In-Situ Resources for the Moon, Mars, and Phobos: Elemental Concentrations

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Resource Questions

- **What are the resources, and where are they?**
- **How sure are we?**
- **What is needed to verify amount and accessibility of the resource?**

- Perspective from elemental abundances
  - Measured with gamma-ray/neutron spectroscopy
    - Bulk abundances to depths of 10s of cm
  - Focus on volatiles (mostly bulk hydrogen)
  - Knowledge exists of other elements
  - Complementary to mineral abundances

- Where: three main destinations
  - Moon
  - Phobos
  - Mars
Resources on the Moon: Hydrogen

• What/where:
  - 0.1 wt.% to ~10 wt.% $\text{H}_2\text{O}$ equivalent hydrogen
  - Permanently shaded craters at lunar poles

• Certainty:
  - Exact concentrations and locations are highly uncertain

• Getting more information:
  - Orbital measurements: low-altitude neutron (Luna H map; future missions)
  - Landed missions (rovers) in permanently shaded craters

Enhanced hydrogen abundances at lunar poles indicated by dark colors
Resources on the Moon: Other elements

Iron

Titanium

Thorium

Hydrogen
Resources on Phobos

• What/where:
  - Hints of volatiles

• Certainty:
  - Amounts and locations are uncertain

• Getting more information:
  - Japanese Martian Moons eXploration (MMX) mission (launch 2024)
  - Comprehensive remote sensing; elemental abundances from NASA-funded MEGANE instrument
  - Return sample to Earth in 2029

*Image of ~20-km diameter Phobos, moon of Mars*
Resources on Mars: Hydrogen/water ice

• What/where:
  - Hydrogen/water ice ranging from 2 wt.% H₂O (equatorial regions) to 100 wt.% (polar regions)

• Certainty
  - Amounts & locations have good certainty, but with broad spatial knowledge of few hundred km

• Getting more information
  - Better spatial knowledge with airplane/balloon missions
  - Landed rovers (e.g., Mars Science Laboratory neutron measurements)