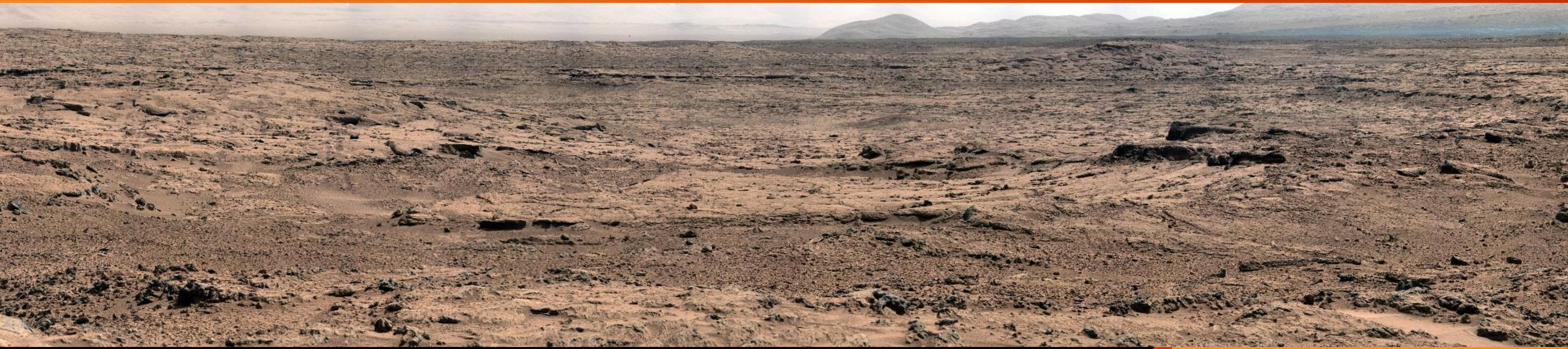
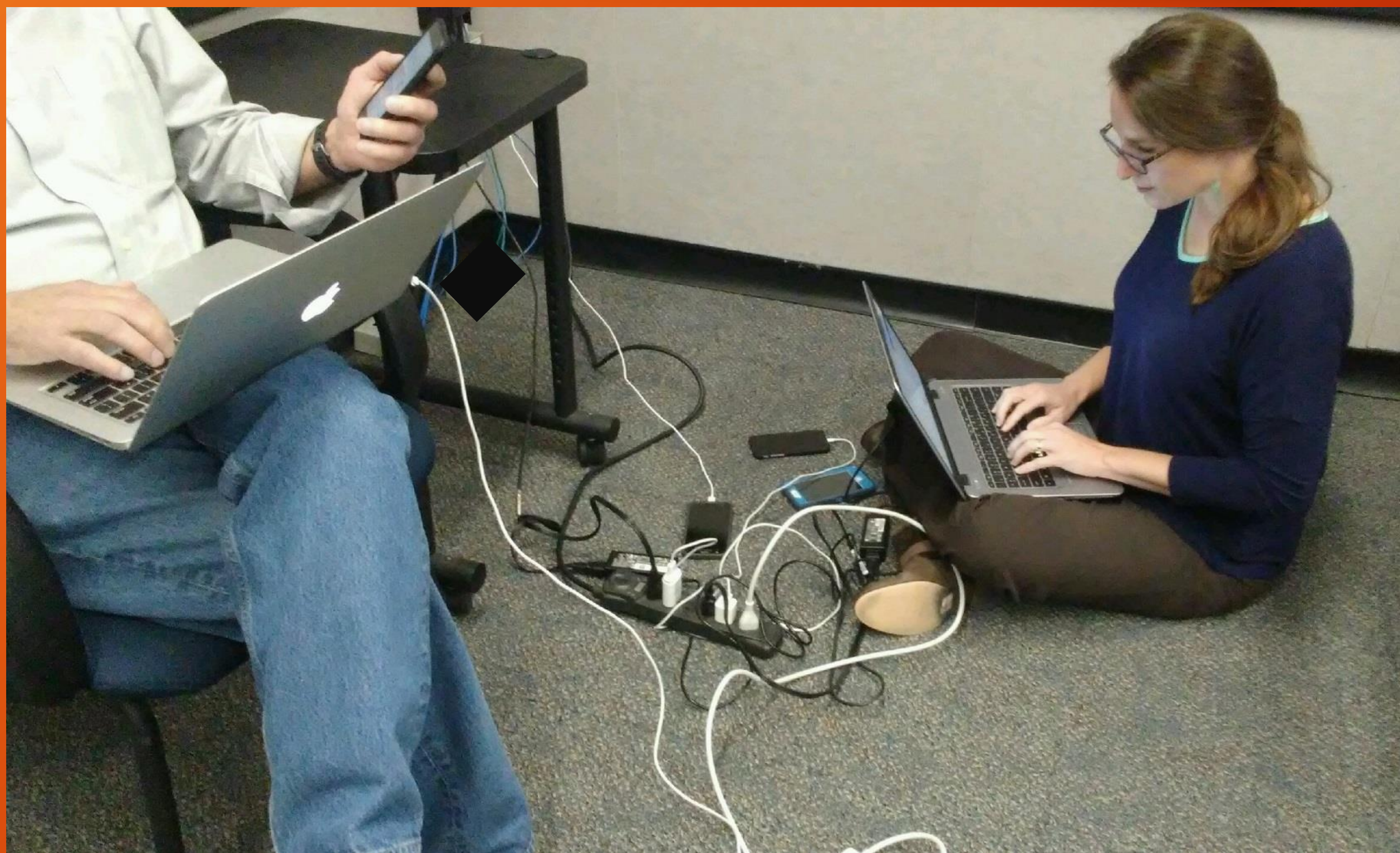


Human Mars Mission Power Architectures

Michelle Rucker
Mars Study Capability Team
NASA Johnson Space Center

35th Space Power Workshop
April 24-27, 2017 • Manhattan Beach

Wherever Humans Travel…



In-Space Power During Transit

- Solar Power makes sense
  - ✓ Continuous sunshine
  - ✓ Extensive experience on International Space Station and robotic Mars missions
  - ✓ Solar Electric Propulsion in development

Mars surface is where things get interesting

Human Mars Mission by the Numbers

No decisions have been made, current thinking

Multiple visits to a single landing site

100 km	Notional excursion from landing site • Goal to extend as far as possible • Robotic assets may rove further
~500	Days maximum stay for any given mission • Driven by orbital mechanics
Twenty Six	Months between opportunities Conjunction class missions
4+	Crew to the surface (and return) per expedition

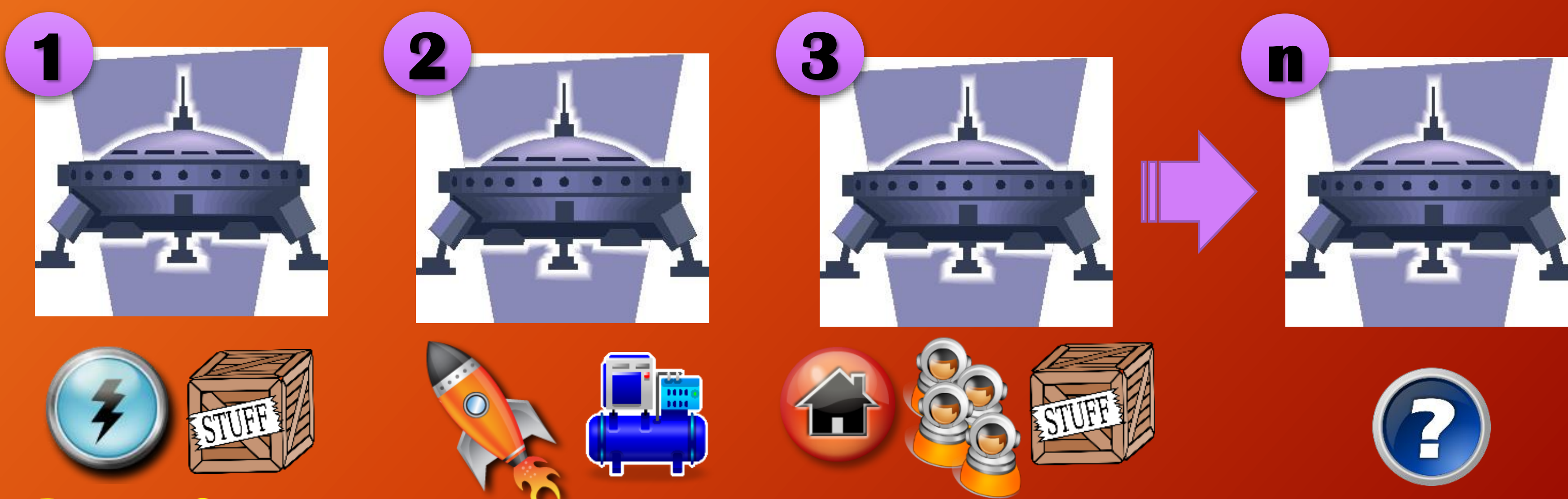
Here's What a Mars Campaign *Might* Look Like

FIRST send cargo, including a surface power system

THEN send Ascent Vehicle and ISRU to fill empty prop tanks

WHEN tanks are full, crew lands and begins surface mission

SUBSEQUENT crews land at same site, use infrastructure



Power System + Cargo

Ascent Vehicle + Propellant Manufacturing

Habitat + Crew + Cargo

Additional Crew + Ascent Vehicles + Cargo

Key To Successful Human Mars Surface Mission: Reliable Power

What we did on the Moon won't work on Mars

	Apollo	Mars
Surface Stay	3 days	500+ days
Peak Load	~4 kW	~40 kW

- ❑ Apollo spacecraft were one-time use, each landing at a different site
  - NASA is looking at multiple missions to a single Mars landing site, with reusable surface elements
- ❑ Apollo crews ventured a few kilometers from landers
  - Mars crews may "road trip" 100+ km

Key To Successful Human Mars Surface Mission: Reliable Power

What we did with Mars rovers won't work for humans

- ❑ Sojourner, Spirit, and Opportunity
  - Fixed solar arrays and batteries
  - Arrays were sensitive to dust accumulation
- ❑ Curiosity
  - Radioisotope Thermoelectric Generator (RTG) and batteries

	Rovers	Humans
Keep-Alive	<25 W	>25 kW
Peak Load	<650 W	>35 kW

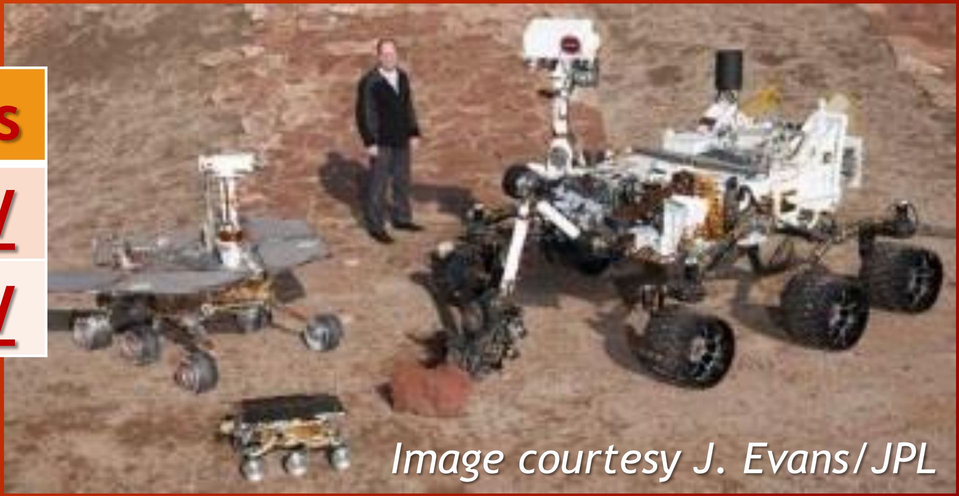


Image courtesy J. Evans/JPL

Rovers Can Hibernate When Power Isn't Readily Available

But humans have to breathe, eat, stay warm
(and possibly make return propellant)

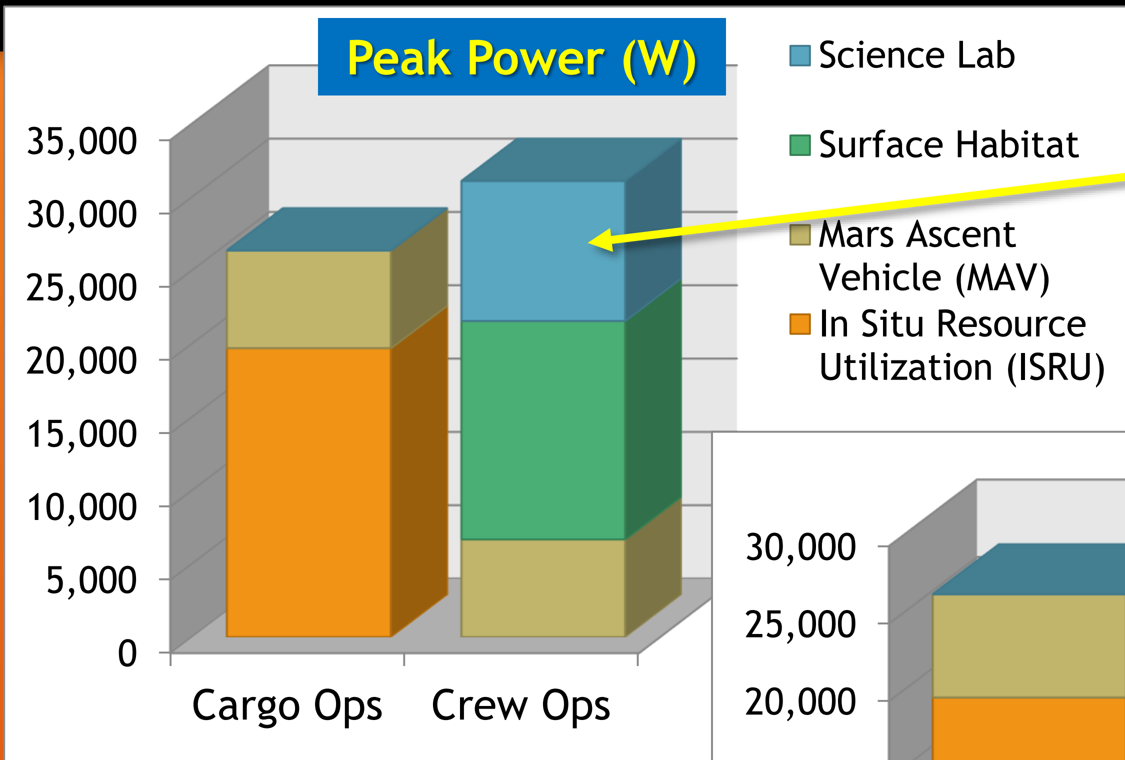
Spirit Selfie on Sol 586

Dust Accumulation on Spirit's solar arrays reduced available power

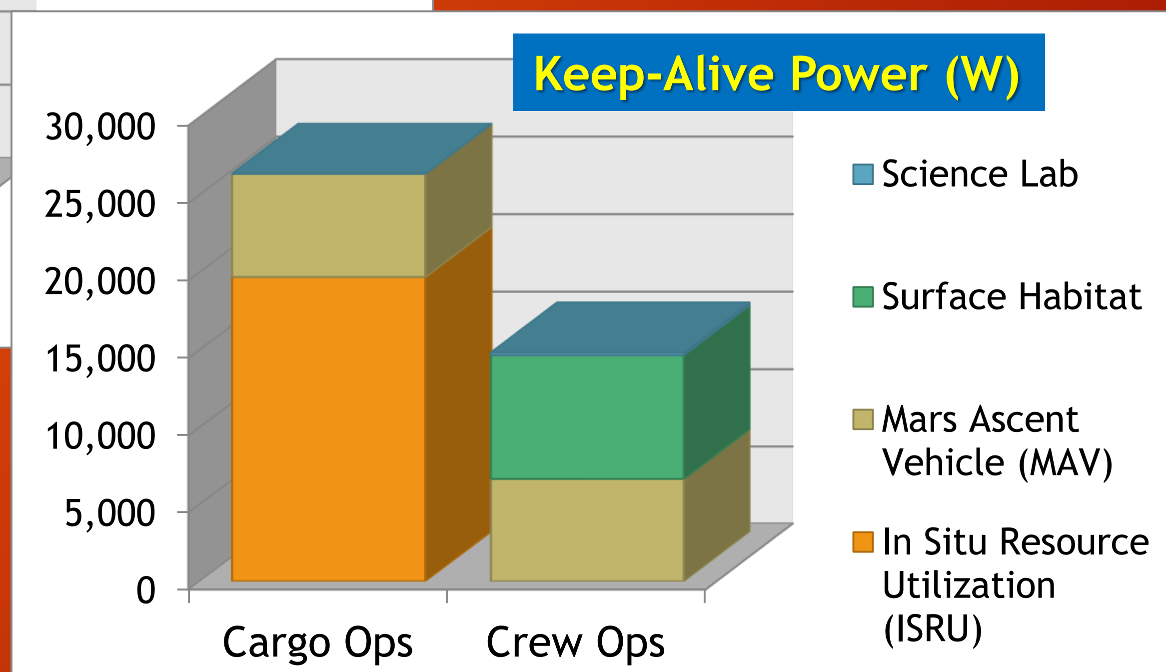
Spirit Selfie on Sols 1,355 - 1,358

Surface Mission Power Example

4 Crew, 22.8 MT Ascent Propellant in 420 Days



Optional Science Lab with all systems running; Assume power can be phased to stay below cargo ops total peak

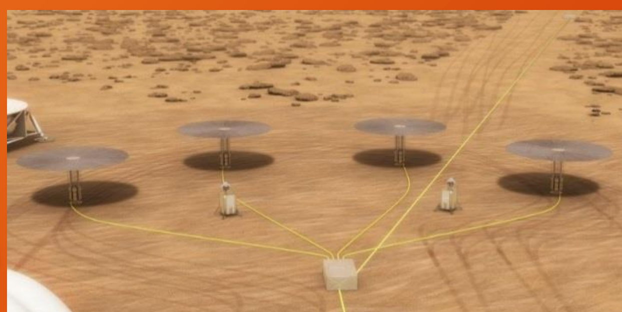


ISRU makes ascent propellant

So How Do We Power a Mars Surface Mission?

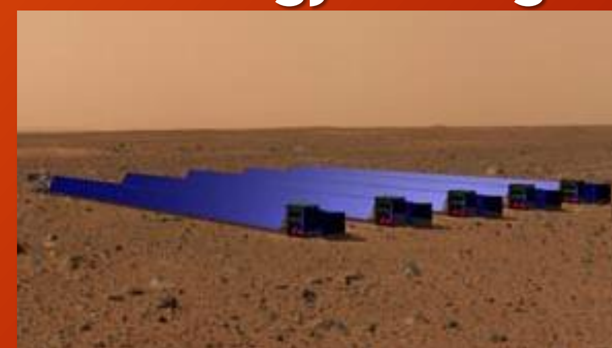
Two Primary Options Being Evaluated

1 Kilopower Fission System



Modules up to 10 kWe ganged together

2 Deployable Solar Arrays with Energy Storage



Possibly with RTG emergency backup

Other options (such as wind turbines) don’t trade as well for mass, volume, reliability

Mars is Like a Bowl of Spaghetti

You can't make one decision without getting tangled up in other decisions

Example: If first decision is to pick a landing site, that dictates:

- ✓ Whether we can rely on solar power for surface operations
- ✓ Whether Mars water is readily available to make reactants for fuel cell energy storage
- ✓ Dust mitigation needs for seasonal dust storms

Image courtesy rgbstock.com

Fission vs. Solar

		Fission Power	Solar Power
Readiness		Lower	Higher
Mass		Lower for most sites	Higher
Reliability	At night	High	Need energy storage
	Dust storm	High	Risky
	At equator	High	Good
	At poles	High	Must be large
Deployment Time		Lower	Depends on size
Cost		High development, handling overhead	Lower
Portability		Higher (compact)	Lower

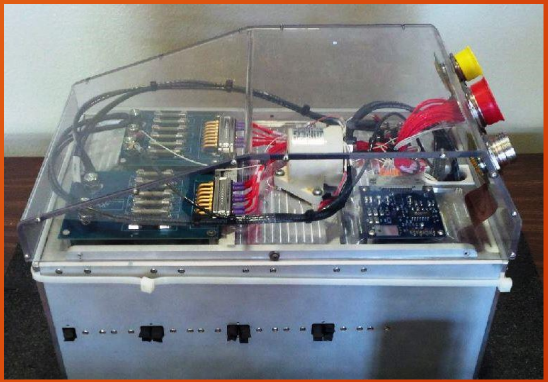
Studies are on-going, selection may depend on landing site

Energy Storage
For Night Use + Portable Equipment

Two Primary Options Being Evaluated

Goal: high energy density, long shelf life (4+ years), long service life (10-12 years), low maintenance, no Earth-origin resupply/consumables

1 Rechargeable Batteries

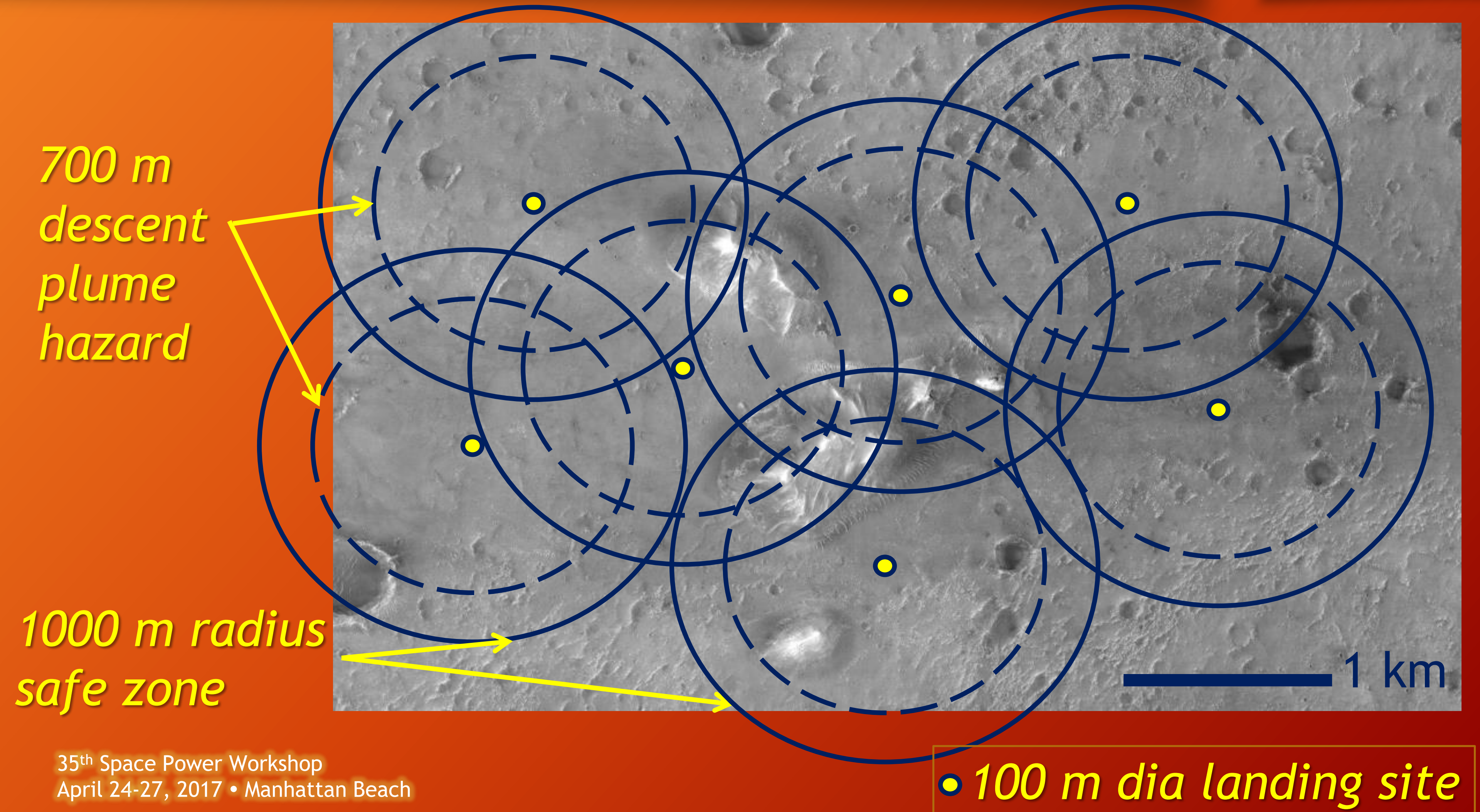


2 Fuel Cells

Reactants ideally from Martian resources

Managing Multiple Landers

Close—but not <u>too</u> close—to each other



Multiple Landers Complicates Power Management & Distribution

We'll need to power multiple elements, up to 1 km apart *(some before crew arrive)*

Autonomously Deployed Cable

Robotic Assembly

Multi-Element Power Management

Options include a single power lander, power generated at every lander, and/or distributed "charging stations"

Mars Power R&D Opportunities

❑ Power Management and Distribution (PMAD)

- Tough, long life, high voltage power cable compatible with Martian temperatures/low pressure
- Autonomous cable deployment (up to 1 km)
- Robotically actuated, dust-resistant connectors

❑ Energy Storage

- High energy density
- Long shelf life (4+ year)
- Long service life (10-12 years)
- Low maintenance
- No Earth-origin resupply/consumables

Mars Power R&D Opportunities

❑ Solar Power

- Dust mitigation for solar arrays
- Lightweight solar array structures
- Autonomous solar array deployment mechanisms
- High efficiency solar cells

❑ Fission Power

- Compact fission reactor
- Stirling development
- Heat pipe/core bonding
- Dust mitigation for radiator panels

Key Take-Aways
Human Mars Mission Power

Modular	30-40 kWe
Infrastructure Build-Up	High Peak & Keep-Alive Power
Reliable	**Portable**
500-Day Missions >12-Year Life	100+ km Excursions

Exciting Mars research & development opportunities await!

NASA Johnson Space Center
XM/Michelle Rucker
Michelle.a.rucker@nasa.gov

EXPLORATION INTEGRATION AND SCIENCE DIRECTORATE

Questions?