Inserting Space Resources into the Future of Space Exploration: Do We Need Control (Alt, Delete)?

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The Space Exploration Vision

- Objectives of the Pursuit of Human Space Exploration
  - Advancing Science – understand our place in the universe
  - Human nature to explore
  - National Pride
  - National Security
  - Planetary Defense
  - Secure Humanity's Survival through expansion
  - Economic Expansion
- Together these have not compelled the government funding necessary to realize the vision

Giving Structure to the Vision

- In the US, NASA has built several successive exploration scenarios (architectures) and related technology development plans (roadmaps)
  - Even when driven to low cost options, the outcomes are extremely expensive to implement and are spread over decades.
- Internationally, the Global Exploration Roadmap faces the same challenge

Giving Structure to the Vision

- All the recent architectures and roadmaps recognize the central role of utilization of space resources to make exploration affordable and sustainable.
- More importantly, the diverse community of space resource advocates (Azimov to Zubrin) have given structure to what is possible:
  - Technologies for resource collection, processing and use
  - Independent visions of exploration
  - Synergies between resource exploitation and science
  - Space law and property rights
  - Terrestrial benefits
- This still has not compelled government funding

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The Role of Government Space Agencies

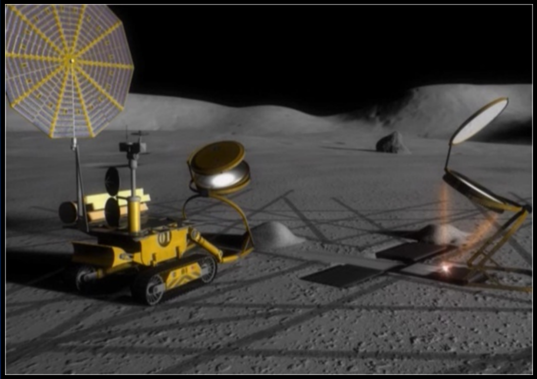
- Until recently, nearly all investment in exploration has been made by space agencies.
- Many clamor for a destination to focus efforts, but things weren't going so well when we had one.
- It seems increasingly likely that the resources for fully implementing exploration visions will never be provided at a rate sufficient to make progress.
- How does the emergence of serious private investment change the role of government in space?
  - Enable, unleash, support
  - High risk/high return technology investments
  - Affordable, adaptable, simple space infrastructure

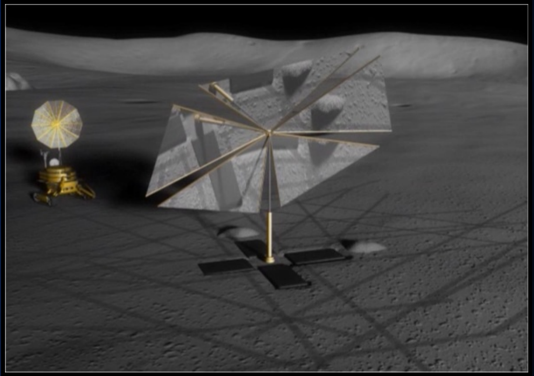
Lunar Exploration Infrastructure:
Minimal infrastructure to enable resource prospecting

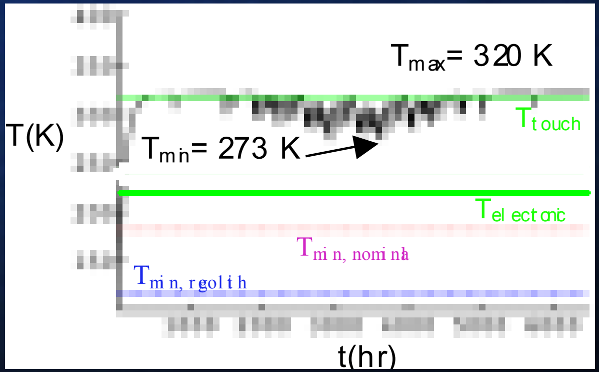
- Benefits to Earth, involving resources and commerce, are critical constituents of a sustainable lunar enterprise

Thermal Wadis:
Engineered Sources of Heat and Power

- Surviving the lunar night previously thought to require nuclear material
- Computer simulations confirm thermal advantages provided by thermal wadis
- Rovers can off-load substantial thermal protection mass and other functions
- Substantial temperature margins possible





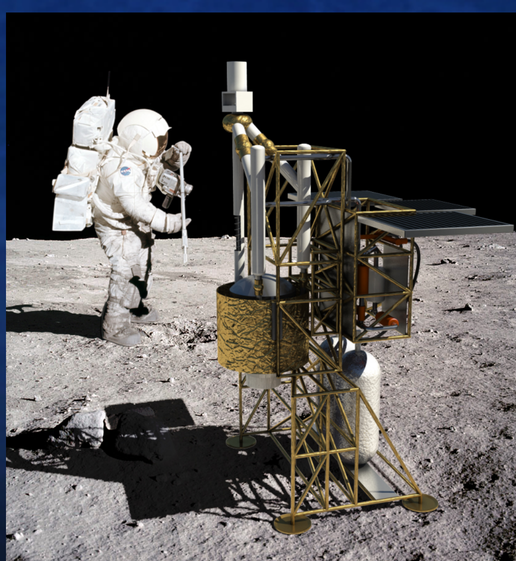


Thermal Mass Production

Solar Concentrators

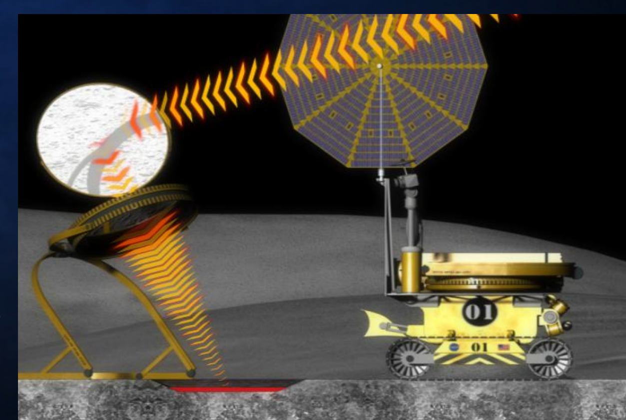
Thermite SHS

In-Situ Vitrification/
Joule heating



O_2 Production
from Regolith

Rover-based
Thermal Mass
Production



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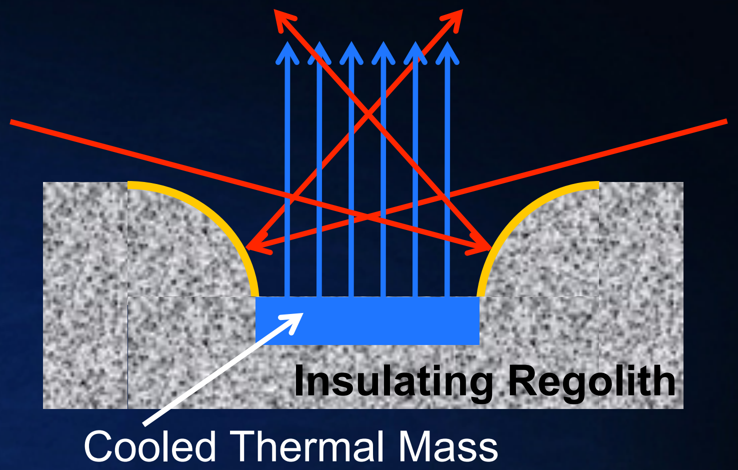
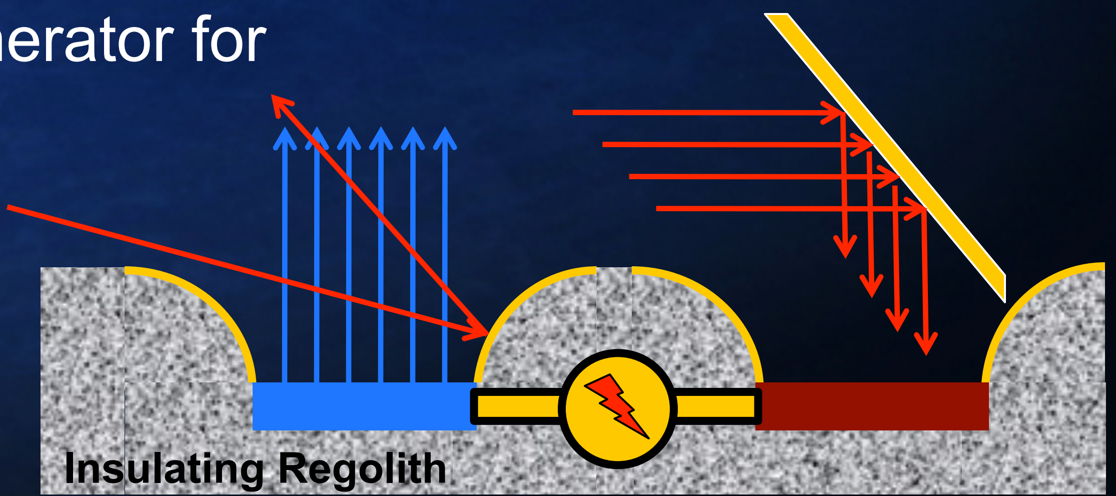
Power Generation and Heat Sinking

- A thermal mass can be configured in an artificial "PSR"* to serve as a daytime heat sink.
- Thermal mass pairs can be configured as high-temp/ low-temp reservoirs, joined with a Sterling generator for electrical power.

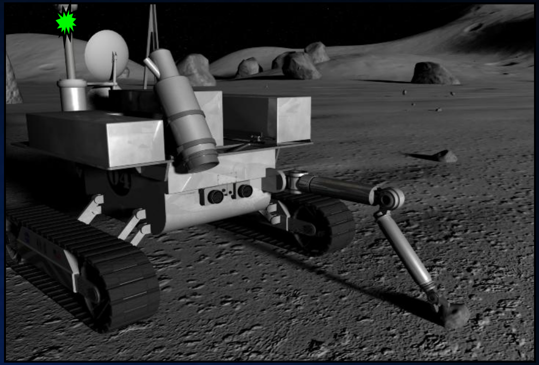


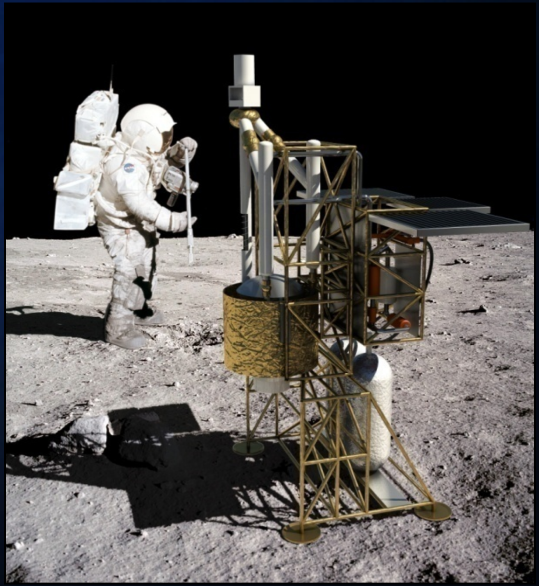


* Permanently Shadowed Region

Resource Characterization:
Paving the Way for Humans to Return to the Moon

- Robotic prospectors, based from thermal wadis, identify resource concentrations & sites
- Promising sites are selected for near-term lunar resource extraction demonstrations
    - Oxygen from regolith
    - Water/Hydroxides
- ISRU technology demonstrators, operated at thermal wadis, further reduce cost and performance risks
- Architectural and engineering studies confirm the economic potential of lunar resources
- Humans return to the Moon with clear economic goals: To make space exploration beyond LEO more affordable and to provide benefits to Earth

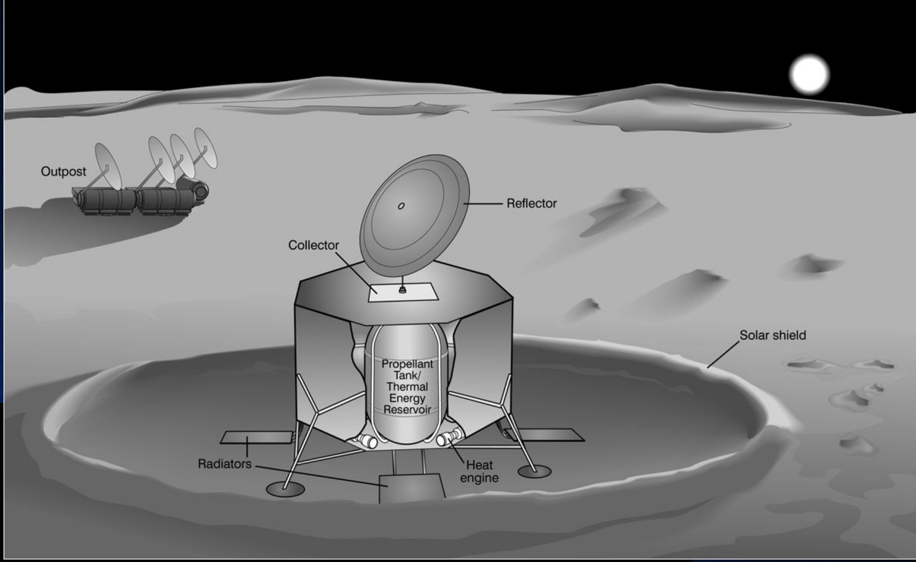


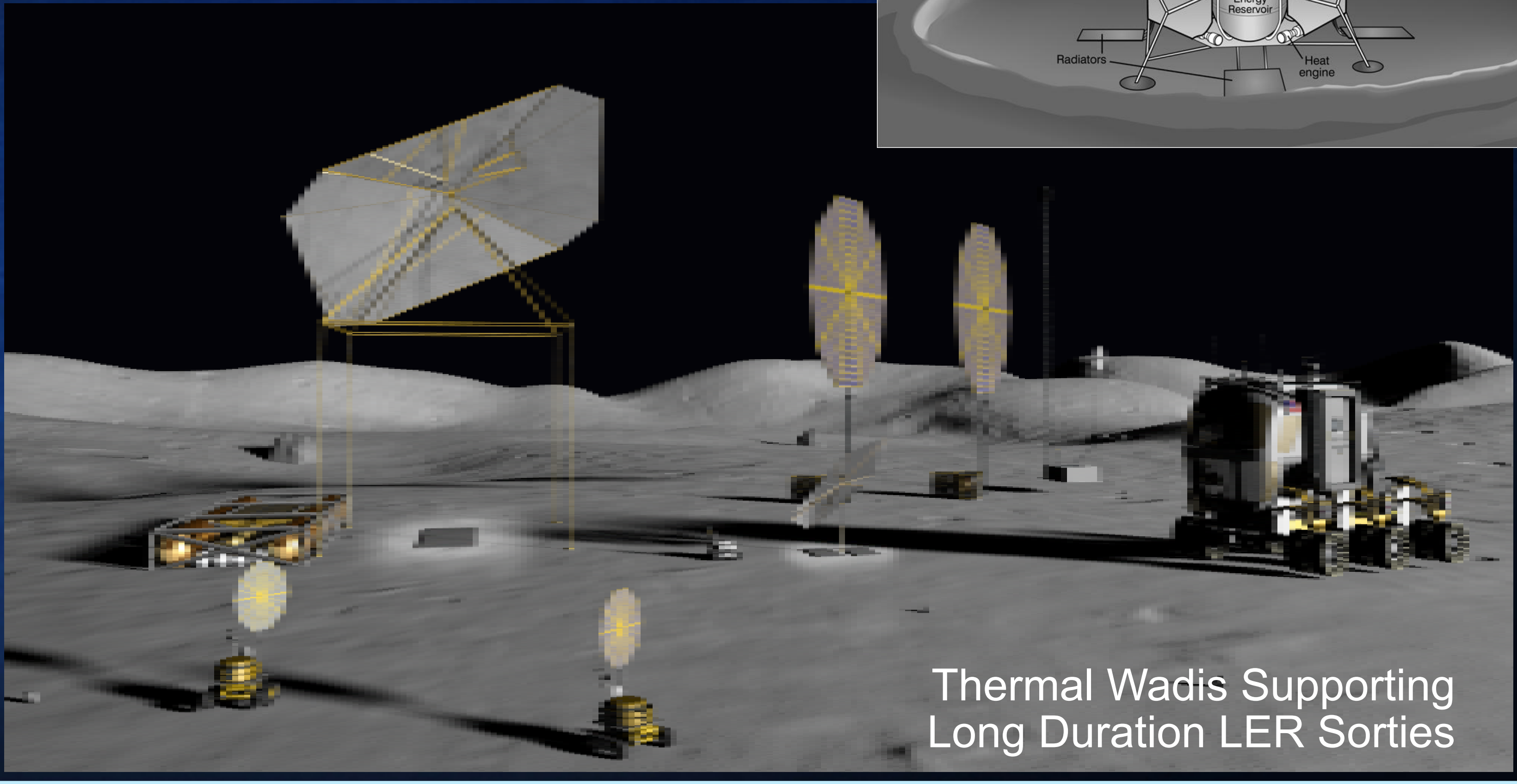


National Aeronautics and Space Administration

Lunar Thermal Energy Reservoirs

Outpost Energy Storage and Power Generation: 8-10 kWe per Lander





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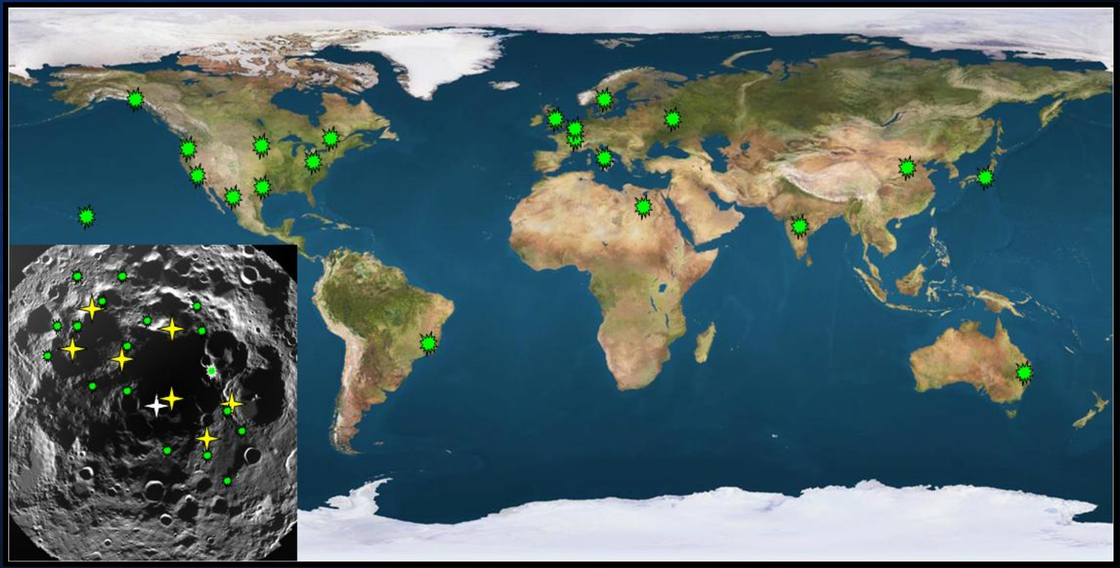
Global Lunar Exploration:
International and Public Participation

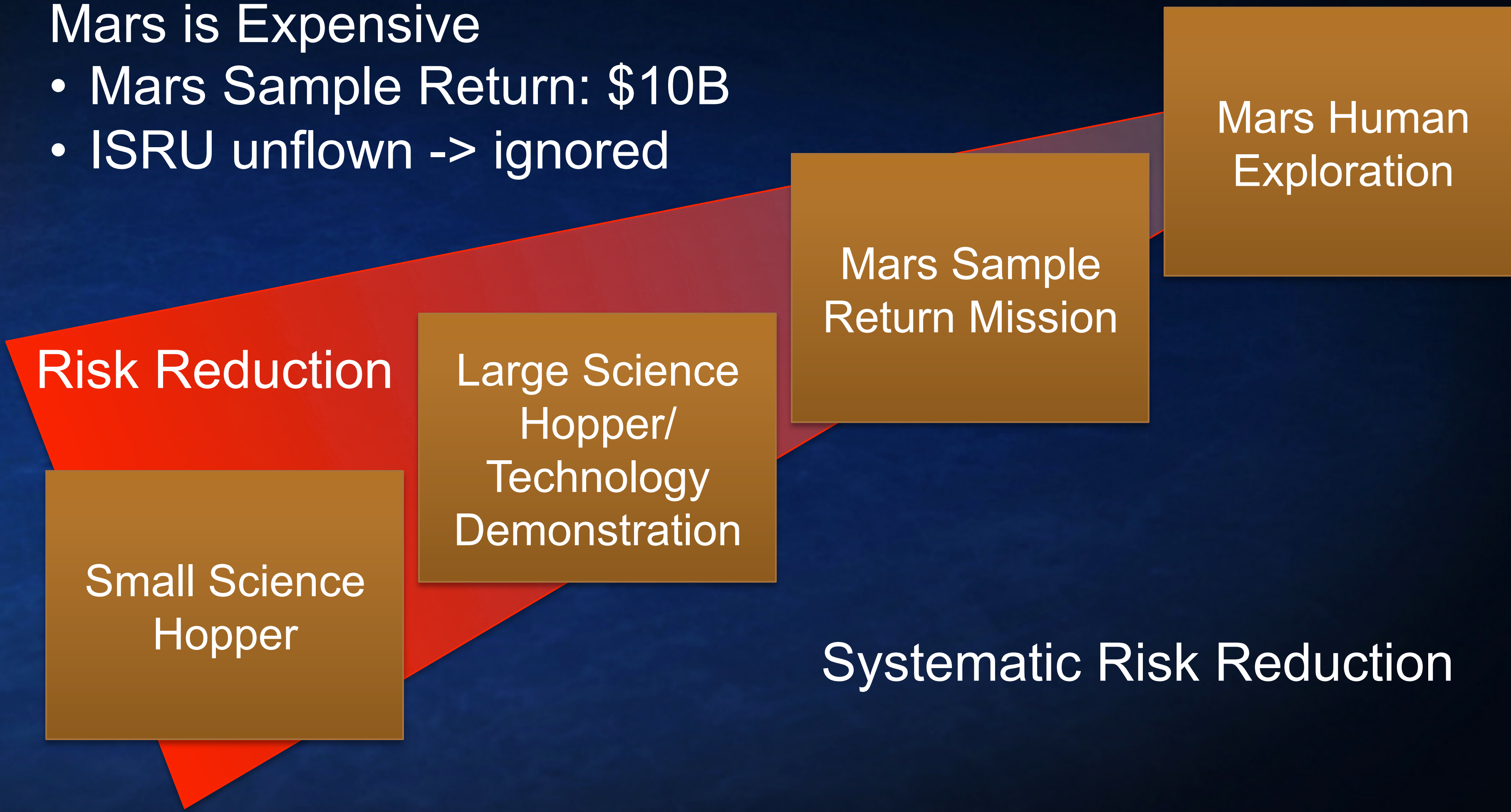
- Worldwide participation in lunar robotic exploration enables a broad collection of data
- Leverages international and commercial partnerships
- Increases stakeholder value through increased public participation; a new paradigm for space exploration



Enabling Mars Exploration

Mars is Expensive

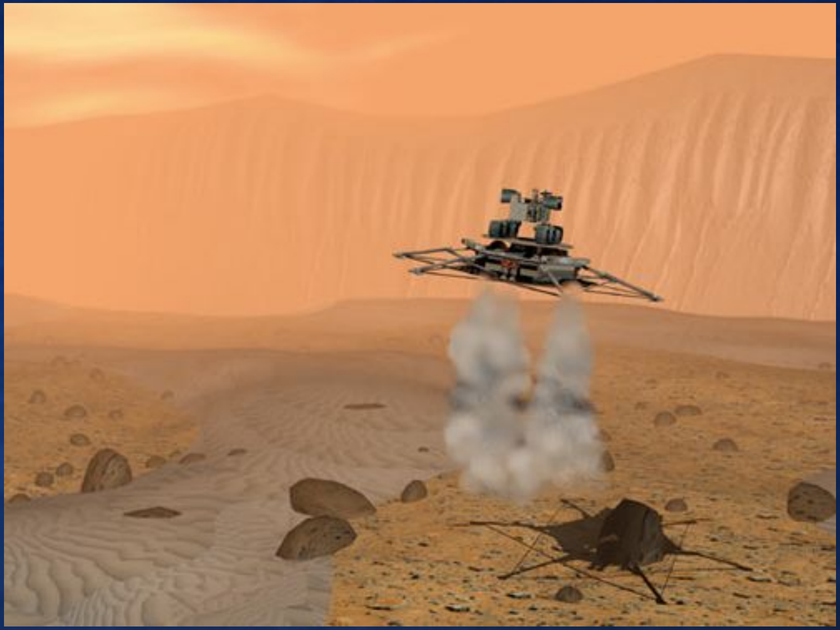
- Mars Sample Return: $10B
- ISRU unflown -> ignored



Systematic Risk Reduction

Mars Small Science Hopper

Mission Description: Explore and prospect for water at multiple locations on Mars using ~2km sub-orbital hops powered by propellant produced at each location from atmospheric CO_2 and terrestrial H_2.



Risks Reduced:

- Demonstrated Mars-made propellants using Mars atmospheric CO_2
- Demonstrated autonomous oxygen/methane propulsion system
- Qualitative determination of subsurface water/hydrogen availability at multiple locations

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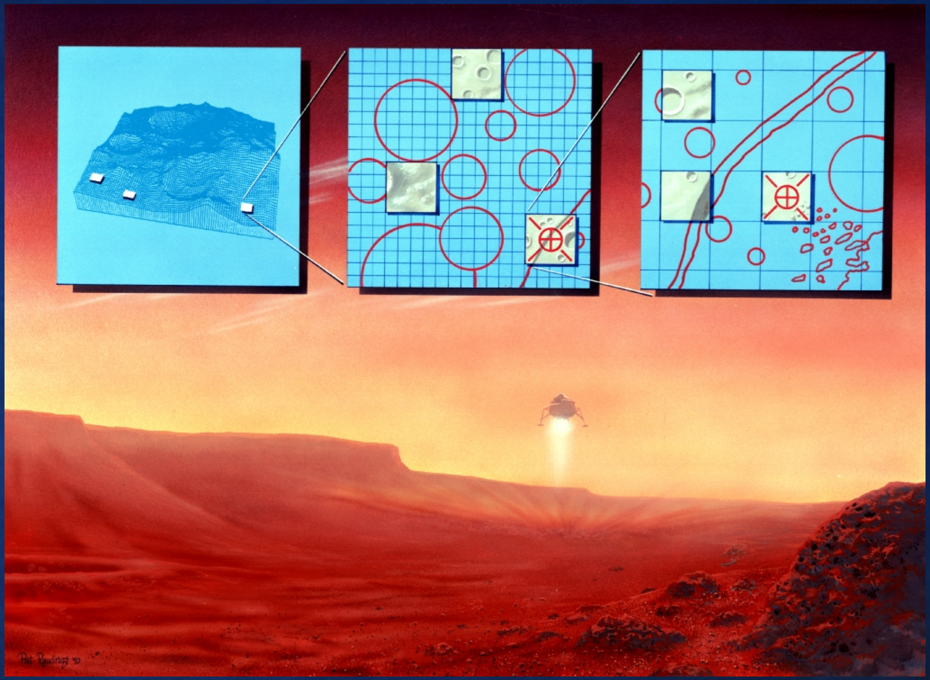
Mars Large Science Hopper/ Tech Demo

Mission Description: Explore and extract water at multiple locations on Mars using longer sub-orbital hops powered by propellant produced at each location from atmospheric CO_2 and subsurface water.



Risks Reduced:

•Demonstrated ground-water extraction for propellant production

•Demonstrated propellant production at full scale for sample return mission

Mars Sample Return

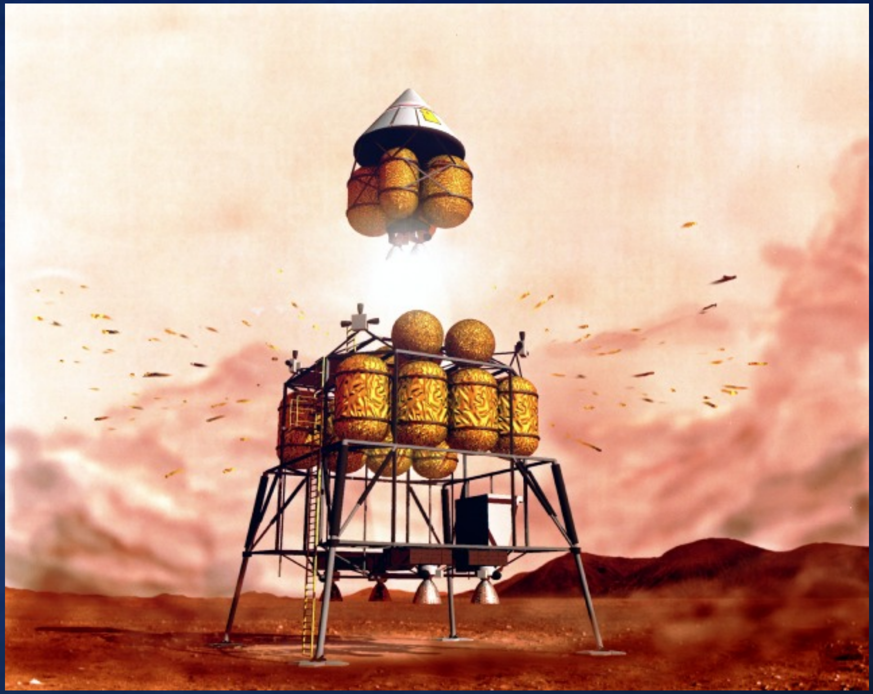
Mission Description: Deliver a scientific specimen to Mars orbit or on a direct return to Earth using Mars-made propellants for ascent.

Risks Reduced:

- Demonstrated mission critical use of Mars-made propellants for Mars ascent enabling highest priority science mission
- Direct return option produces propellants at 1/10th scale for crewed missions.

Human Mars Exploration Precursor

Mission Description: Deliver full-scale propellant production plant to Mars surface and produce and store cryogenic propellant sufficient for a crewed ascent vehicle.



Risks Reduced:

•Demonstrated full-scale propellant production plant, liquefaction, and storage before crew launch.

•Demonstrate life support consumable supplementation.

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Conclusion

- Existing NASA Exploration Architectures may never be funded for realization as envisioned
- Aggressive, well-financed private investment may be enabled by re-directed government attention to high-risk technology development and carefully designed space infrastructure.
- Such a paradigm shift will need a lot of work to teach it's value.

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