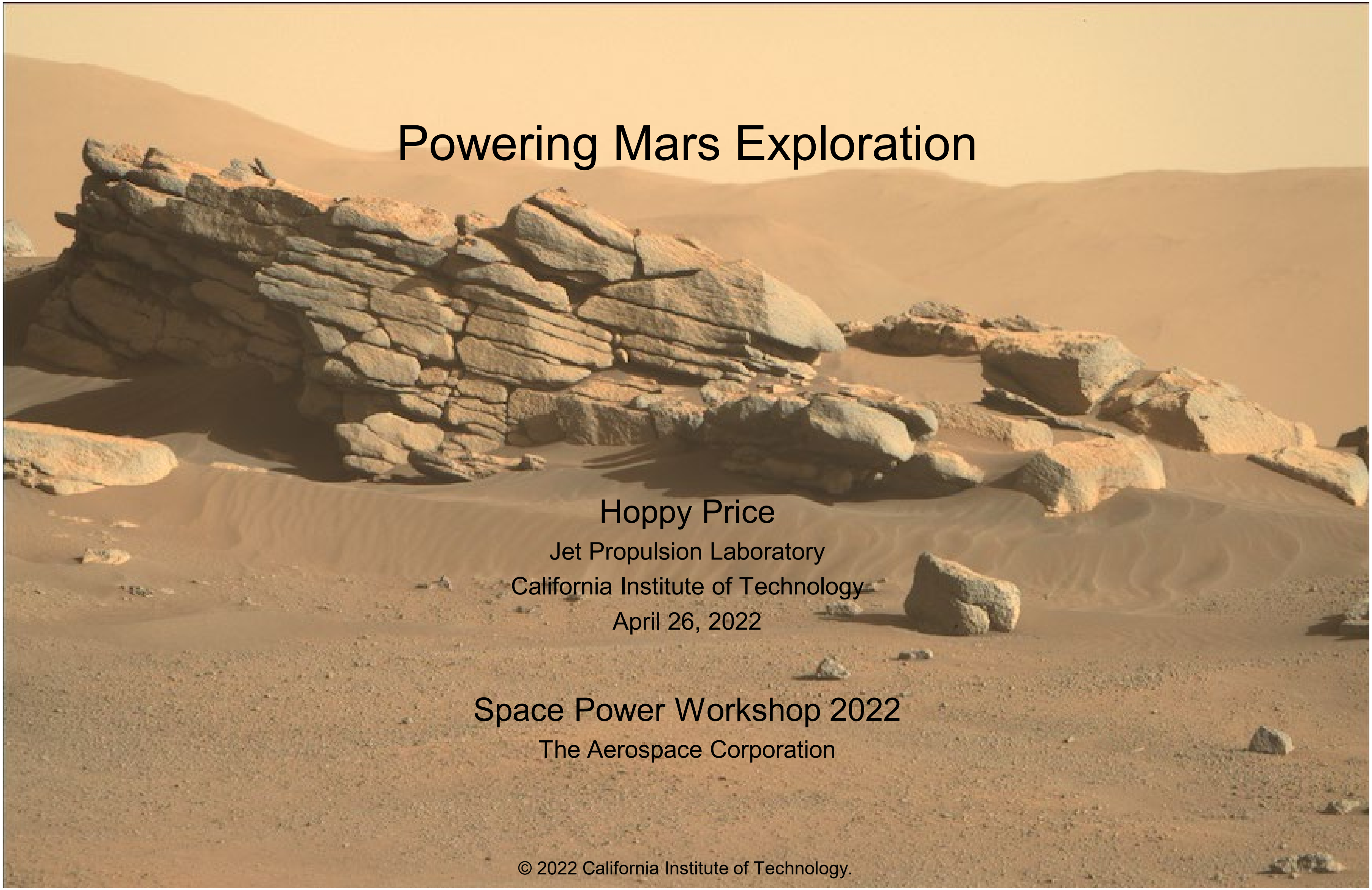

Powering Mars Exploration

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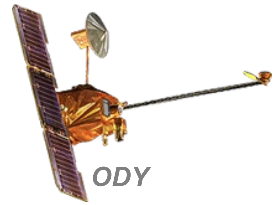
April 26, 2022

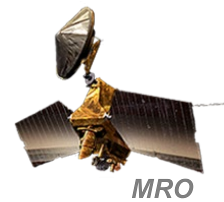
Space Power Workshop 2022

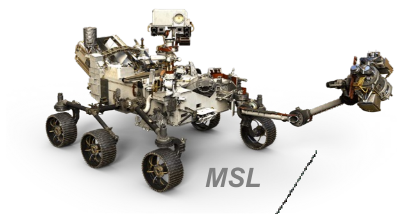
The Aerospace Corporation

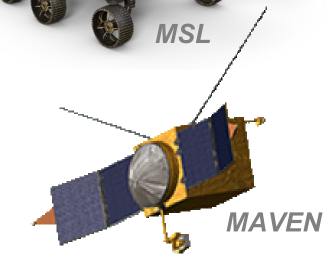
Current Operating Mars Missions

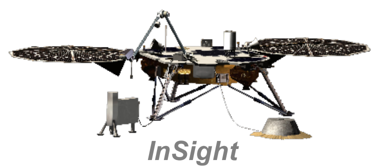
- Mars Odyssey - 2001
- Mars Reconnaissance Orbiter - 2005
- Mars Science Laboratory (Curiosity) - 2011
- Mars Atmosphere and Volatile EvolutioN (MAVEN) - 2013
- Mars InSight - 2018
- Mars 2020 (Perseverance and Ingenuity) - 2020
- Non-U.S. missions
  - ESA: Mars Express (2003)
  - ESA: Trace Gas Orbiter (2016)
  - China: Tianwen 1 orbiter and Zhurong rover (2020)
  - India: Mars Orbiter Mission (2013)
  - UAE: Hope orbiter (2020)

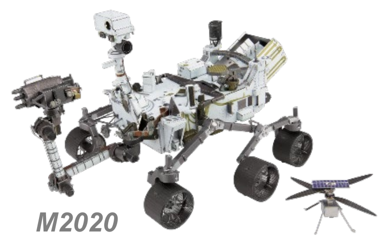










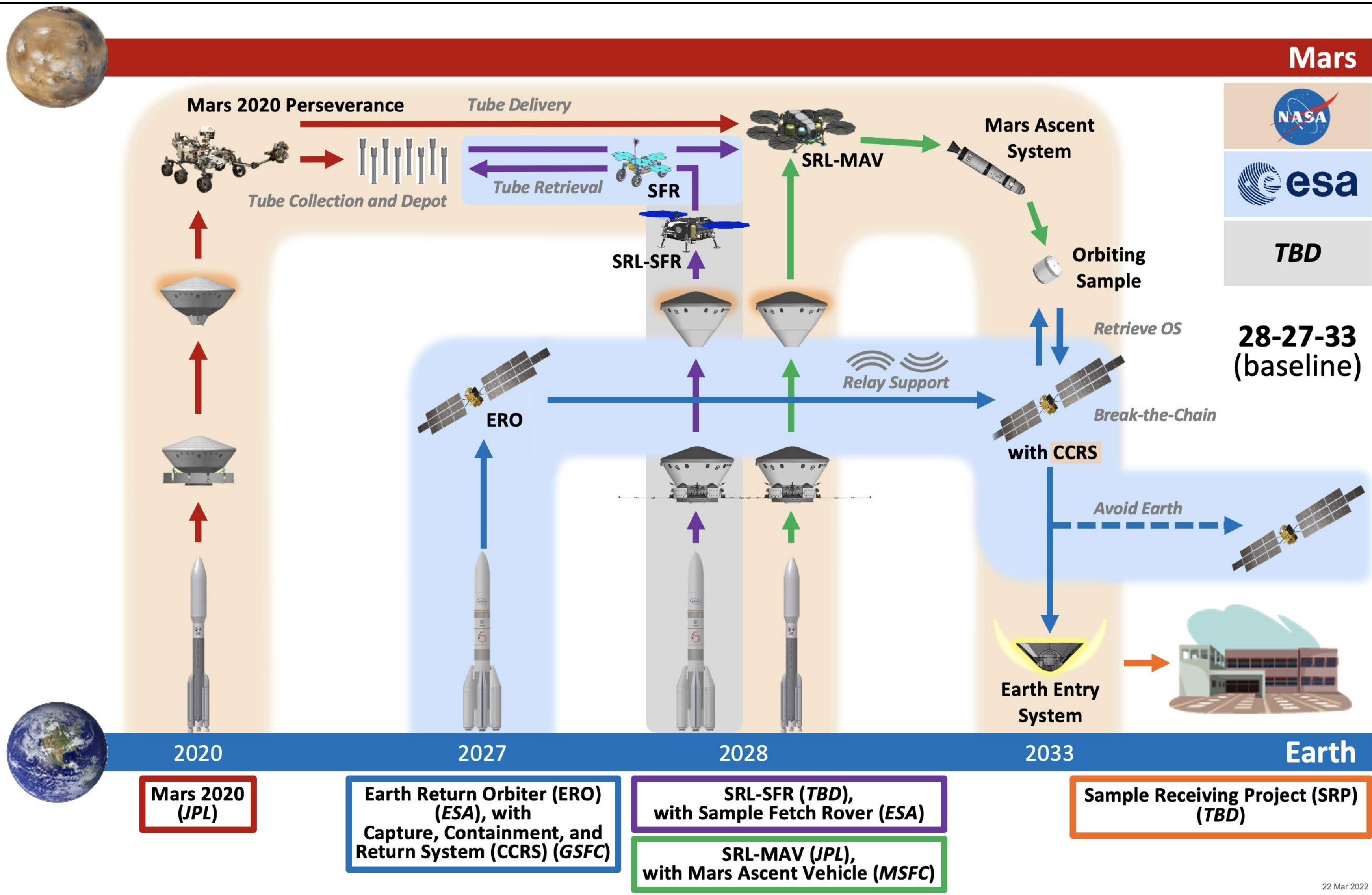


Mars 2020 Mission Progress

Mars Program

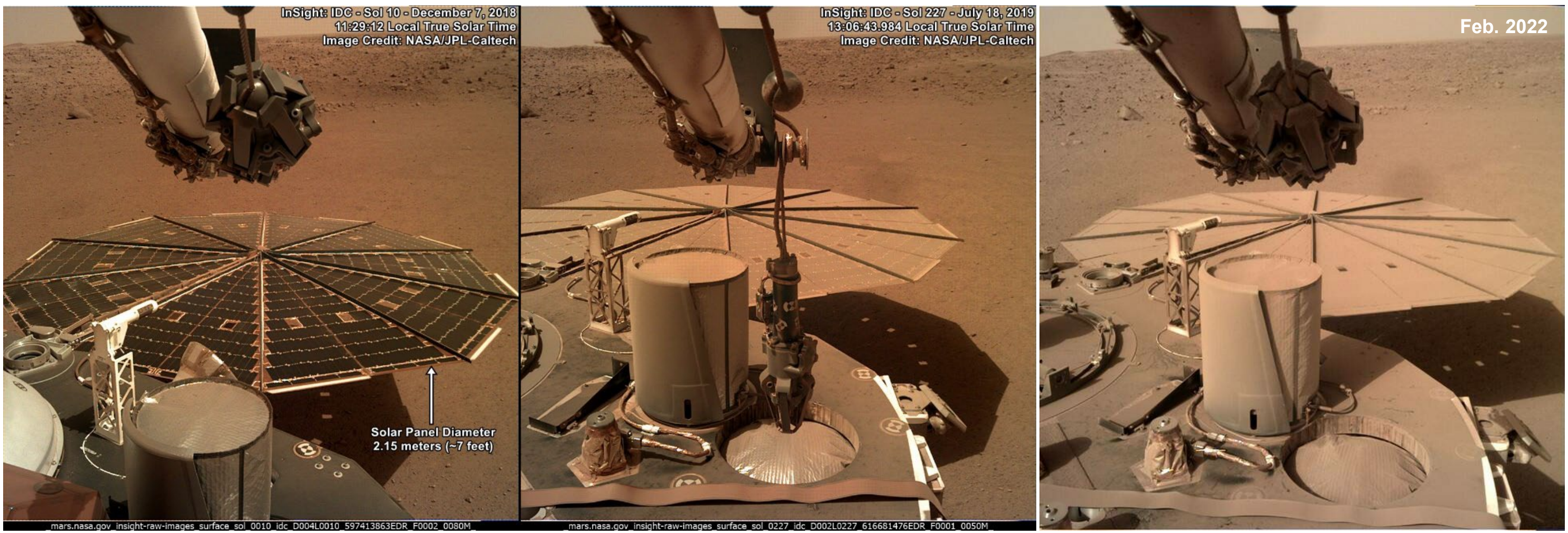
- Perseverance Rover has traveled ~10.5 km and taken 8 rock core samples which may be returned to Earth in 2033
- Ingenuity Helicopter has flown ~6.2 km in 26 flights

Mars Sample Return Planning



Power Issues for Mars

- Solar array dust deposition
  - Spirit and Opportunity had lucky wind cleaning events
    - Opportunity survived for 14 Earth years
  - InSight has not been so lucky
- Limited power, high cost, and limited availability of RTGs
- Surviving the cold Martian nights (RHUs can help)



Future Robotic and Human Missions

Mars Program

- Artemis surface systems as pathfinders for Mars missions
  - Crewed ascent vehicles: typically ~ 5 kWe
  - Surface habitats: typically ~ 15 kWe
  - Crewed rovers, pressurized and unpressurized
    - Current concepts use solar power and batteries, but fuel cells or multi-kW radioisotope (~5 kWe) systems could have significant advantages
  - Drilling systems: multi-kilowatt, probably robotic
  - In Situ Resource Utilization (ISRU), probably robotic
    - Multi-megawatt power systems (e.g. fission)
  - Lunar surface periods of darkness are extremely challenging, typically ~ 3 days duration at the poles and 14 days for non-polar (very cold)

- Mars missions
  - Similar systems and power requirements as Artemis, except that periods in darkness are limited to ~12 hours, except during dust storms
  - Surface missions longer than ~6 months need to deal with dust storms and dust deposition
  - Larger helicopters have mass and energy challenges

Future Power Challenges

Mars Program

- Surface fission power systems would have great utility for Moon and Mars
  - High power nuclear fission could enable deep drilling operations and ISRU systems
  - Shielding, placement, and power transmission over distance are issues
- Higher efficiency solar arrays (possibly restowable) and higher density energy storage could be enabling for larger helicopters
- Solar array cleaning technologies could enable long-duration non-nuclear Mars surface power for all applications
- High efficiency dynamic conversion radioisotope power systems could be attractive options for surface habitats and crewed rovers (~5 kWe units)
  - Could also serve as reliable backup for outages of other power systems
- More affordable and more available radioisotope power could provide better options for future Mars surface systems (e.g. polar missions, cave explorers)
  - Sr 90 heat sources could be an enabling option for some applications:

		Pros	Cons
Might be optimal for crewed surface missions and rovers	**Sr 90**	Greater availability	~75% heavier than Pu 238 RTG
		Lower cost	Shorter half-life (29 vs. 88 years)
		No neutron emissions	Requires more shielding (β vs. α)
			Requires new design and qualification
Probably optimal for robotic planetary missions	**Pu 238**	Lower mass and volume	Limited availability
		Longer half-life (88 vs. 29 years)	High cost
		Easier to shield (α vs. β)	Some neutron emissions

Parting Thoughts

- Future Mars missions, both robotic and human, have power challenges
  - New systems and technologies need to be developed and qualified (e.g. solar array cleaning)
- Human surface missions probably need more than one type of power source
  - For functional redundancy in addition to block redundancy
  - Power sources will likely be phased over time, with later missions needing higher and longer-term power
  - Mobile systems will likely require different power sources than stationary systems
- Identify backup and descope options, in the event some of the new power technologies encounter development issues
- Keep looking at alternative options (e.g. Sr 90)