







The Need for Science Operations Research in Preparing for Coordinated Human and Robotic Exploration

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The Problem Before Us

- The goals and activities for the most transformational scientific research that can be done by humans or their agents on the Moon are the same as those of field geology on Earth
- The reliance of 'terrestrial' field geology on novel technology has been extremely limited
- Thus, we are poorly prepared to take maximum advantage new and emergent technologies to develop an advanced approach to planetary field geology

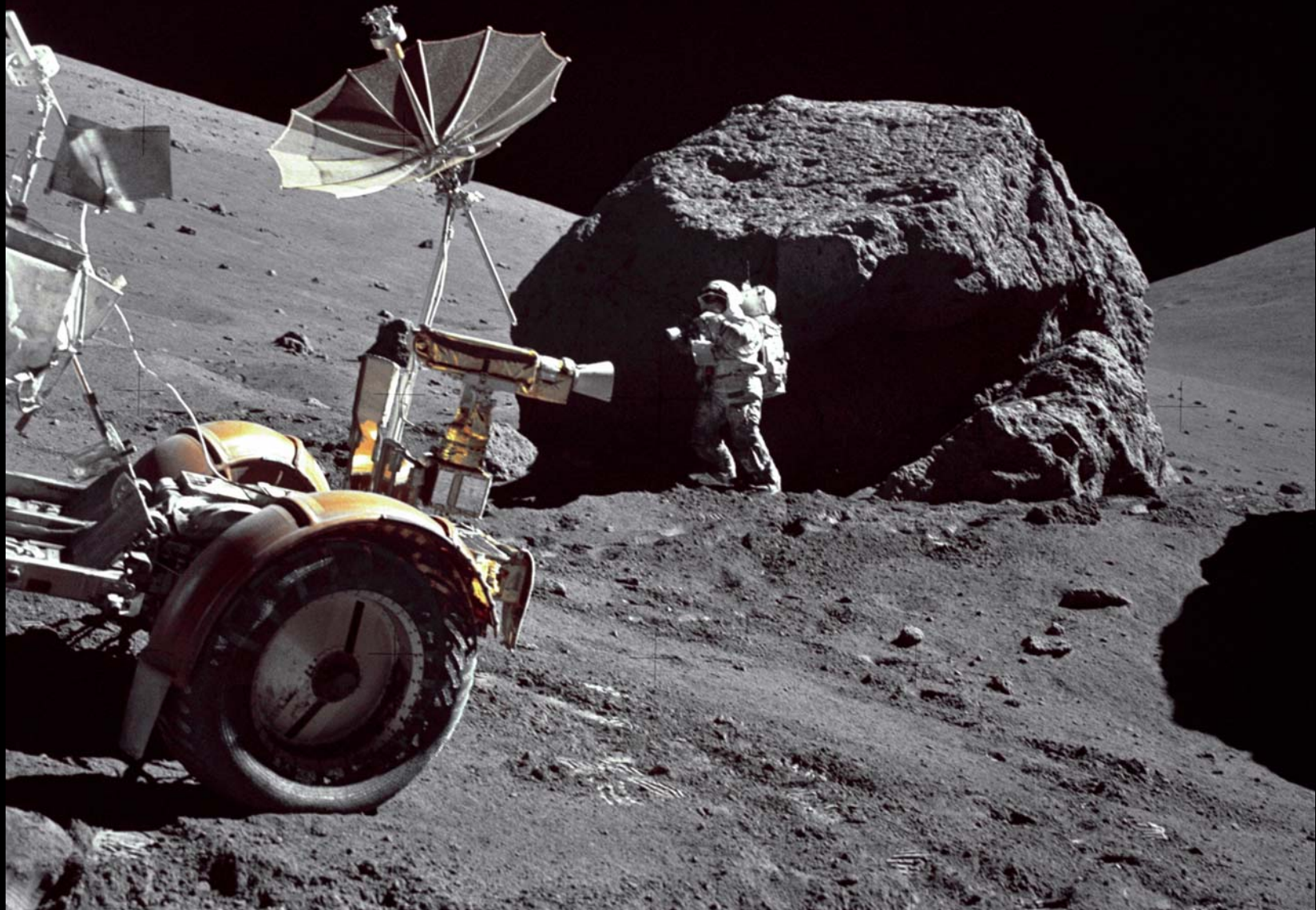
Terrestrial Field Geology...

- Is primarily an *adaptive* observational science
- Relies on abductive and inductive reasoning
- Involves progressively disproving multiple working hypotheses
- Benefits from varied perspectives
- Is *not* simply a matter of collecting samples

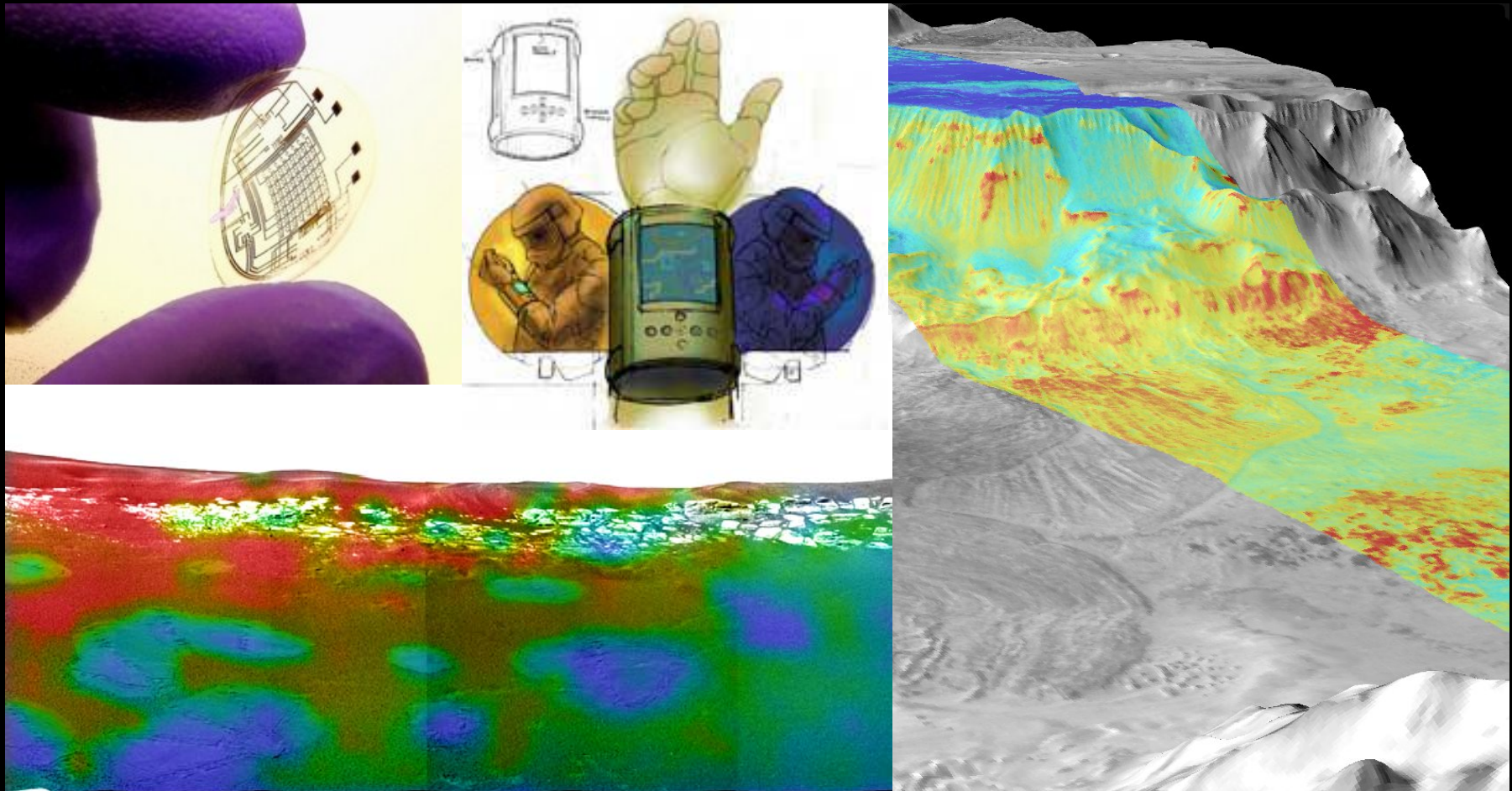
Future Field Geology on the Moon...

- May permit few or no second chances
- Will require extreme efficiency
- Could be encumbered by technology, but also...
- Could be enabled by technology
- Will require collaborations among scientists, engineers, and astronaut/explorers

Can We Be Better Than This?



Field Observations With Augmented Reality



Telescience as an Exploration Strategy



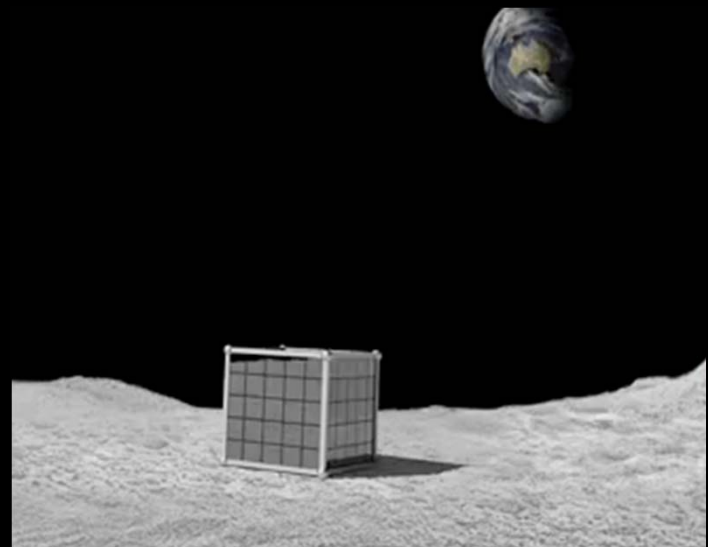
Virtual Field Geology



Robots: Scouts, Collaborators, and Surrogates



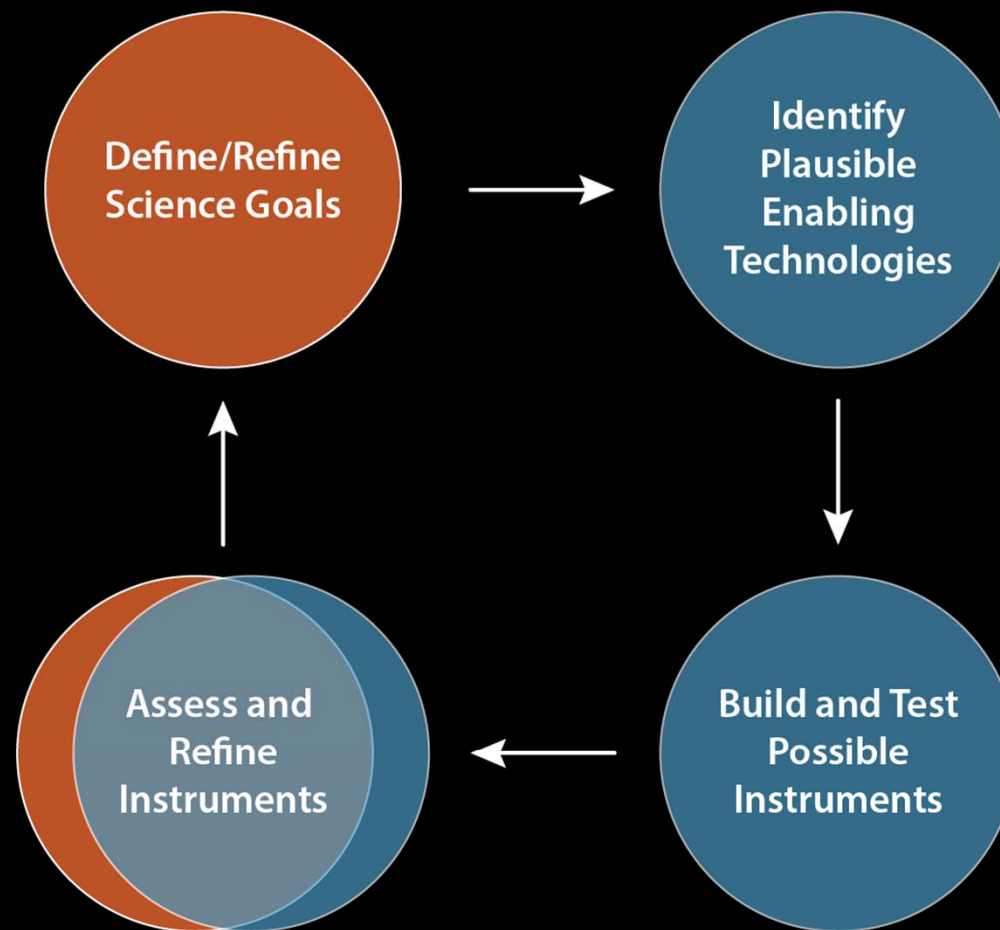
- Permit autonomous or coordinated science activities
- Improve scope, minimize risk



Better Options for Human Surface Mobility



Step 1: Exploring Technology Alternatives



Science Input
Engineering Input

Preparation 1a: Scientist Basic Training

- Scientists must understand the engineering and operational challenges of planetary field geology
- Curriculum must include the risks and costs of lunar exploration
- Pedagogy must emphasize optimization of activities to minimize risks and costs (e.g., energy, oxygen consumption, etc.)

Preparation 1b: Engineer Basic Training

- Engineers must understand the challenges of planetary field geology
- Curriculum must include scientific motivations and practical goals for lunar exploration
- Pedagogy must emphasize optimization of activities to maximize scientific return

Step 2: Science Operations (SciOps) Research

- Treat science operations on the Moon as a research domain rather than something we already know how to do well
- Design, execute, and assess the results of integrated laboratory and field experiments in a meaningful way
- Experiments must focus on technology-enabled, adaptive problem solving where the problems are defined by larger science goals

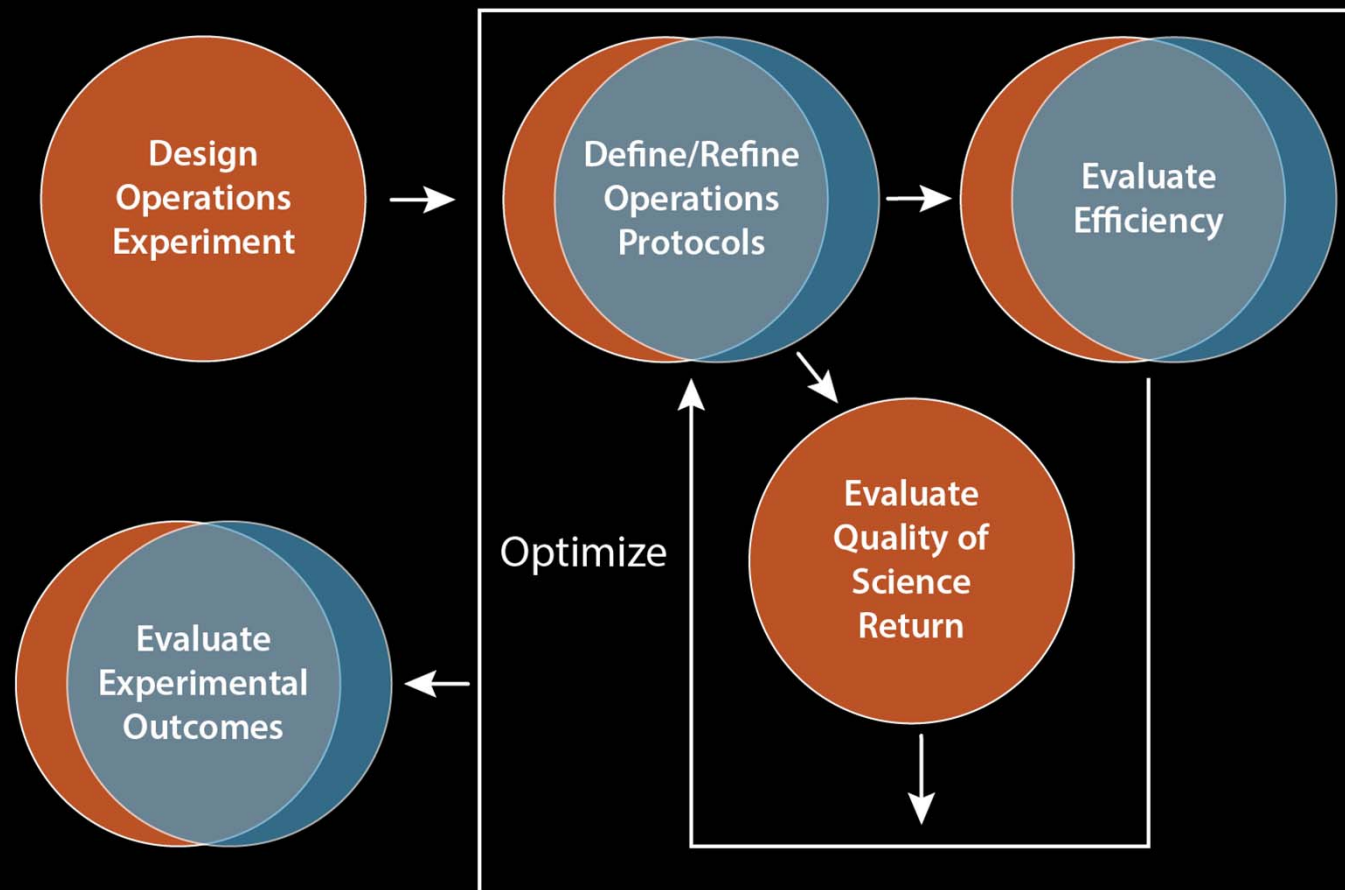
A Martian Example



And Another



Science Operations Research



Science Input
Engineering Input

Step 3: Astronaut Basic Training



Step 3: Astronaut Basic Training

- Astronaut/explorers, only some of whom might be geologists, must be schooled in the essentials of planetary field science with advanced technologies
- Curriculum must include scientific context, field observation, instrument deployment, and sample collection
- Pedagogy must emphasize the value of multiple perspectives and multiple working hypotheses for on-the-fly problem solving
- A goal should be to educate them to contribute to SciOps experiments as part of their preparation for future planetary surface research

Take-Away Messages

- We are ill-prepared for optimal planetary field geology operations
- Care must be taken to avoid adding complexity just because we can; we must add, not subtract
- Effective preparations will require recursive efforts among scientists, engineers, and astronaut/explorers
- New enabling technologies for planetary field geology could revolutionize terrestrial field geology