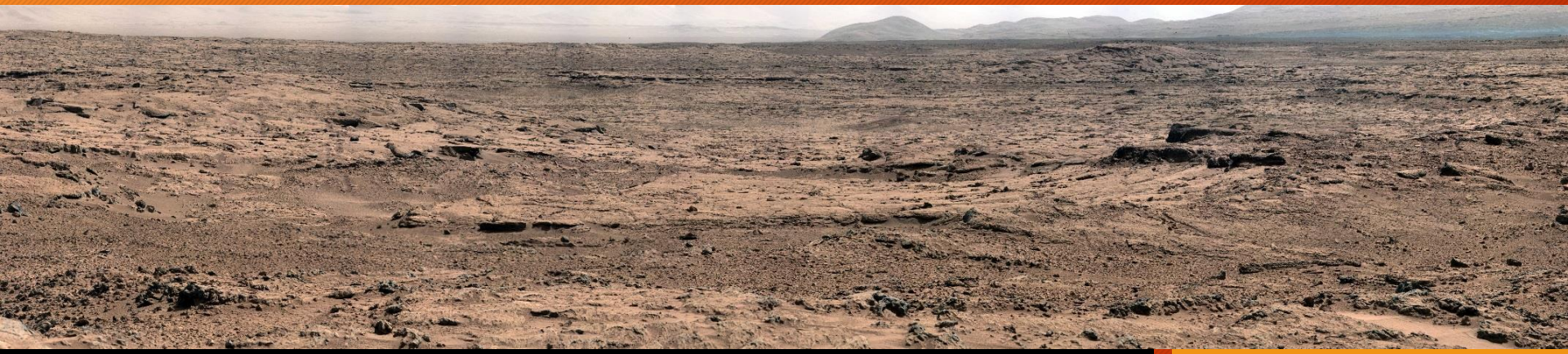

Dust Storm Impacts
on Human Mars Mission Equipment and Operations

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Dust In the Atmosphere of Mars
Houston, June 13-15, 2017

Mars Isn't Your Daddy's Surface Exploration Mission

- **Apollo spacecraft were one-time use, each landing at a different site**
  - NASA is looking at multiple missions to a single landing site
- **Apollo missions were about a week long**
  - Mars mission will start *at least* two years before the crew even launches from Earth, when cargo is pre-deployed to Mars
  - Mars surface equipment life may be 10+ years of active use
- **Apollo crews only ventured a few km from Lander**
  - NASA is looking at Mars surface scenarios where crews may take "camping trips" hundreds of kilometers from a landing site
- **Apollo didn't worry about forward contamination**
  - If we're searching for life on Mars, we have to be more careful

Surface Mission By the Numbers

No firm decisions have been made
But this is the current thinking

Multiple visits to a single landing site

Economics are better if we re-use assets, rather than abandon them

Notional crew excursion radius from landing zone

- Goal is to extend as far as possible
- Robotic assets may rove even further

~500

Days maximum surface stay for any given mission

- Driven by orbital mechanics
- Short (<30 day) stays have been considered, but don't save $

Twenty Six

Months between mission opportunities

Conjunction class missions

Number of crew to the surface for any given mission

Studies have assessed 2 to 6 crew per mission

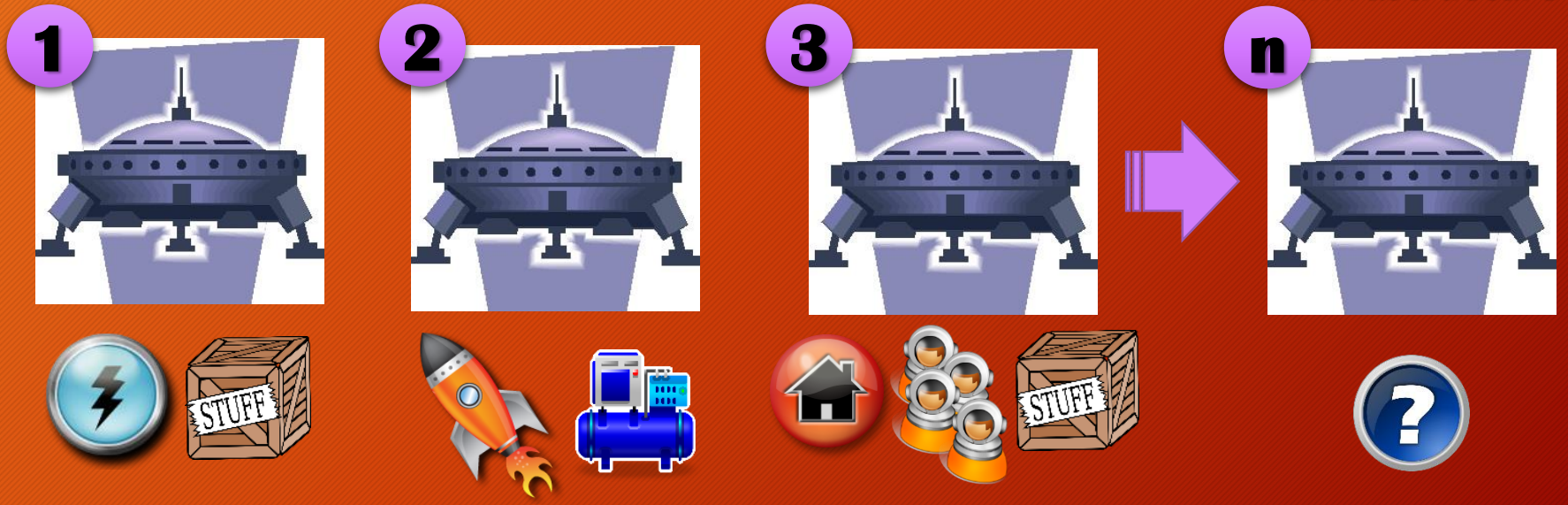
Here's What a Mars Campaign *Might* Look Like

FIRST we send cargo, including a surface power system

THEN we send an Ascent Vehicle and ISRU to fill its empty tanks

WHEN the tanks are full, crew lands and begins surface mission

SUBSEQUENT crews land at the same site and use existing infrastructure

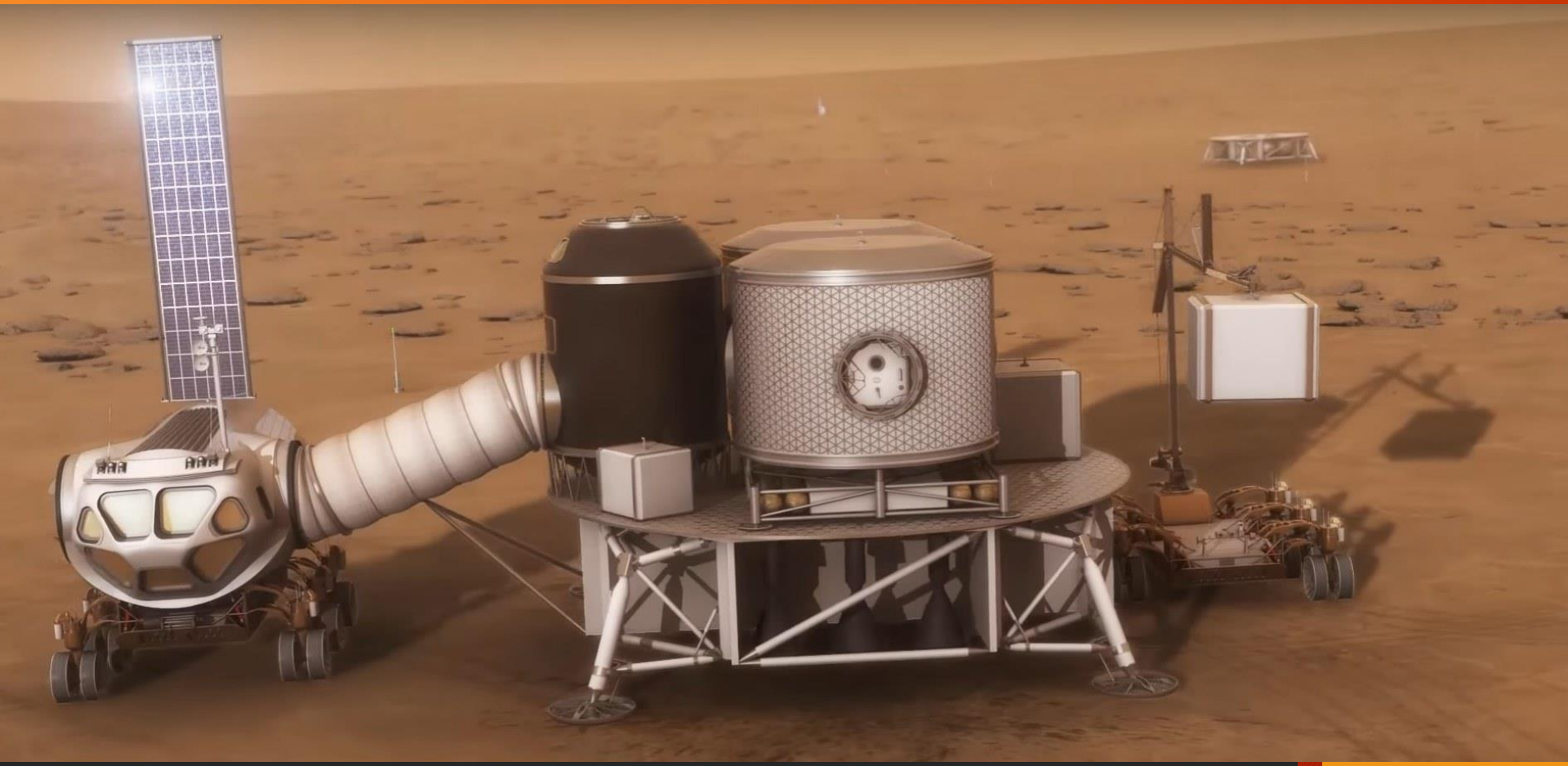


Power System + Cargo

Ascent Vehicle + Propellant Manufacturing System

Habitat + Crew + Logistics

Additional Crew + Ascent Vehicles + Cargo



Impacts to Equipment

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Surface Habitat

- **Habitat is re-used for multiple long-duration expeditions**
- **Considerations**
  - Crew ingress/egress: open hatch alternative, dust-resistant pressure seals, locking mechanisms
  - Cabin fans/filters to remove airborne dust in the cabin and portable vacuum cleaners to clear surface dust (+ power for both)
  - Regenerative air/water system compatibility with chemicals in dust
  - Ability to remove embedded dust from softoods
  - Cleaning tools
  - Clothing and cleaning rags: dispose or wash?
  - Dust accumulation on windows, handrails, radiator panels
- **In spite of best efforts, some dust is likely to migrate into the habitat**

Surface Power Systems

- **Solar Power is sensitive to accumulated *and* atmospheric dust**
  - Robots can go dormant, but humans can't
- **We can clean dusty solar arrays—but can't fix atmospheric dust**
  - Over-size arrays and increase energy storage capacity to survive storm
  - Or develop alternatives, such as fission power
- **Power cable connections between surface assets will be challenging**
  - Need dust-resistant connectors
  - Some of these connections may be made by robots before the crew arrive

Robots Can Hibernate When Power Is Low

But humans have to breathe, eat, stay warm and get back home

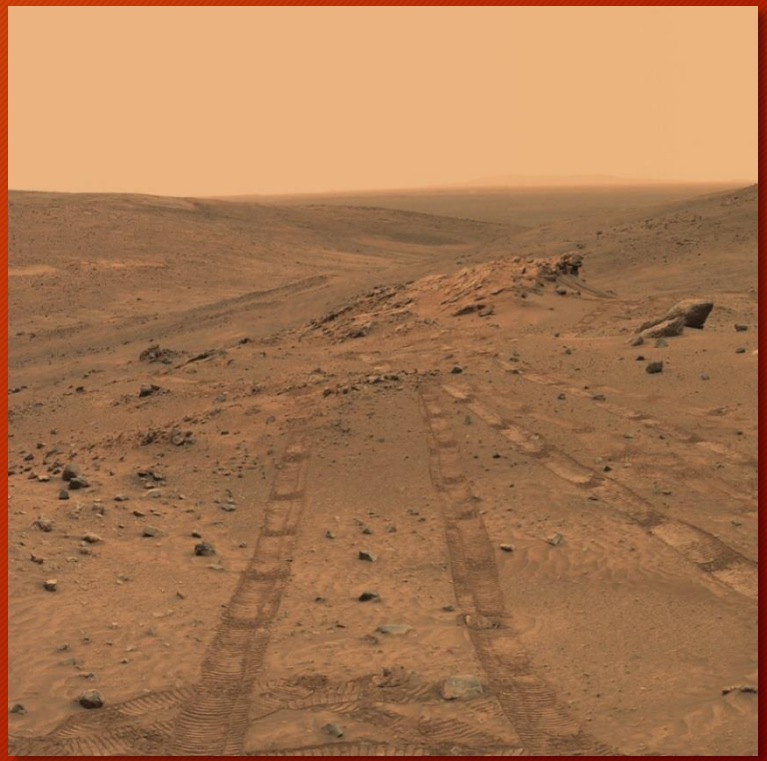
Spirit Selfie on Sol 586

Dust Accumulation on Spirit's solar arrays reduced available power

Spirit Selfie on Sols 1,355 - 1,358

Rovers

- **Pressurized Crew Rovers are Mobile Habitats**
  - All the same concerns as a stationary habitat
  - Accumulation can compromise even non-solar rovers (Apollo battery)
  - Navigation optics
  - Worst-case: solar-powered rover caught in lengthy, severe storm away from the habitat



EVA Spacesuits and Tools

EVA
Extravehicular Activity

- **Biggest concern: How/where to perform routine maintenance on dusty spacesuits?**
- **Considerations:**
  - Crew ingress/egress dust mitigation
  - Seal and mechanism integrity
  - Managing dust accumulation on helmet visor, backpack, boots, gloves, thermal components
  - Abrasion damage to seals, visors, cameras
  - Dust embedded in softgoods, such as suit fabrics
  - EVA Tools: overheating, grit abrasion of mechanisms
- **May need to leave EVA suits on Mars unless cleaned to meet planetary protection guidelines**
  - Cost penalty to bring new suits with new crews
  - Alternative is to refurbish/resize old suits on Mars for new crews

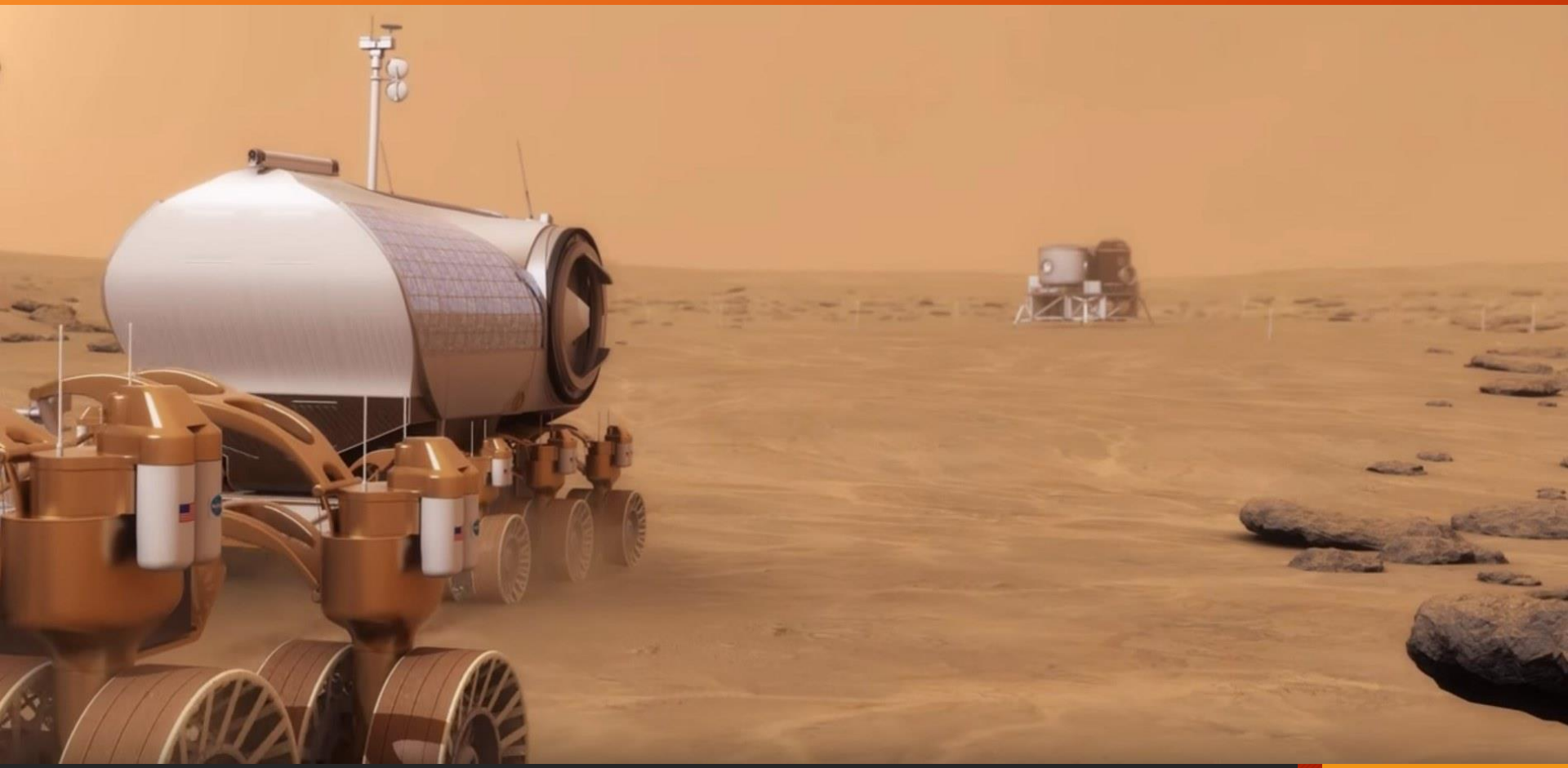
Apollo 17
Dusty EVA suit & Astronaut Cernan

Notional Mars EVA Suit Soiling

Mars Ascent Vehicle

MAV
Mars Ascent Vehicle

- **MAV is the first leg of the crew's return to Earth**
- **Similar concerns as habitat**
  - Airborne dust in the cabin, grit abrasion on seals and mechanisms, reduced window visibility or thermal system malfunction due to dust accumulation
- **MAV is a key link in the planetary protection chain**
  - If we can keep dust out of the MAV, we can keep Martian dust from migrating back to Earth
- **Key to minimizing dust in MAV is to never expose cabin to Mars**
  - One option is tunnel from a rover to the MAV



Impacts to Operations

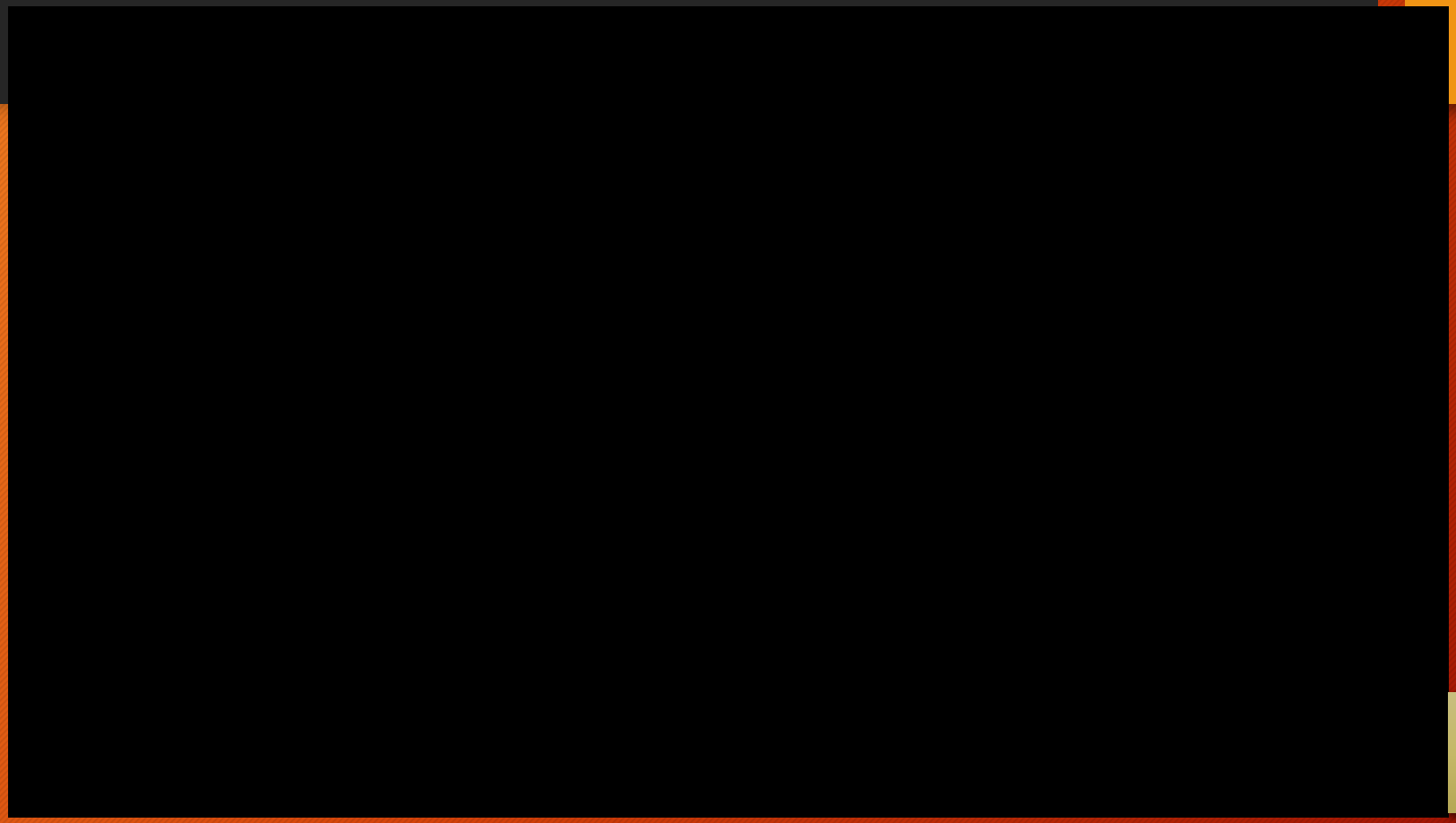
Landing on Mars

- Storms along well-worn tracks may influence landing site selection
- Landing during a dust storm could make it difficult to detect and avoid hazards
  - Boulders, sand dunes, rovers, surface habitat
  - Mitigation might include advanced hazard detection and avoidance systems
- Lengthy storm could cut into schedule margins for critical surface operations, such as manufacturing propellant from Mars resources for crew departure
- Equipment sensitive to dust accumulation is equally affected by man-made dust storms produced by lander descent engines

Click below to play on-line video

Descent Engines Will Kick Up Dust

Morpheus Free Flight #10, NASA Kennedy Space Center



Jump to 2:15

Engine dust plumes will have the added complication of unburned propellants or propellant byproducts mixed with the dust

https://www.youtube.com/watch?v=sI5tsetrbpA

Habitat Operations

- **Keeping dust out of the habitat is likely to involve special operational procedures**
  - May add time getting EVA crew back inside
  - Concern for emergency ingress
- **Housekeeping is likely to be time-consuming on Mars**
  - How will we clean the cleaning tools?
  - How much consumables mass will be devoted to cleaning, and will this mass have to be delivered from Earth?
- **Reduced visibility through habitat windows could disrupt telerobotic operations or science activities**

Rover Excursions

- **Reduced driving visibility and solar power availability could influence surface exploration planning**
  - Poor visibility makes driving treacherous
  - Crew rescue schemes, remote safe havens, better storm prediction, or surface navigation and hazard avoidance provisions
- **Special operational procedures could add time getting EVA crew back into the rover**
- **Housekeeping will be time-consuming**
- **Will need time and consumables to repair grit-damaged pressure seals and mechanisms**

EVA Operations

EVA
Extravehicular Activity

- Clearing dust off of solar/radiator panels, windows, etc. could be time-consuming
  - Cuts into science operations time
- Ideally, equipment will be designed to shed dust, or will include autonomous dust clearing provisions
- Getting crew in/out of dusty suits may add time
  - Cuts into overall EVA time

MAV Ascent

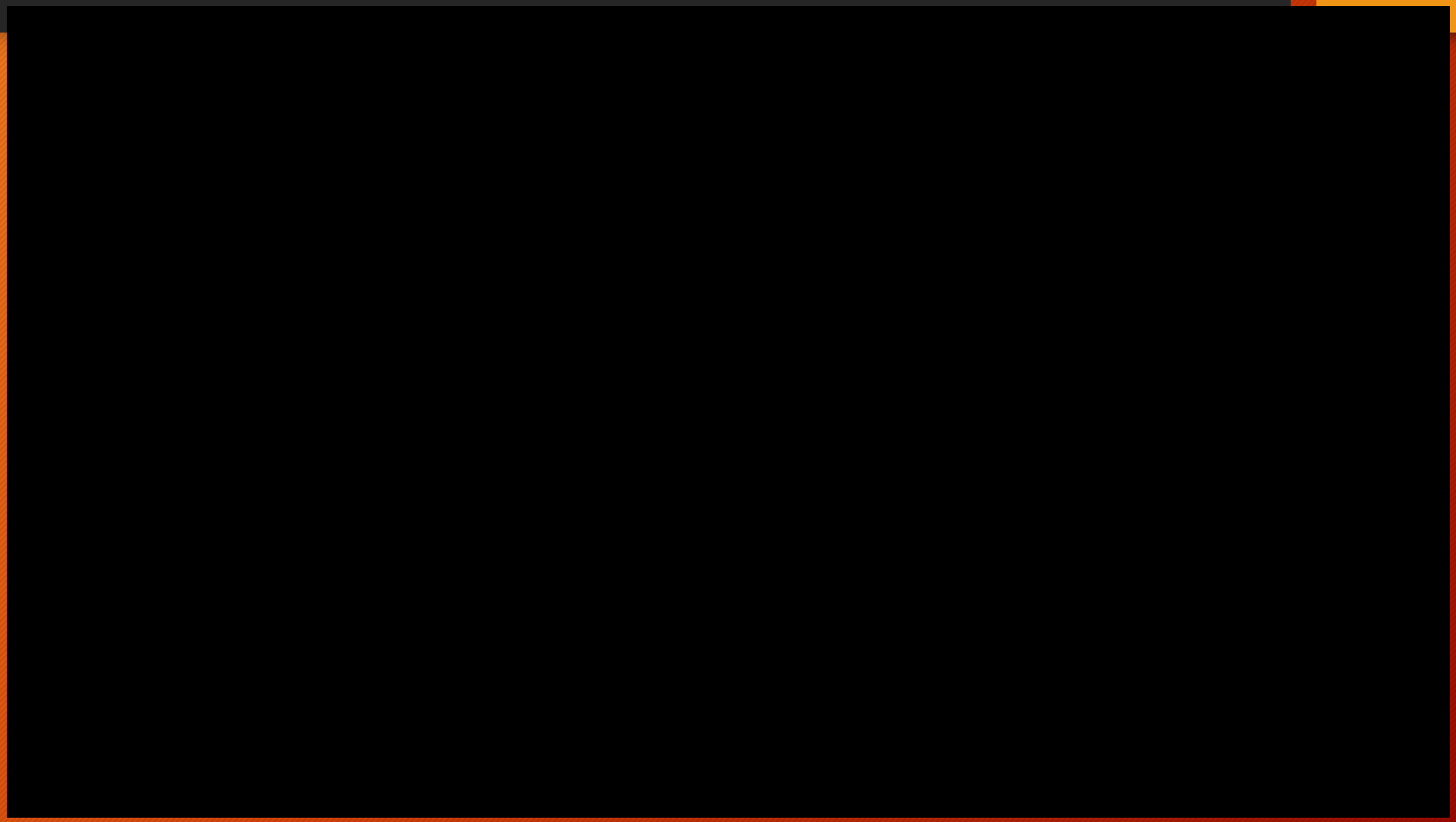
MAV
Mars Ascent Vehicle

- Like the lander's descent engines, the MAV's ascent engines will create a man-made dust storm
  - Lofted dust—potentially mixed with ascent propellants or residues
  - Settling on the habitat or rovers
- Ascent flight paths that avoid surface infrastructure overflight will be desirable
- Haven't identified any reason MAV can't launch in a dust storm
  - Visibility may make pre-launch preparations difficult

Click below to play on-line video

Ascent Engines Also Kick Up Dust

Morpheus Free Flight #7, NASA Kennedy Space Center



https://www.youtube.com/watch?v=bXsl7dnY85w

Key Take Aways

- Robotic missions have provided valuable insights into Martian dust storms
- Dust storms pose challenges for a human Mars mission
- NASA is actively considering ways to reduce the impact of dust storms
  - Robust equipment designs
  - Contingency operations planning

Questions?

Dust In the Atmosphere of Mars Workshop
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