

Invasion of the Mars Rovers

Image courtesy NASA/JPL

Invasion of the Mars Rovers

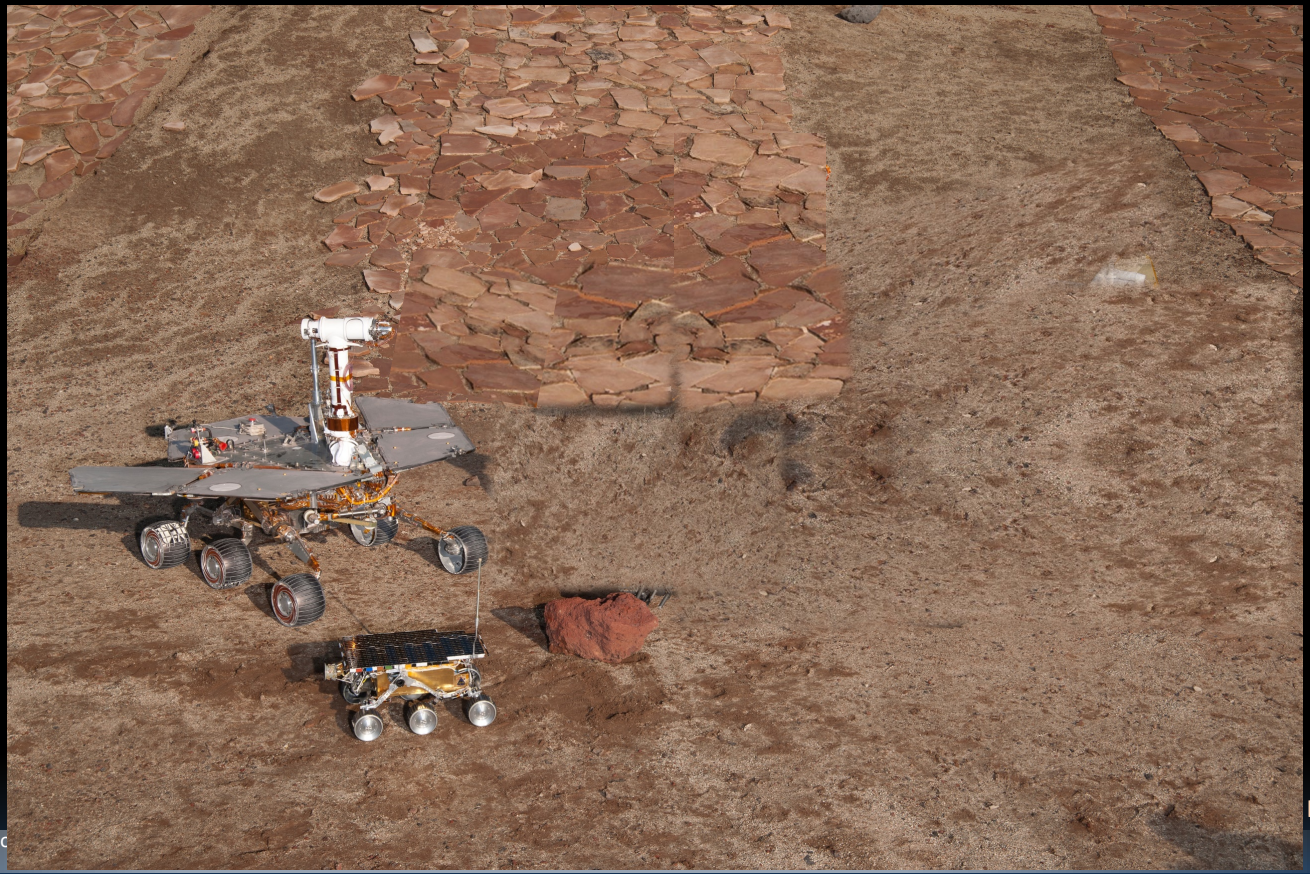
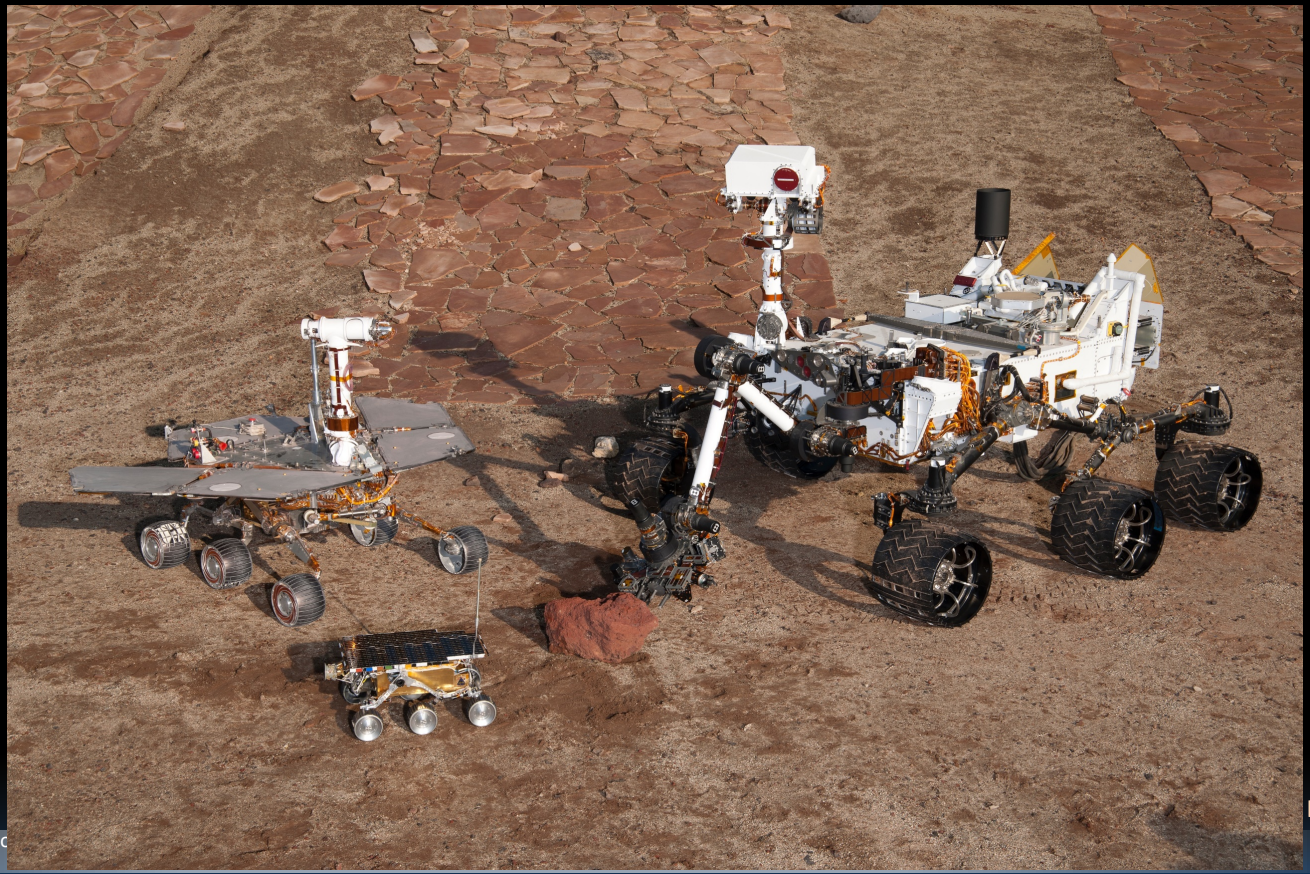


Image courtesy NASA/JPL

Invasion of the Mars Rovers



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Invasion of the Mars Rovers

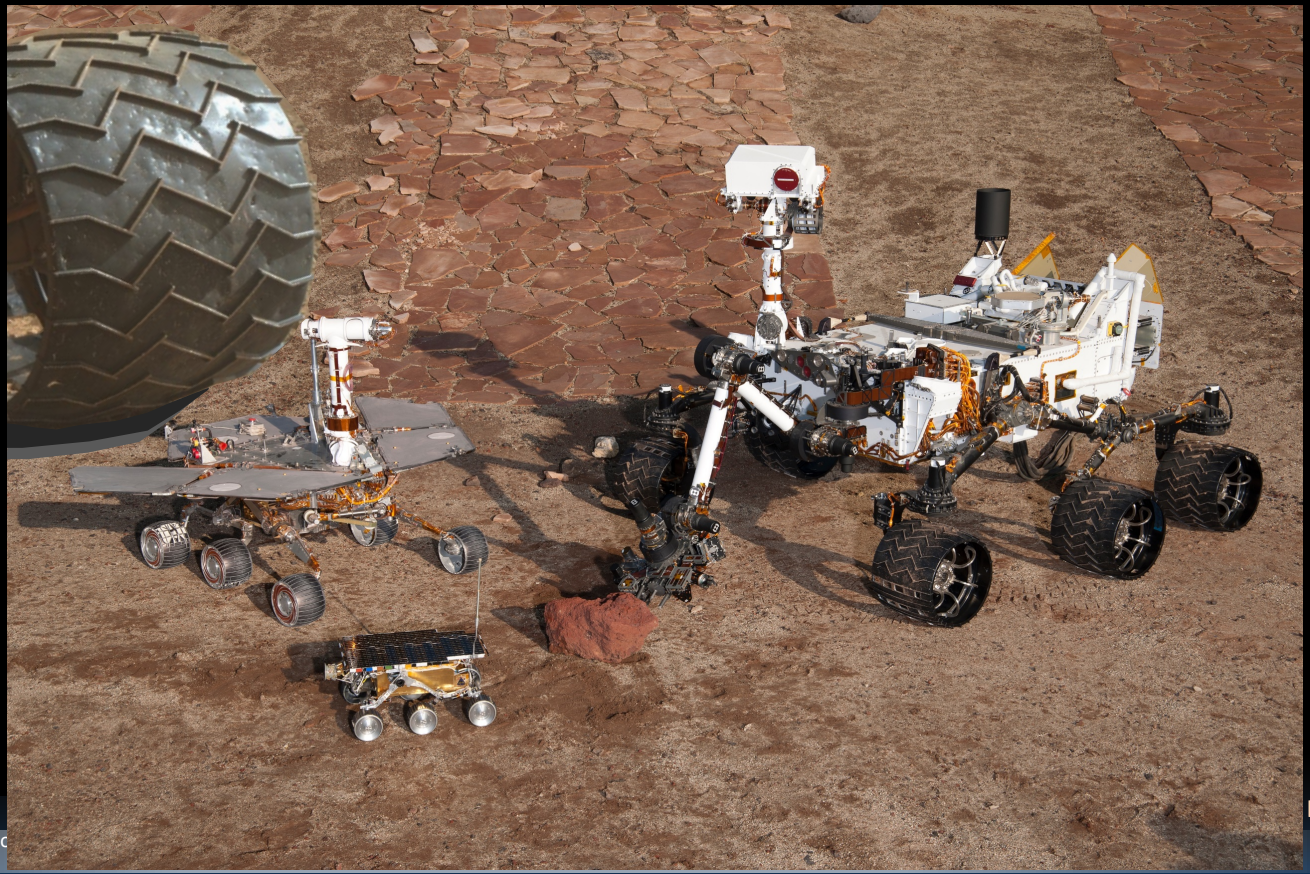


Image courtesy NASA/JPL

Invasion of the Mars ~~Rovers~~ Helicopters

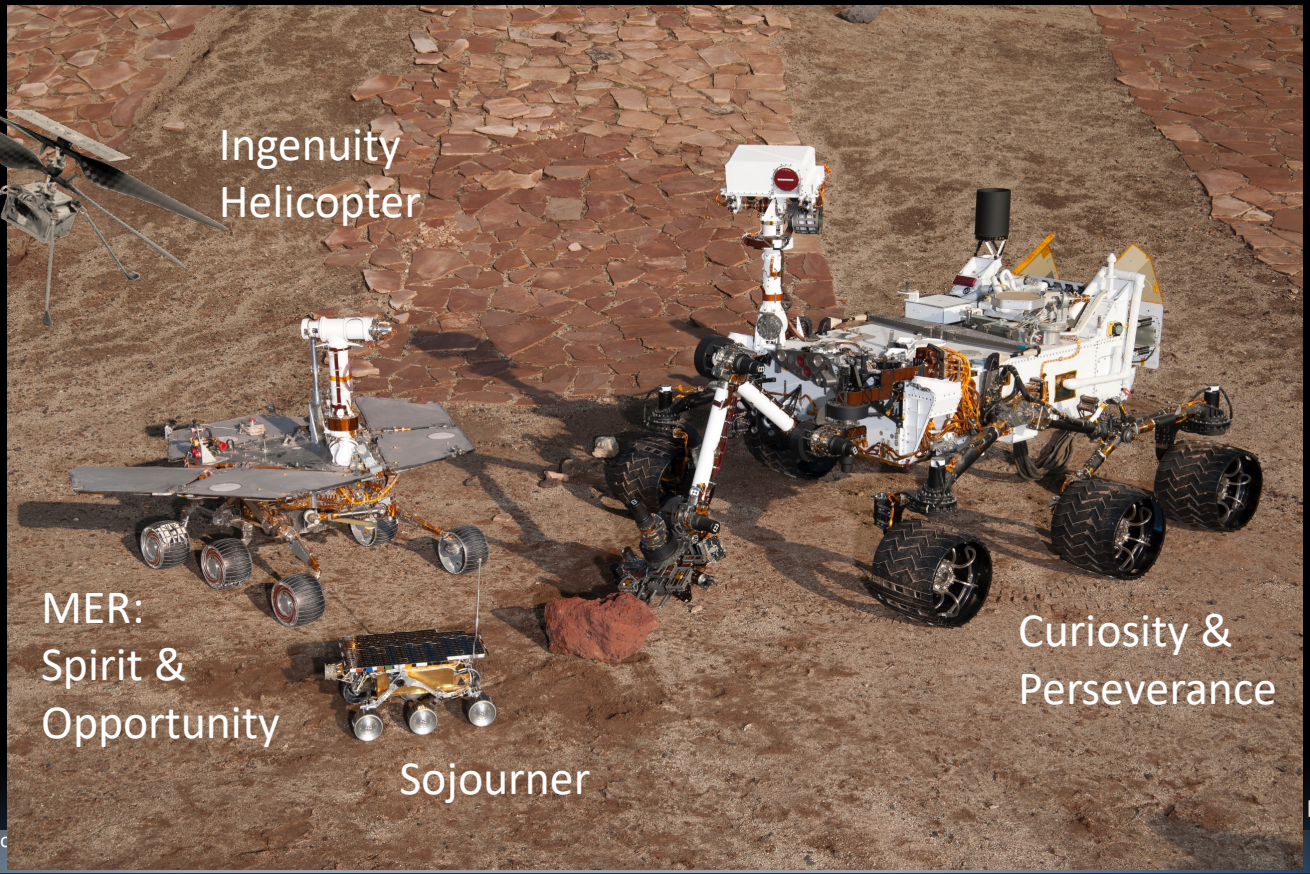


Image courtesy NASA/JPL

Mobile platforms have revolutionized Mars Science

- Ground truth of the >0.3 m scale orbital observations
- 0.5 m down to <1 mm scale investigations
  - soon to be <100 μm
- In situ analyses (e.g. geochemistry)
- Enhancing explorative discovery: able to trek from one geological unit to another.

Key Sensing Technologies for Autonomous Roving

- Sojourner
  - Stereo imaging of Structured Light → Hazard Avoidance → Object Detection & Approach
- MER → Curiosity → Mars 2020 & Ingenuity
  - Stereo vision → Hazard Avoidance → Path Planning → Visual Odometry → Target Tracking → Approach & Arm Placement → Hardware Acceleration

Other Rover Hobbies

- Flying to Mars
- Autonomously running “Entry Descent and Landing”
- Robotic arm sample manipulation
- Drilling
- Imaging, remote sensing
- In-situ surface sensing
- Sample laboratory operations
- Autonomous communication
- Power and Thermal control
- Many others

Persistent Mars Rover Challenges

1. Energy (& Energy efficiency)
2. Mass & volume
   - You need to fit inside a space capsule which needs to fit inside a rocket fairing.
3. Mars unique environment (diurnal & seasonal cycles, dust)
4. Inventing affordable technologies that can help challenges 1-3 above.

Energy Challenge

- You only have 2 options
  - Use what little there is there.
  - Bring your energy with you

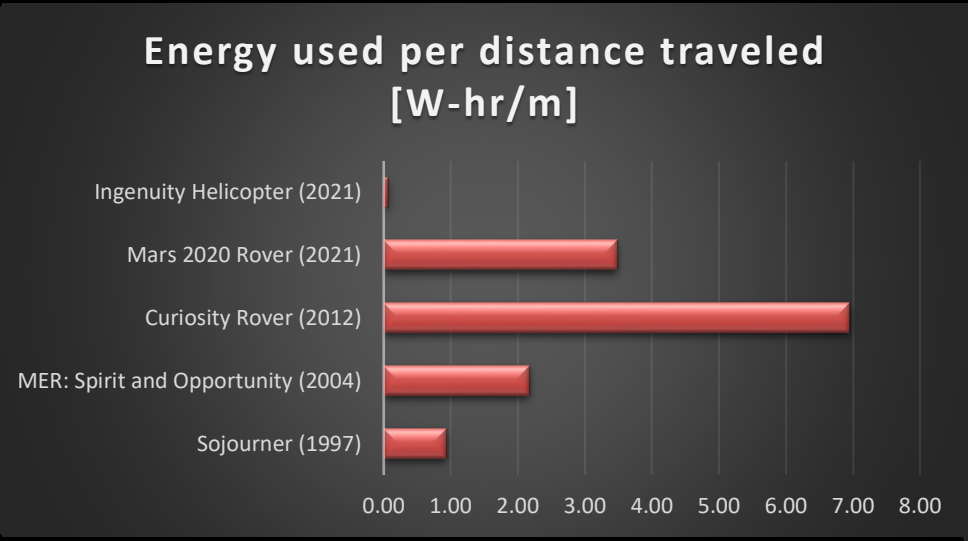
Use the energy available on Mars

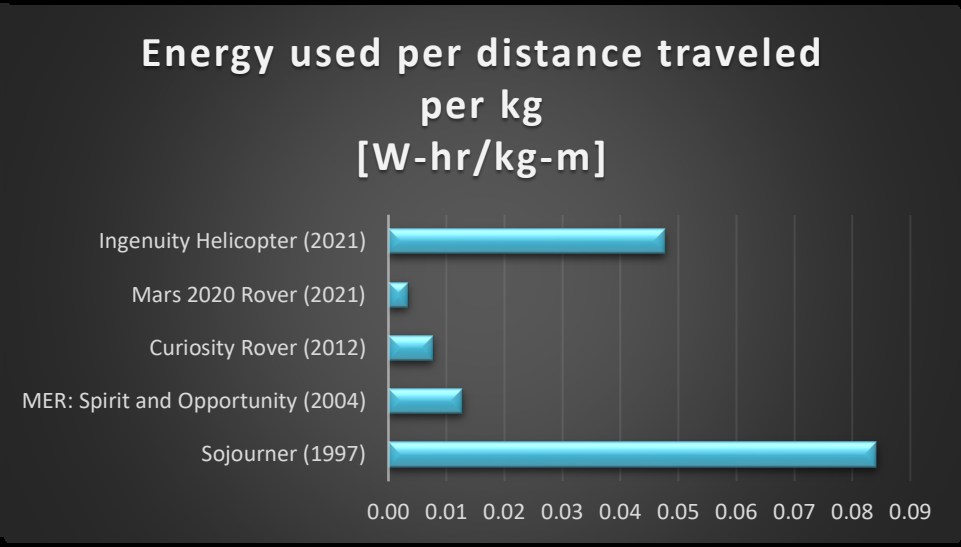
- In the future, we might be able to mine Mars … but right now you only have 1 option:
- Solar arrays
  - Solar arrays have been used on 3 out of 5 rovers so far.
- At 1.6 AU → 38% the solar incidence on earth → you need 2.6 x more array on Mars.
- The arrays on MER rovers produced about 300-700 W-hr of power per Mars day (Sol)
- Daily dust accumulation reduces the solar array power by about 0.25% every day.
  - You might get lucky with occasional wind-driven “dust cleaning events”
- Every 2 years or so there are dust storms.
  - You could try to clean off the dust with a dust removal tool but …
  - The sky can get pitch dark for weeks at a time (Opportunity Rover’s fate)
- Solar array technology advances for terrestrial applications will eventually go to Mars.

Bring your own energy

- Pre-charged batteries, fuel cells, reactors, and radioisotope generators.
  - Pre-charged batteries work, but don't carry enough energy to last months.
  - Fuel cells work well but are too large
  - Stirling radioisotope generators and reactor power for Mars are both are still years away
  - Right now, you only have one other option: MMRTG
- (Multi-Mission) Radioisotope Thermoelectric Generators (MMRTGs).
  - Many small thermocouples sandwiched between hot Plutonium dioxide and the cold air of Mars.
  - The MMRTG on Curiosity and Mars 2020 produces roughly 100 W of electrical power (producing about 2500 W-hr of power per sol)
  - In addition, 2000 W of waste heat can be captured in a fluid loop and pumped around inside the rover to keep it warm.
  - No worries about dust storms!!
- But note that MMRTGs are few and relatively expensive.

Locomotion Energy

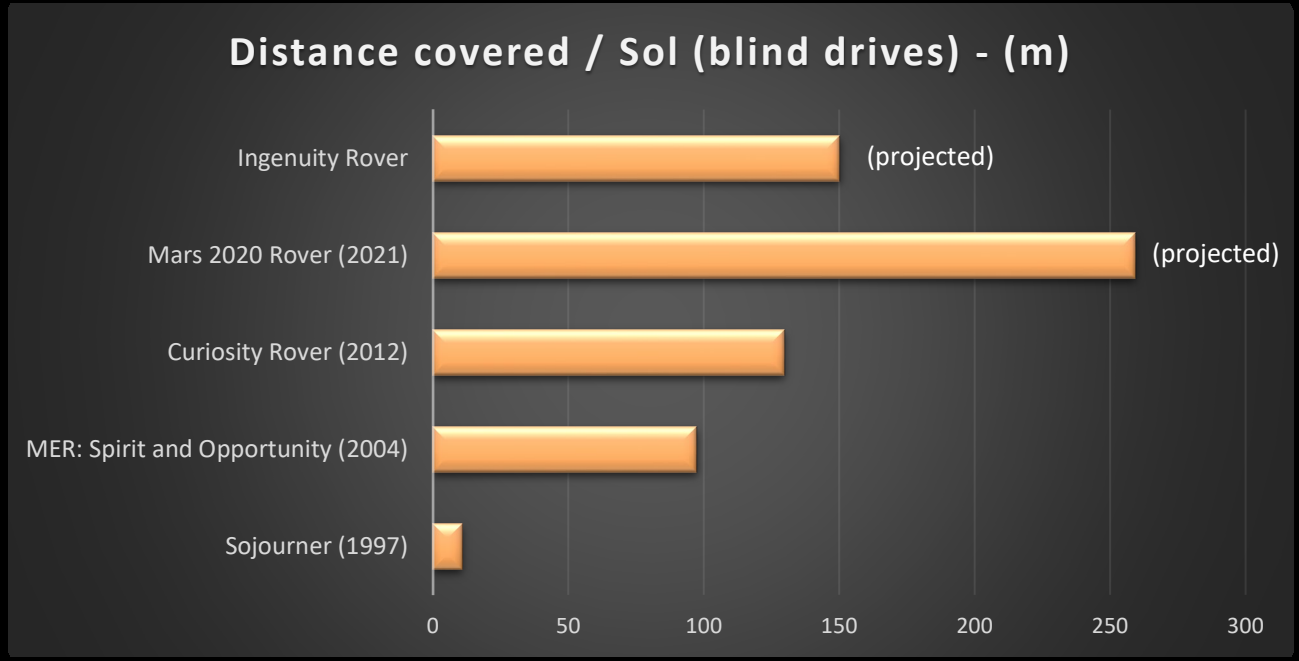




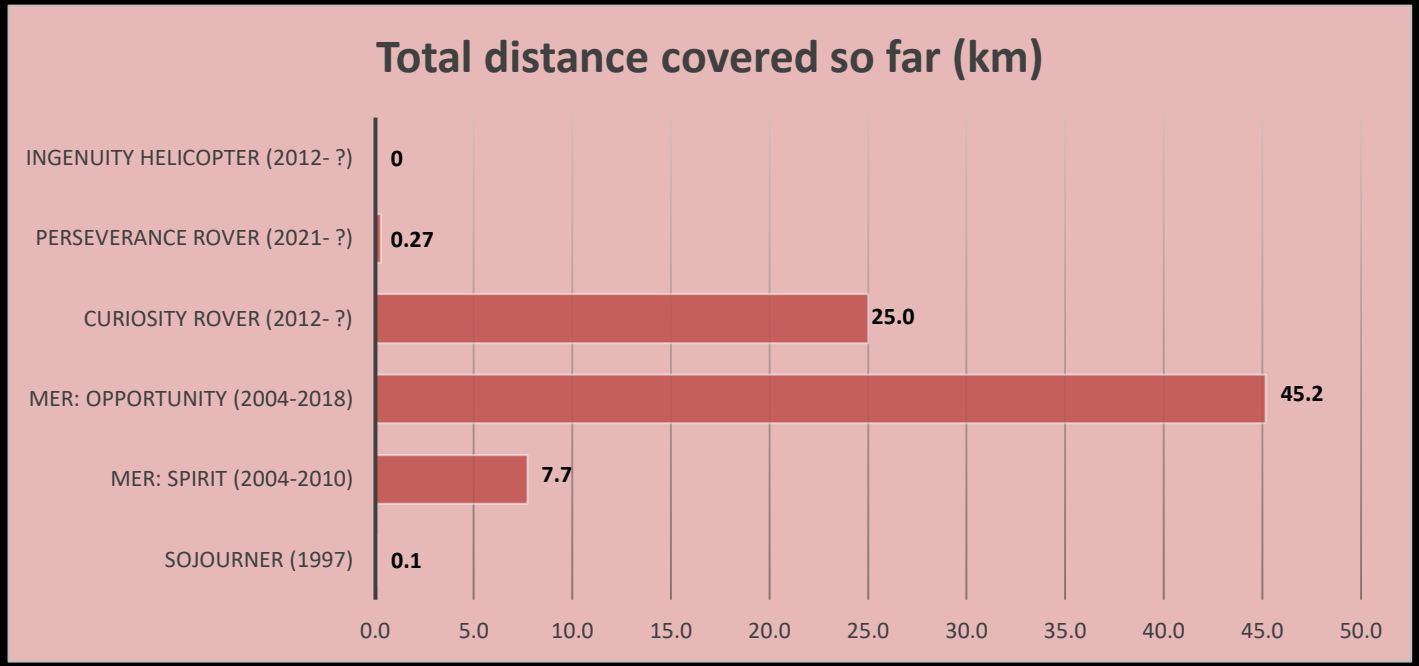
Be energy efficient

- Don’t hurry your science.
  - 100 m per sol is a big drive. What if you missed something?
- Sleep a lot.
  - All of our rovers spend about 18 or more hours of the 24.4 hrs/Sol sleeping (mostly off and quiet).
  - The helicopter sleeps at least 22 hrs / sol (90% of the time)

Distance traveled per “Drive Sol”



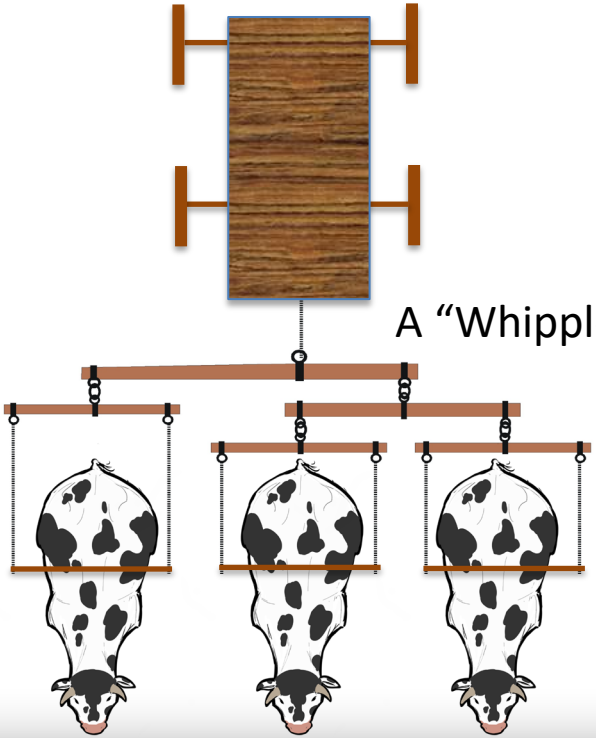
Total Distance Traveled (so far)



More energy efficiency

- Put your precious stuff inside a thermos bottle
  - Every lost watt to entropy is precious.
- Put every extra watt into re-chargeable batteries for a later day.
- Use a passive articulated mobility suspension system
  - Every Mars rover so far has used the “Rocker-Bogie” articulated suspension system developed by Donald Bickler in ‘88 and first used on Sojourner.

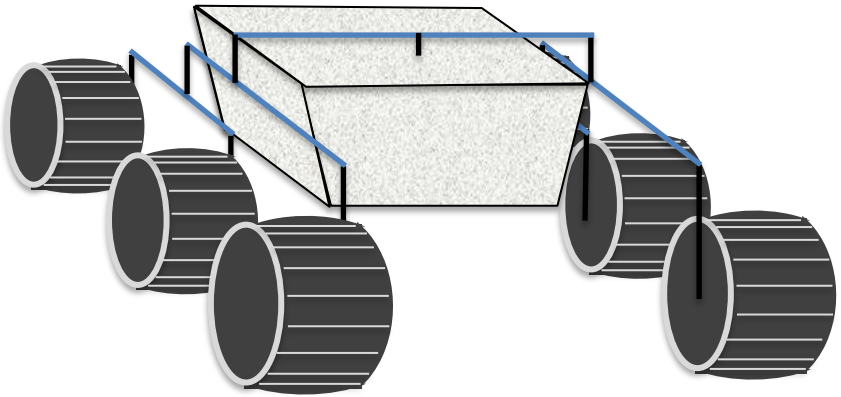
Energy-efficient mobility suspension



A “Whipple tree”

A Mobile Sculpture

A mobile mobile (simplified)



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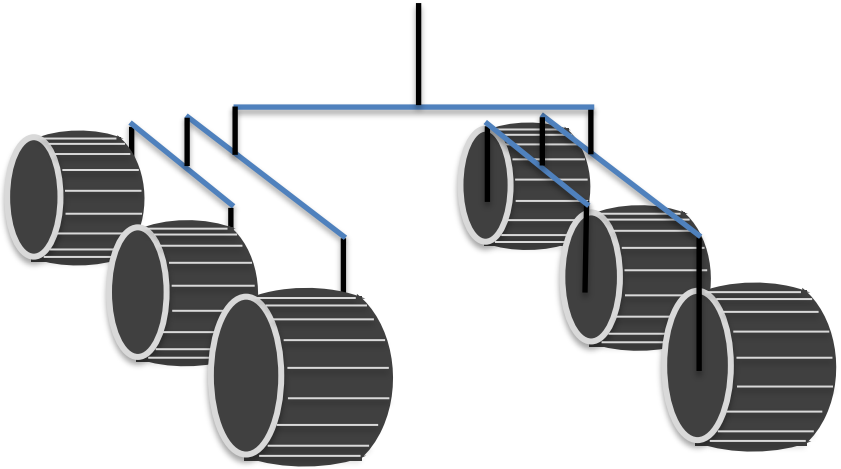

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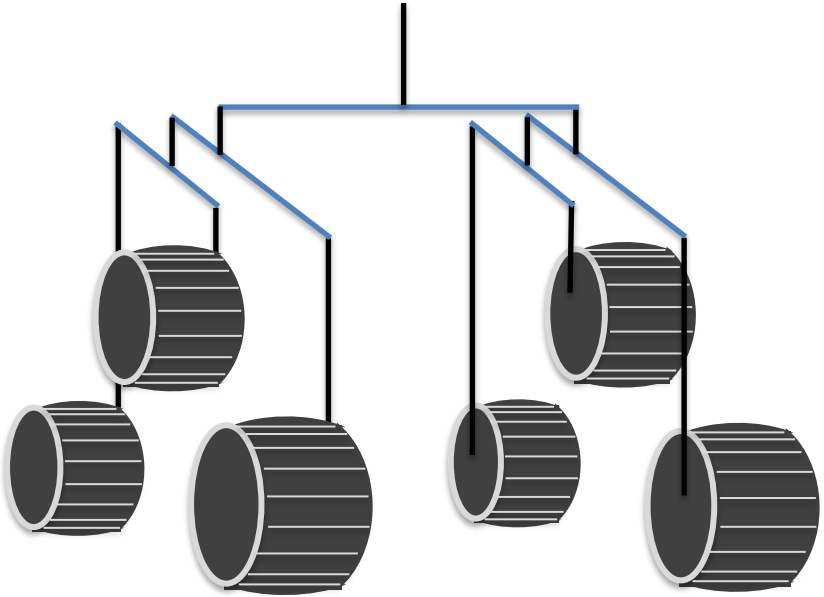

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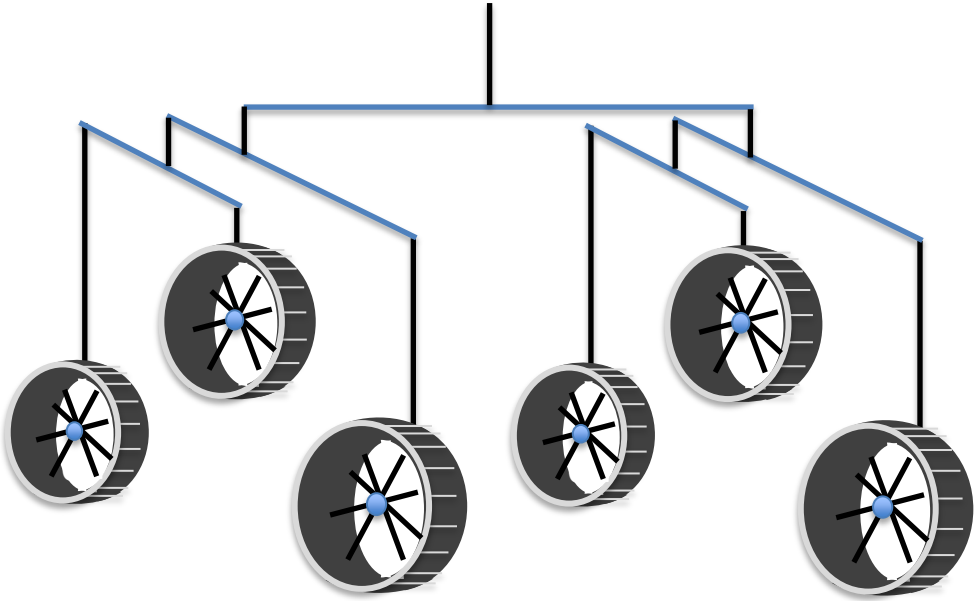

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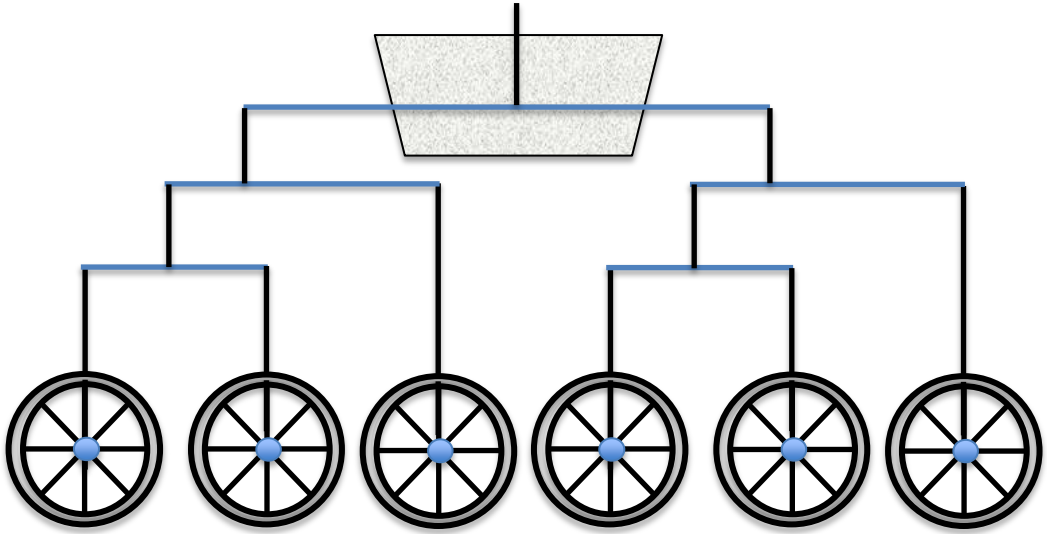

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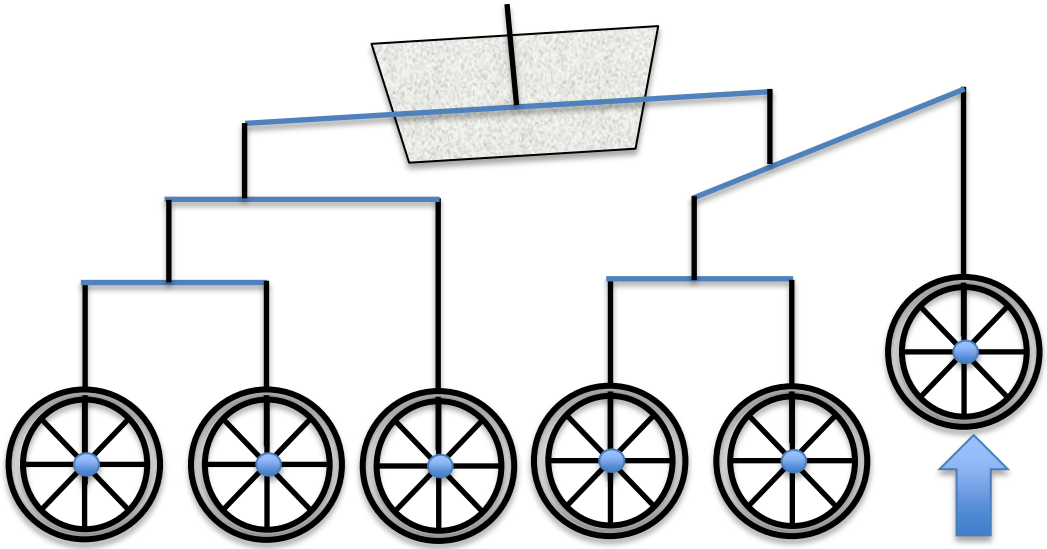

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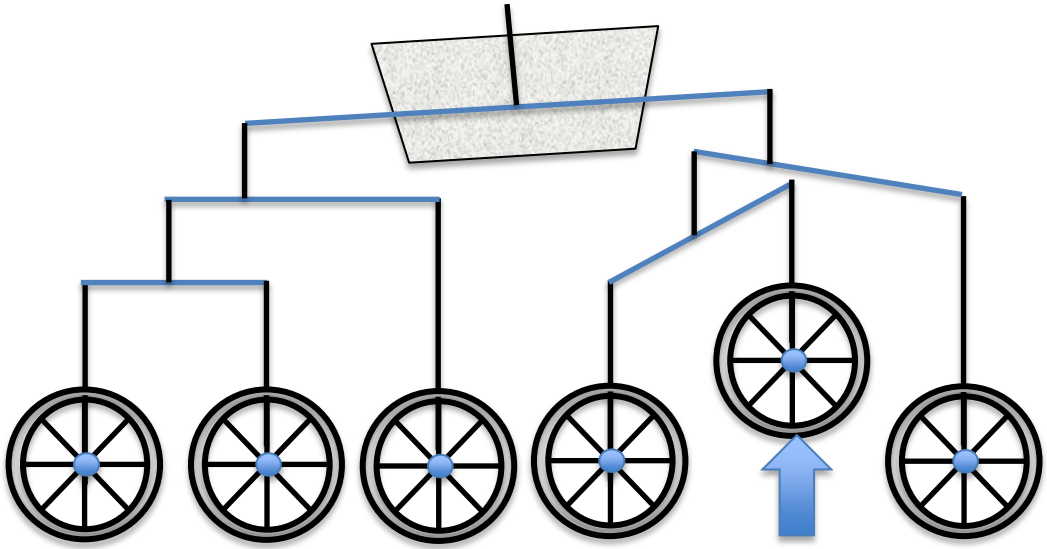

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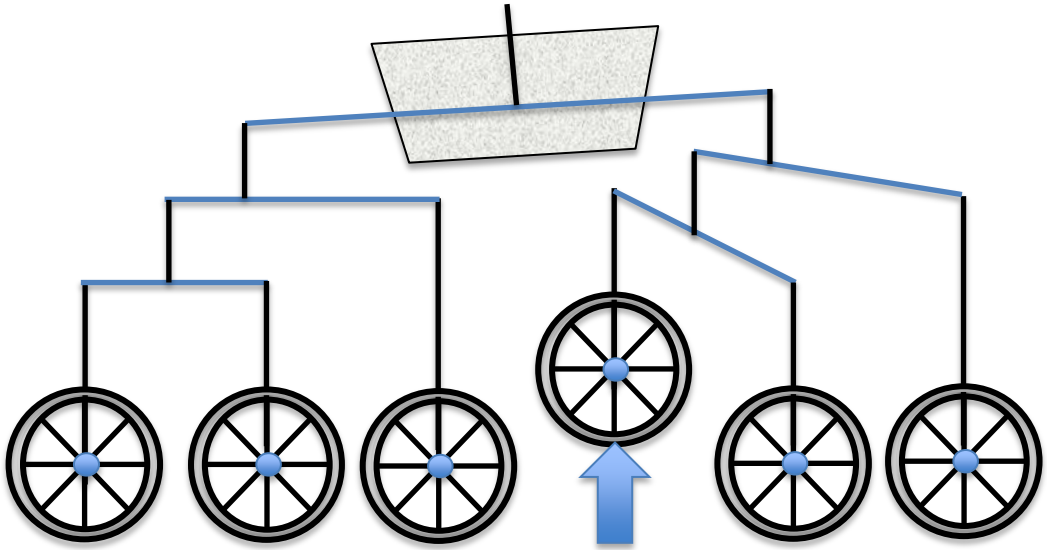

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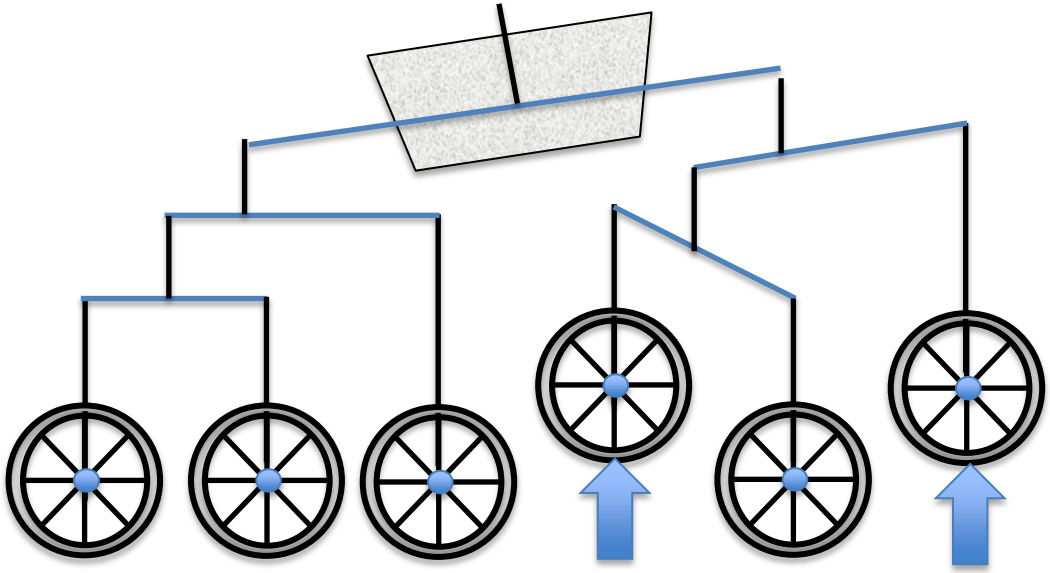
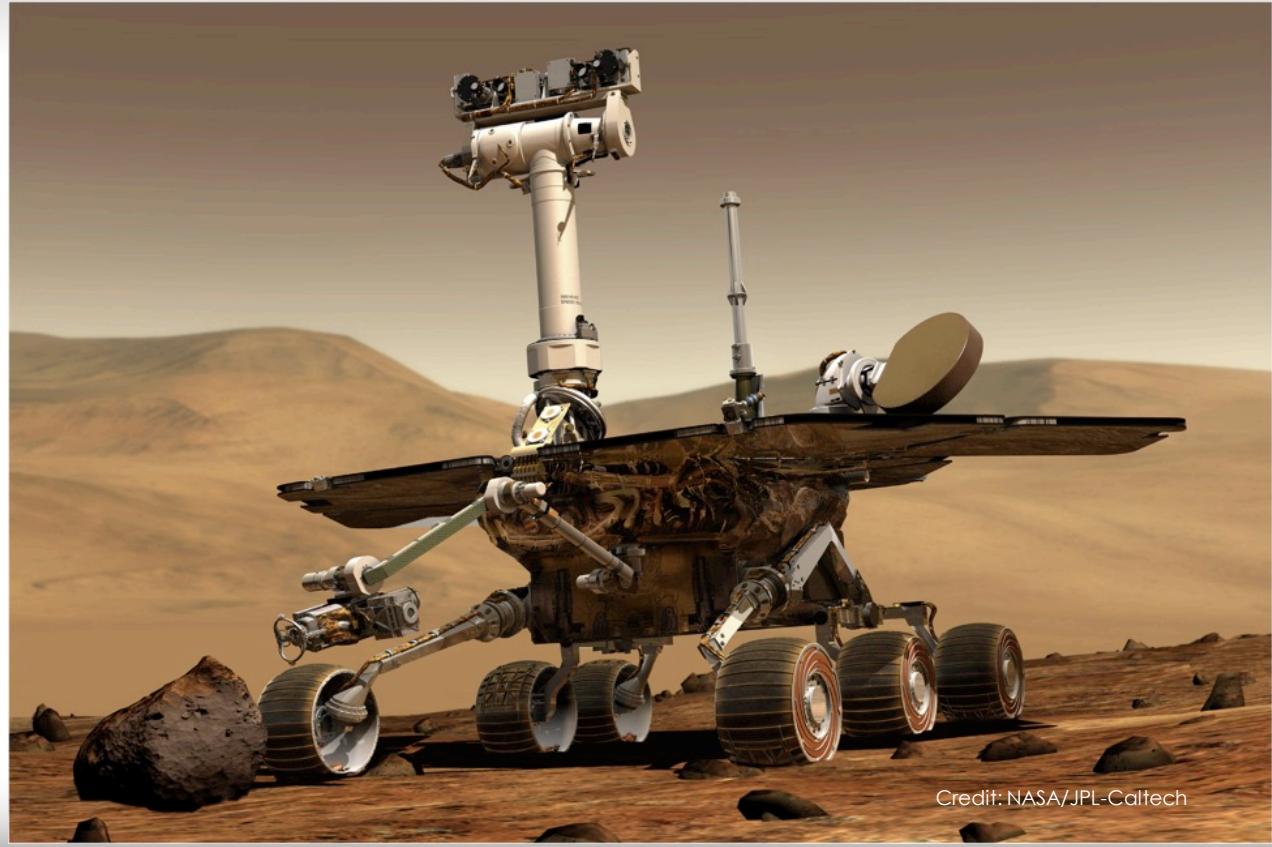


Sojourner 1997

- Learned how to operate a rover

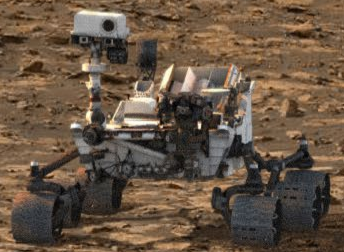
Spirit and Opportunity Rovers 2004-2010 & 2004-2018

- We learned how to be remote geologists.



Curiosity Rover 2012 - present

- We've learned how to be remote mobile geochemists.

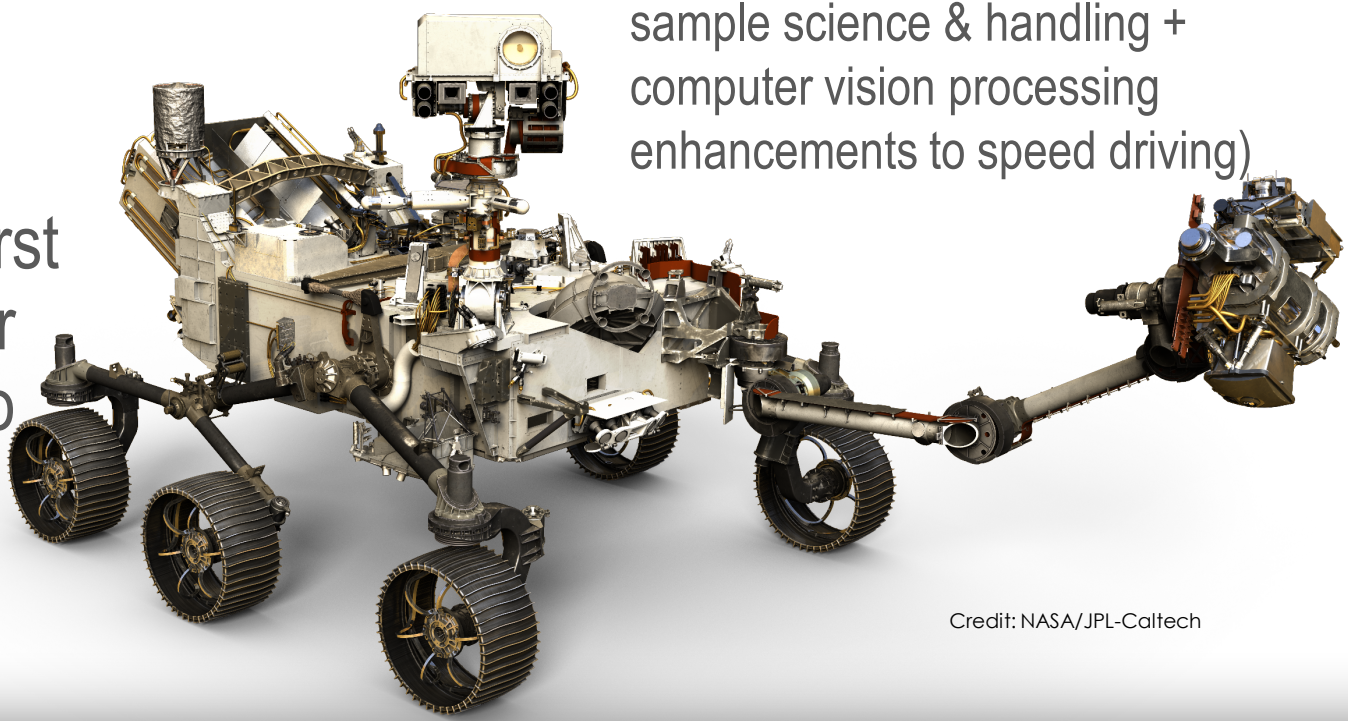


Credit: NASA/JPL-Caltech/*Ken Kremer*

Mars 2020 Rover 2021 - ?

- We hope to see at finer scales than ever before
- We hope to core and collect our first Mars samples for possible return to Earth

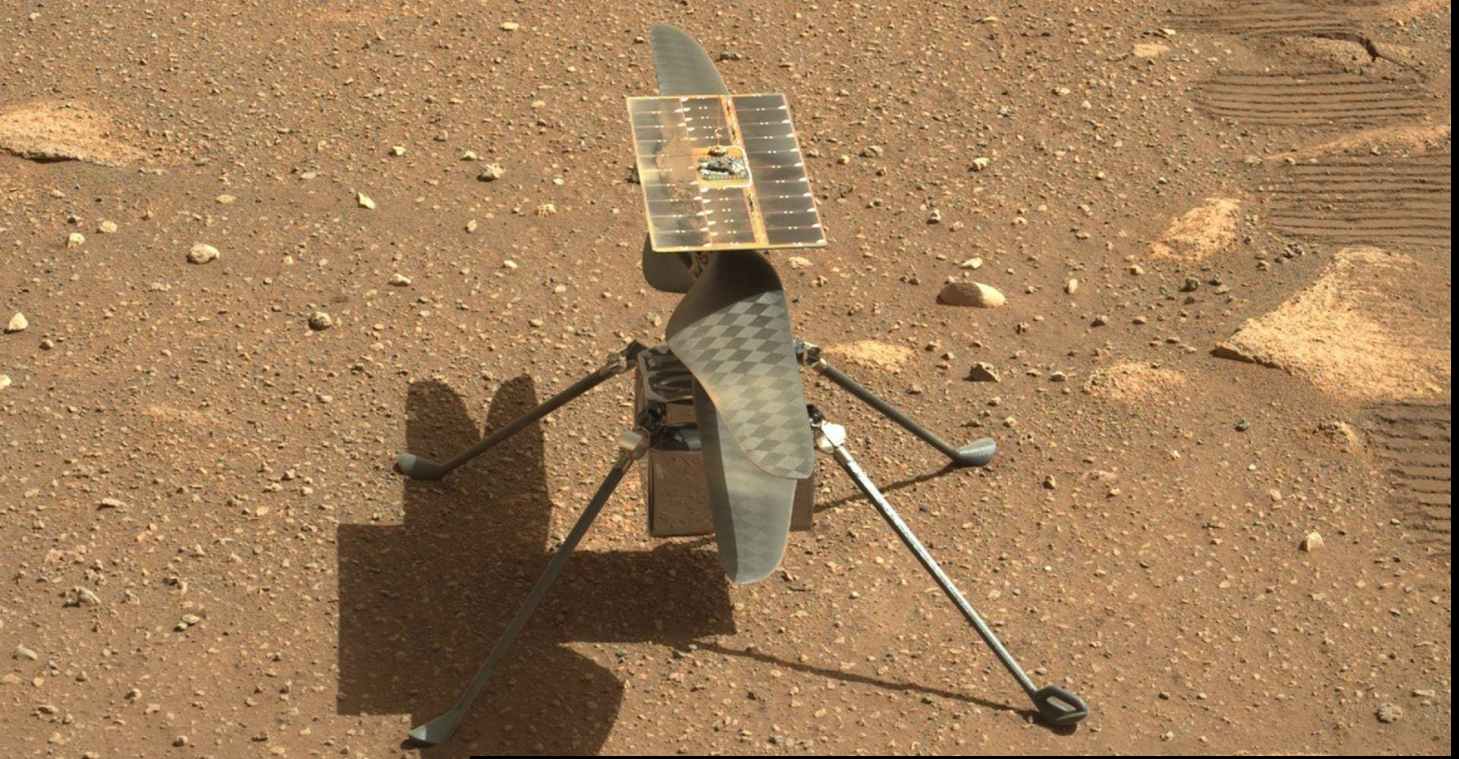
(Essentially Curiosity Rover + sample science & handling + computer vision processing enhancements to speed driving)

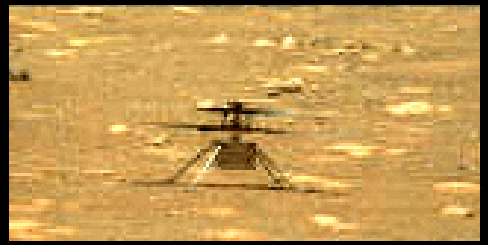


Credit: NASA/JPL-Caltech

Ingenuity Helicopter

- 1.4 kg
- 2,700 rpm
- 3 min flights
- 3- 5 flights





Credit: NASA/JPL-Caltech

What's next?

- Can we build a rover that can efficiently traverse 100's of km?
  - We need faster computers and more powerful sensors (e.g. Lidar) that require more power. Where will we get it?
    - Use "Cheetah mode": race far and fast, then sleep for days?
- What about better instrumentation?
  - E.g. In Situ isotopic analysis for age dating.
- What about better mobility?
  - E.g. Access to steep slopes & cliff's
- What about drone explorers like Ingenuity?
  - Helicopter needs to become "untethered" to lander/rover with its own radio to orbiters

- These are the next frontier.

Thank you