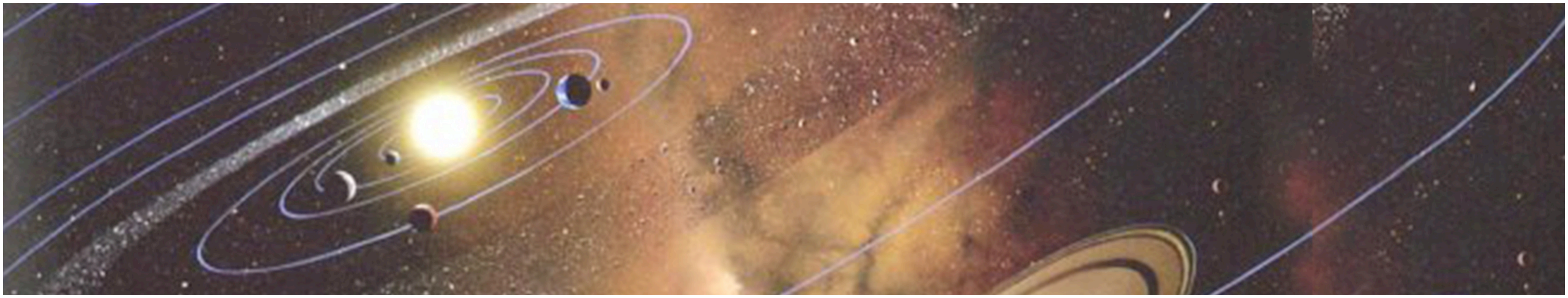


Global Exploration Roadmap (GER) Synergies in Science and Exploration

Greg Schmidt, Deputy Director
Solar System Exploration Research Virtual Institute (SSERVI)

Topics

GER: Strategic alignment effort

Destination Science: Human/Robotic Organizational Scheme

SSERVI: Brief Introduction

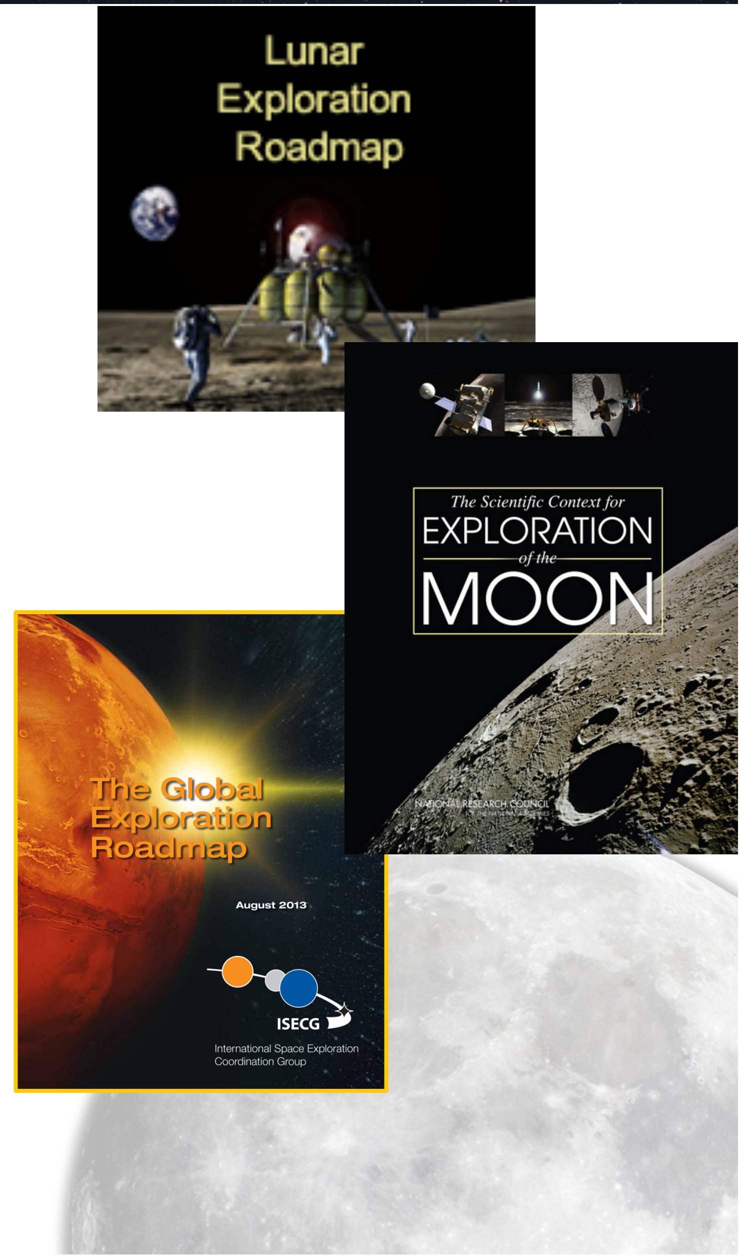
GER: Strategic Alignment

Process initiated by members of international community (Neal, Schmidt, Crawford, Carpenter et. al.) to create alignment between key science and exploration related documents and GER

Objectives:

- Strengthen GER
- Provide additional level of detail through community-developed documents

- Initial documents include LEAG Lunar Exploration Roadmap, HEOMD Strategic Knowledge Gaps, Scientific Context for Exploration of the Moon and other high-level study efforts
- Initial summary to community planned at European Lunar Symposium, 15-16 May 2014 in London
- Follow-up presentation at Exploration Science Forum, 21-23 July 2014 at NASA Ames Research Center



Mapping SKGs, SCEM, & LER into the GER

Example: Polar Volatiles

Global Exploration Roadmap Priority:

- Advance knowledge base related to use of lunar resources.

Strategic Knowledge Gaps:

- Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps:
  - Map & characterize broad features of polar cold traps;
  - Determine lateral and vertical extent of polar volatiles;
  - Processes and history of water and other polar volatiles;

SCEM Report:

- <u>Priority 4</u> - The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.

Lunar Exploration Roadmap

- **Objective Sci-A-3**: Characterize the environment and processes in lunar polar regions and in the lunar exosphere (4 Investigations).

COSPAR

- Support studies and precursor activities toward “International human bases”**;**
- Sample return missions to the Moon, near-Earth asteroids and Mars.

Science via humans and robots: An Initial Perspective

GER (p. 6): Robotic science missions provide an important technique for obtaining the data needed to prepare for human exploration beyond low-Earth orbit. It is generally accepted by both the science and exploration communities that measurements and data sets obtained from robotic missions support both the advancement of science and preparation for human exploration. (GER, pg 6)

GER (p. 14) Human/Robotic Partnership – Maximize synergy between human and robotic missions
Combine unique and complementary capabilities of humans and robotic systems, enabling a greater set of goals to be met effectively, cost-efficiently and safely
Robotic precursor missions will prepare for human missions by acquiring strategic knowledge about future destinations and demonstrating critical technologies
Use of robots to assist and complement crew activities will also enhance the productivity and benefits of eventual human exploration missions to any given destination

But..
"*The unfortunate truth is that most things our rovers can do in a perfect sol* [i.e. a martian day] *a human explorer could do in less than a minute"* (Squyres, Roving Mars, 2005)

Sample return: Apollo (382 kg from 2000 discrete locations) vs. robotic Luna (.32 kg from 3 locations)

Robotic missions can help prepare for and supplement human exploration, but aren't a substitute

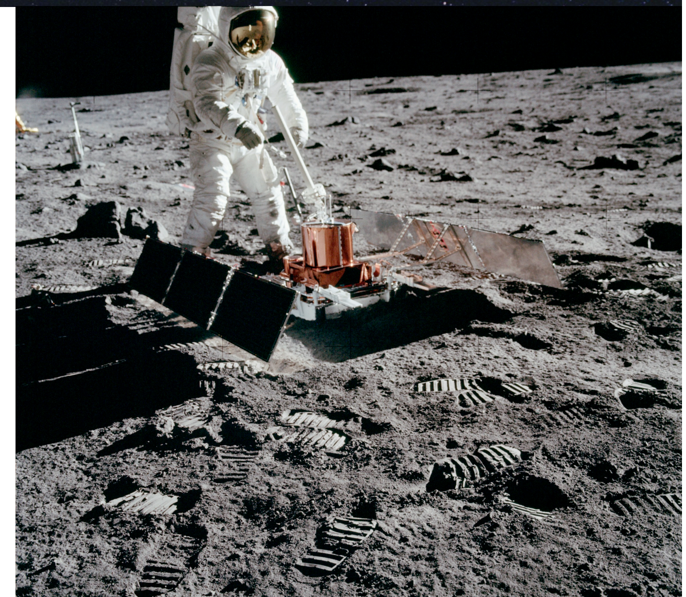
Destination Science

- Crew-performed Science Operations
- Crew-operated Robotic Vehicles
- Crew-Robot Collaboration
- Semi-Autonomous Robots
- Fully Autonomous Robots

Autonomy

Crew-performed Science Ops

Crew-performed Science Operations
Crew-Operated Robotic Vehicles
Crew-Robot Collaboration
Semi-Autonomous Robots
Fully Autonomous Robots



- Two prime examples from past exploration (not including ISS & other LEO):
  - ALSEP deployment
  - Apollo sample collection

GER (p.22) Human Assisted Sample return

- Increased science return with a larger and more diverse set of samples
- Reduced complexity of robotic mission, transferring sample handling responsibilities to the crew
- Improved mission robustness and reliability due to having a human in the loop
- Better opportunities for public engagement due to astronaut involvement enabling demonstration of the significance of lunar science to a broader community
- Broader opportunities for int’l cooperation

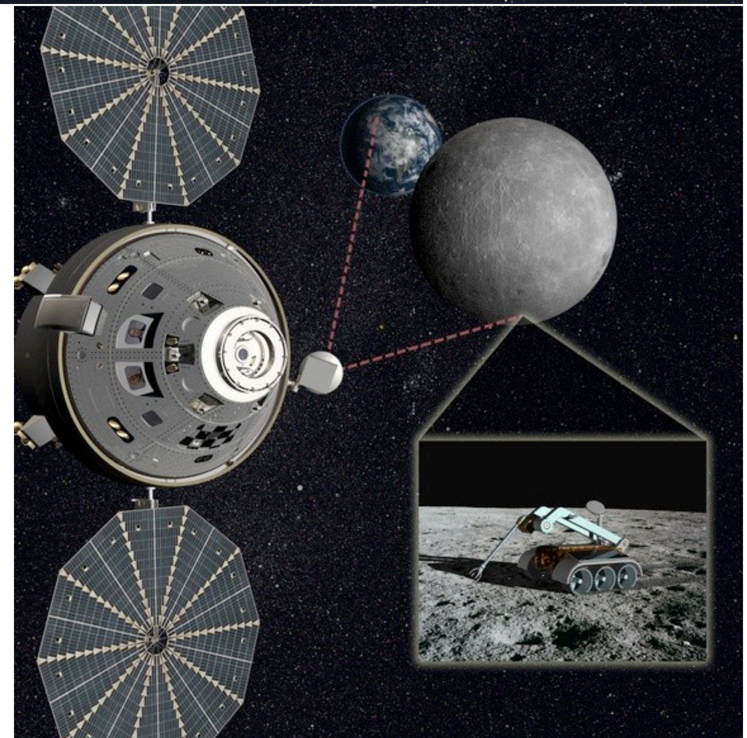
Field Training

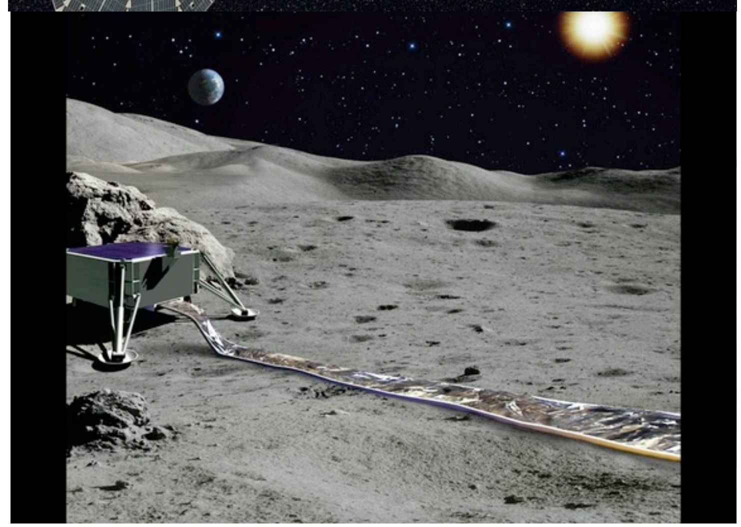
Crew-performed Science Operations
Crew-Operated Robotic Vehicles
Crew-Robot Collaboration
Semi-Autonomous Robots
Fully Autonomous Robots

- Field training is of key importance to enabling in-situ science
    - Numerous analog environments (e.g., Barringer crater, Sudbury, Hawaii volcanic fields) useful for obtaining relevant knowledge
    - Opportunity for international collaboration (e.g., Sudbury)
    - Highlighted by GER (p.38)

Human Operated Robots

- Crew-performed Science Operations
- **Crew-Operated Robotic Vehicles**
- Crew-Robot Collaboration
- Semi-Autonomous Robots
- Fully Autonomous Robots



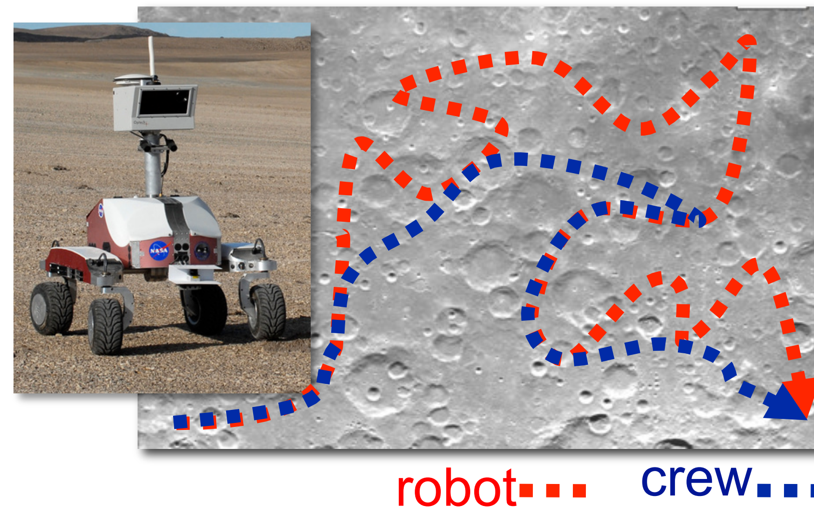


Proposed Orion mission to Earth-Moon L2

- Emplace dipole antennae on lunar farside (*Burns*)
- Sample return via robot and Orion (*Kring*)
- Both make use of unique, important location
  - Farside important for astrophysics
  - Sample return location of key importance (planetary decadal)
- GER (p. 22): New mission concepts, such as human-assisted sample return and tele-presence should be further explored, increasing understanding of the important role of humans in space for achieving common goals.

Robotic Recon

- Crew-performed Science Operations
- Crew-Operated Robotic Vehicles
- Crew-Robot Collaboration
- Semi-Autonomous Robots
- Fully Autonomous Robots



Scouting for human exploration

- Reduces unproductive crew time and increases science return
- Traverse-based (examining stations on a route)
- Systematic survey (collecting data in a bounded area)

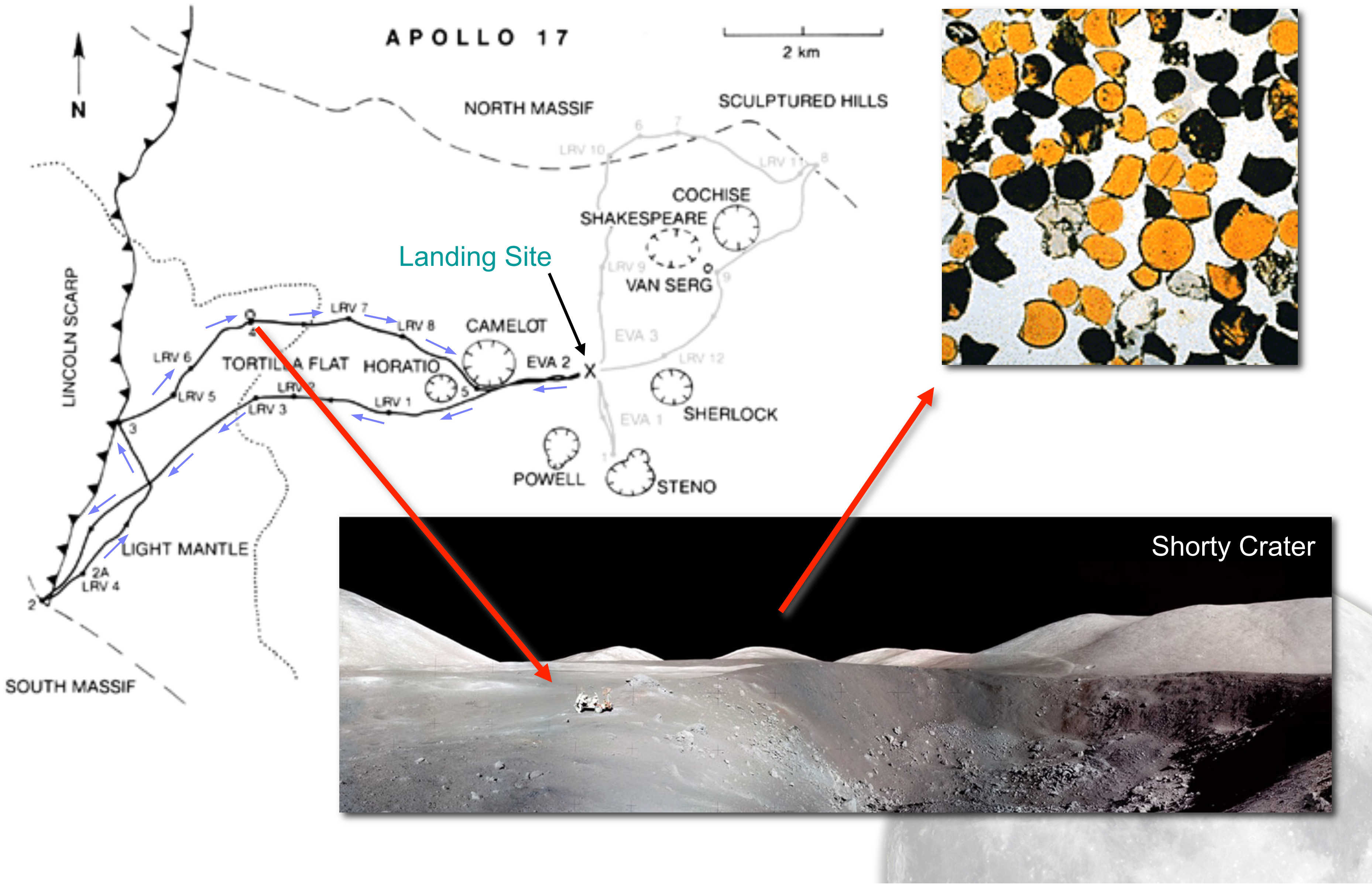
Surface data vs. orbital data

- Higher resolution
- Oblique & close-up views (non-nadir)
- Contact & subsurface measurements

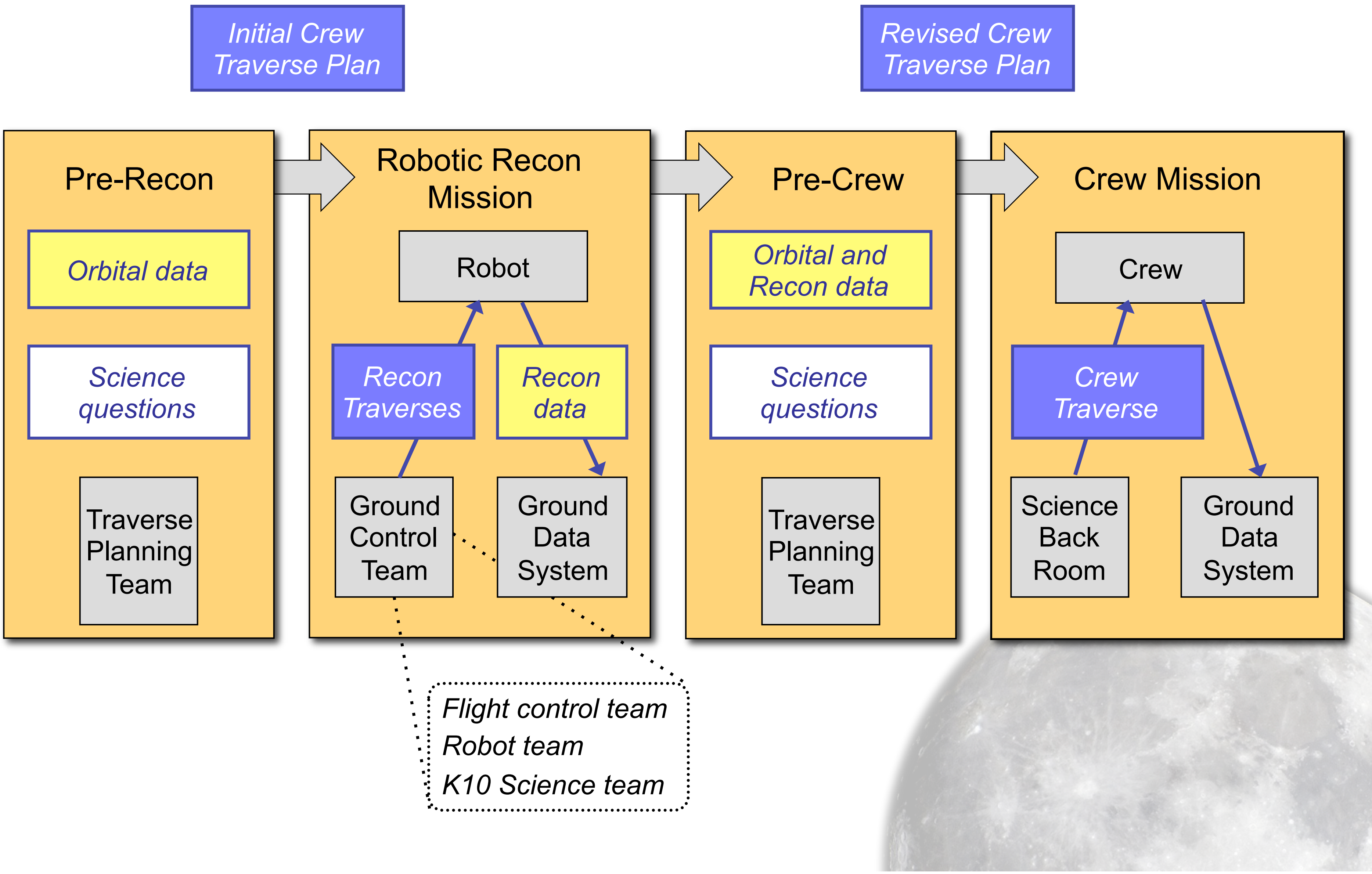
Robots collect surface data

- Cameras, lidar, spectrometers, penetrometers, etc.
- Ground control with a science team
- Robot is not the primary instrument (e.g., robotic recon is not like MER !!!)

Why Is Recon Useful?



Robotics Leading to Crewed Missions



Benefits of Robotic Recon

- Benefits of robotic recon
  - Improves science (traverse merit & science return)
  - Reduces operational risk (assess trafficability, comms, etc.)
  - Improves crew productivity (better activity planning & pre-flight briefing)
- Robotic recon improves understanding
  - Increases familiarity with site (terrain, extents, scale, etc.)
  - Reduces uncertainty (target selection & designation)
  - Enhances preparation: helps crew know what to expect
- Primary bottleneck = science operations speed
  - Robot speed is not the limitation during recon
  - Robotics operates faster than the science team can vet data, analyze & plan

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Semi-Autonomous Robots

- Crew-performed Science Operations
- Crew-Operated Robotic Vehicles
- Crew-Robot Collaboration
- **Semi-Autonomous Robots**
- Fully Autonomous Robots

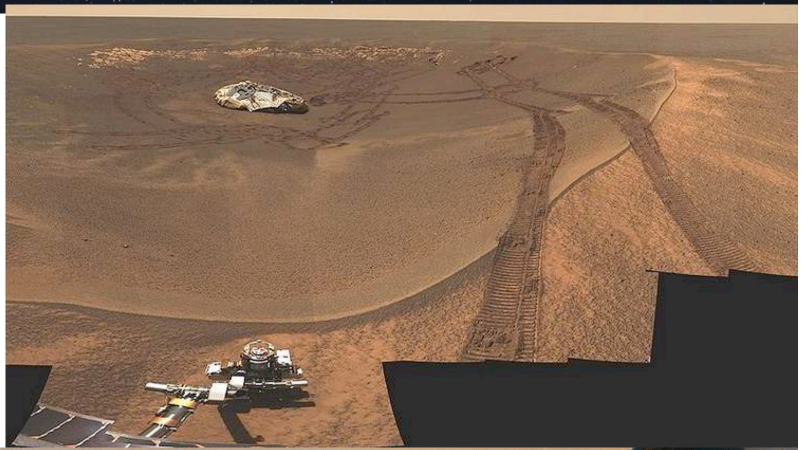
Key characteristic for semi-autonomous robots: Science team sets goals, robots figure out path

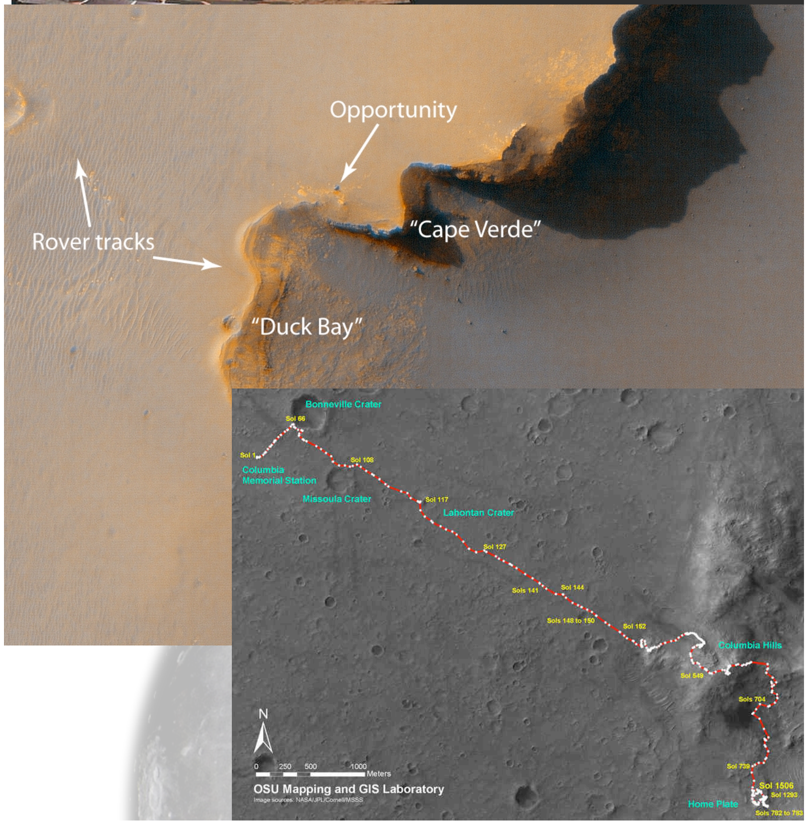
- Useful for long communication delays (e.g., Earth – Mars); e.g., MER, MSL

Potentially useful in other circumstances

- Multiple robots (“swarms”) using high-level control, but with lower communication delays

Key question – in this circumstance does a crew provide added value over a (remote) science team?

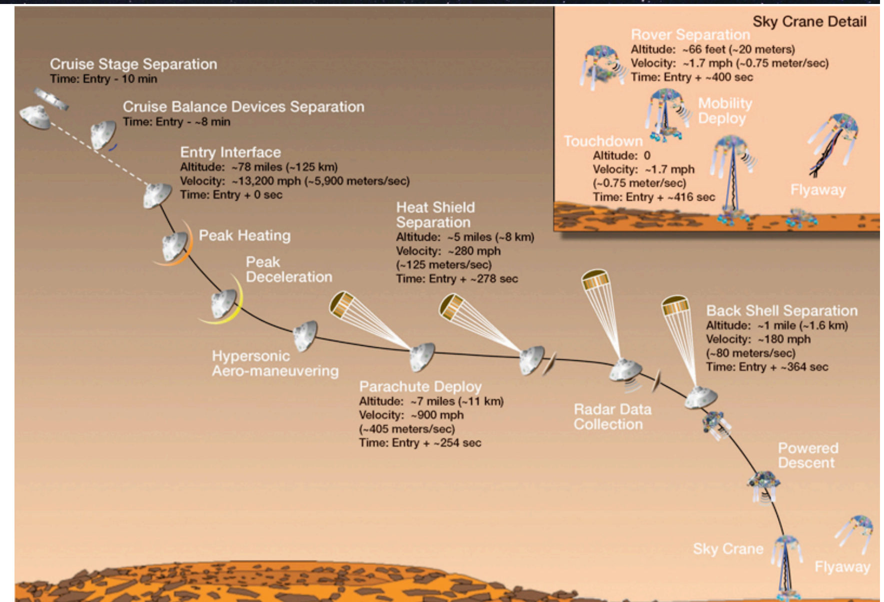




Full Autonomy

Robots operate without human interaction

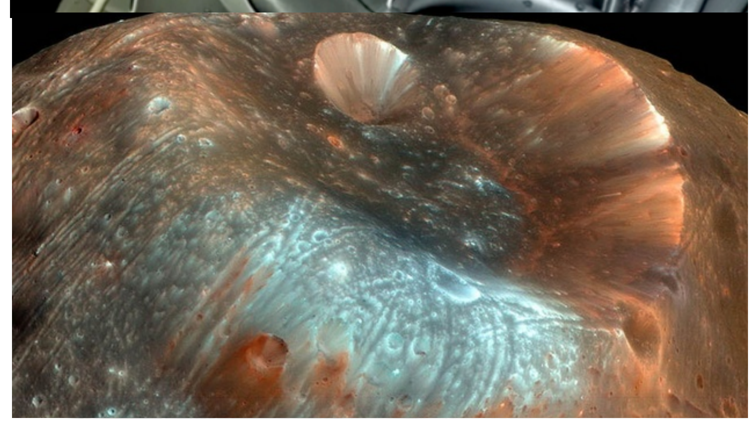
- Best example: MSL descent sequence
  - EDL phase of the MSL: took 7 minutes and unfolded automatically
  - Pre-programmed by JPL engineers in advance, autonomous EDL sequence occurred in four distinct event phases
  - The final landing place for the rover was less than 2.4 km (1.5 mi) from its target after a 563,270,400 km (350,000,000 mi) journey.
- Excellent for well-defined series of operations; inadequate for fundamentally unpredictable nature of science operations



SSERVI Science

SSERVI provides scientific, technical and mission-defining analyses for relevant NASA programs, planning and space missions, including:

- The role of the Moon, NEAs, Phobos & Deimos in revealing the origin and evolution of the inner Solar System
- Moon, NEA, and Martian moon investigations as windows into planetary differentiation processes
- Near-Earth asteroid characterization (including NEAs that are potential human destinations
- Lunar structure and composition
- Regolith of Target Body(s)
- Dust and plasma interactions on Target Body(s)
- Volatiles (in its broad sense) and other potential resources on Target Body(s)
- Innovative observations that will advance our understanding of the fundamental physical laws, composition, and origins of the Universe



SSERVI at a Glance

- **Nine domestic teams, each for 5 years:**
- **Bill Bottke**, Southwest Research Institute. "*Institute for the Science of Exploration Targets: Origin, Evolution and Discovery" (ISET)*
- **Dan Britt**, University of Central Florida. *"Center for Lunar and Asteroid Surface Science" (CLASS)*
- **Ben Bussey**, Applied Physics Lab, Johns Hopkins University. *"Volatiles, Regolith and Thermal Investigations Consortium For Exploration and Science (VORTICES)"*
- **Bill Farrell**, Goddard Space Flight Center. *"Dynamic Response of Environments at Asteroids, the Moon, and moons of Mars (DREAM2)"*
- **Tim Glotch**, Stony Brook University. *"Remote, In Situ and Synchrotron Studies for Science and Exploration"*
- **Jennifer Heldmann**, Ames Research Center, *"Field Investigations to Enable Solar System Science & Exploration" (FinESSE)*
- **Mihaly Horanyi**, University of Colorado. *"Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT)"*
- **David Kring**, Lunar and Planetary Institute. *"Inner Solar System Impact Processes"*
- **Carle Pieters**, Brown University. *"Evolution and Environment of Exploration Destinations: Science and Engineering Synergism (SEEED)"*

- **Seven international partnerships**
  - additional partnerships in development

Canada
PI: Gordon "Oz" Osinski,
University of Western Ontario
Partnership signed July 2008

Korea
PI: Im Yong-Taek,
Korean Institute for Advanced Science & Technology (KAIST)
Partnership signed November 2008

United Kingdom
PI: Mahesh Anand,
Open University
Partnership signed January 2009

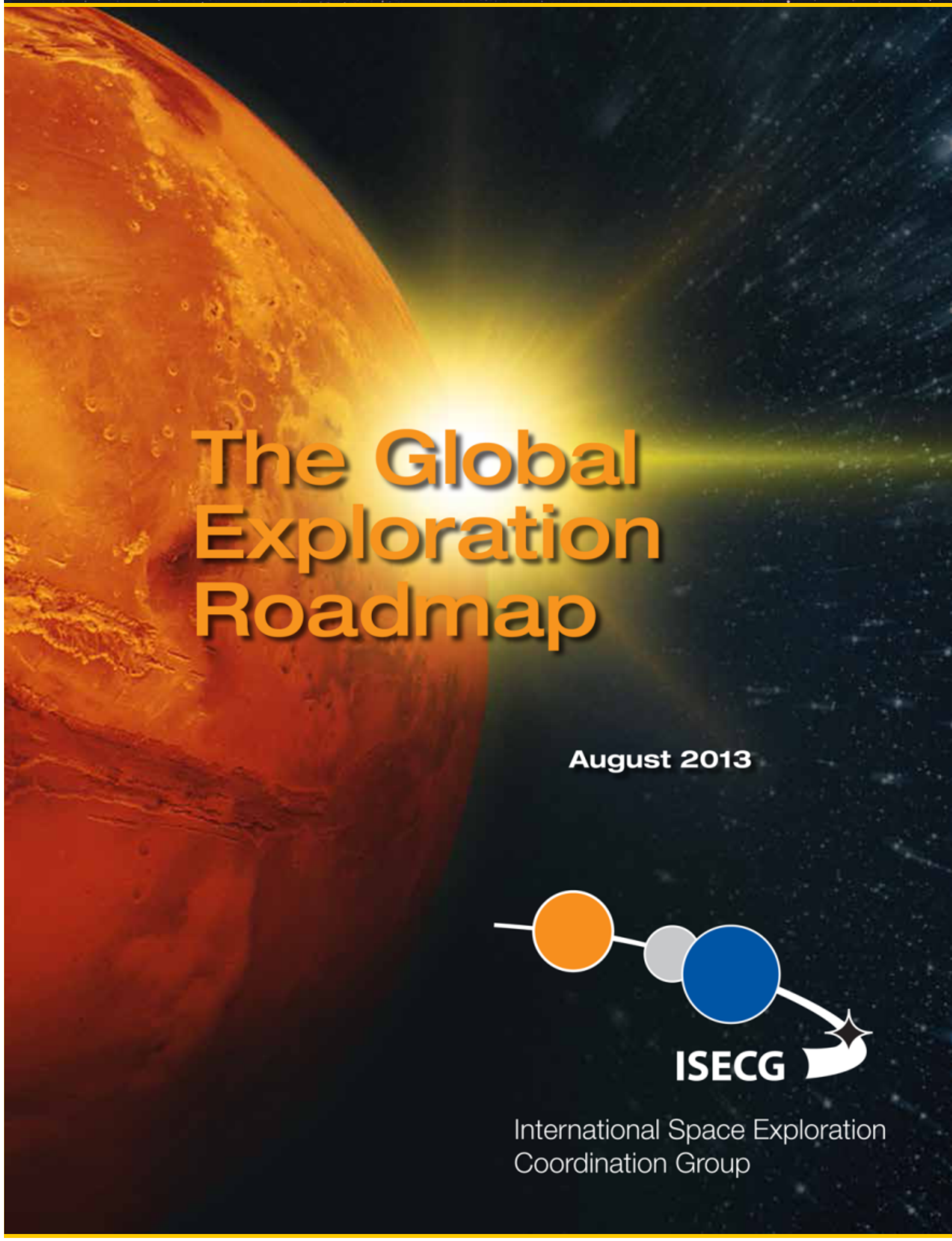
Kingdom of Saudi Arabia
PI: Abdulaziz Alothman
King Abdulaziz City for Science and Technology (KACST)
Partnership signed in Dec. 2009

Israel
PI: Shlomi Arnon
Ben-Gurion University at the Negev
Partnership signed in January 2010

Netherlands
PI: Wim van Westrenen
VU University Amsterdam
Partnership signed August 2010

Germany
PI: Ralf Jaumann
DLR
Partnership signed Dec. 2010

Conclusions



- Science can be infused into exploration at all levels of human-robotic collaboration

- Although the best science is performed directly by humans *in situ*, there is a need for robotic precursor explorers and then parallel mission element partners, for a fully developed human exploration program