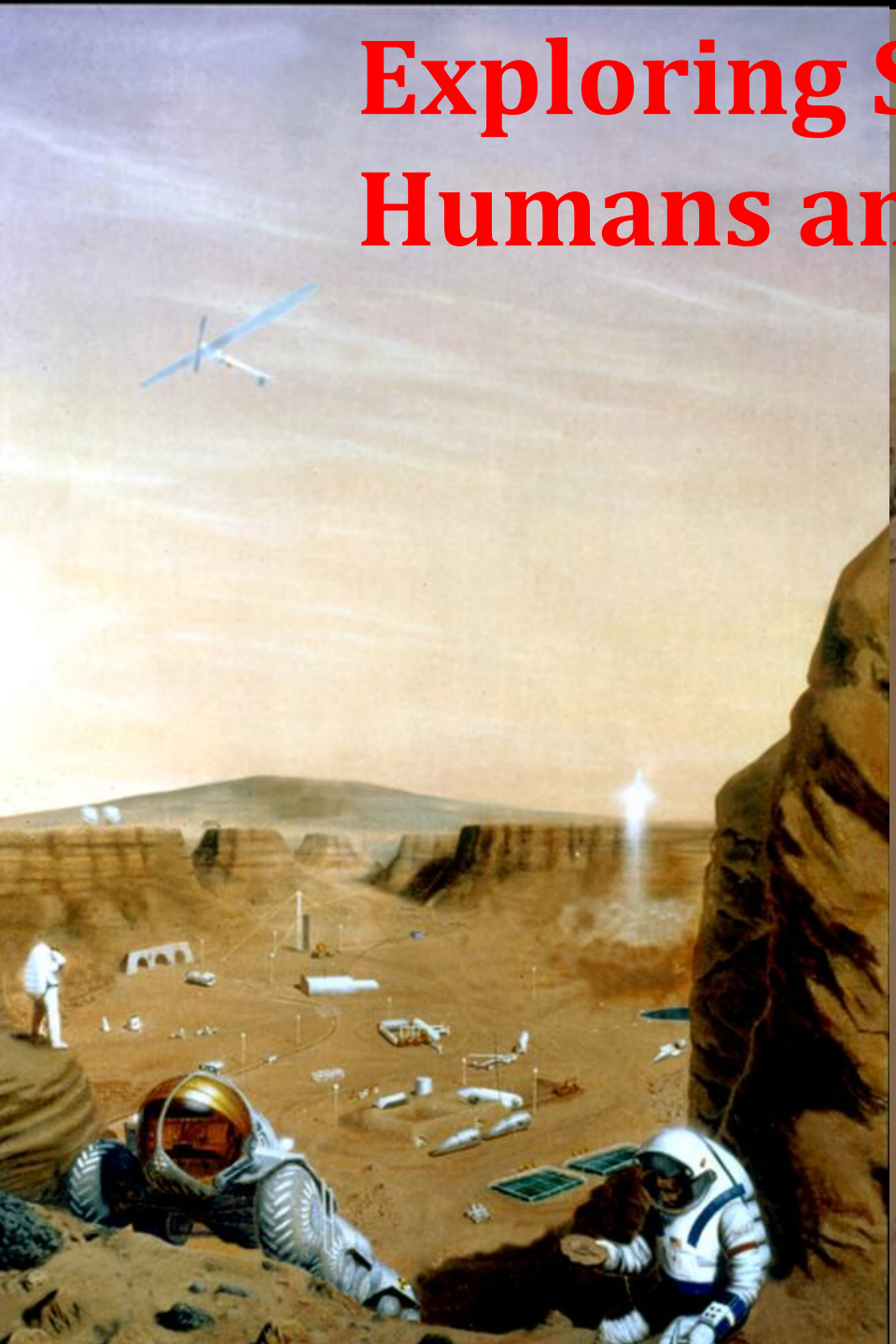
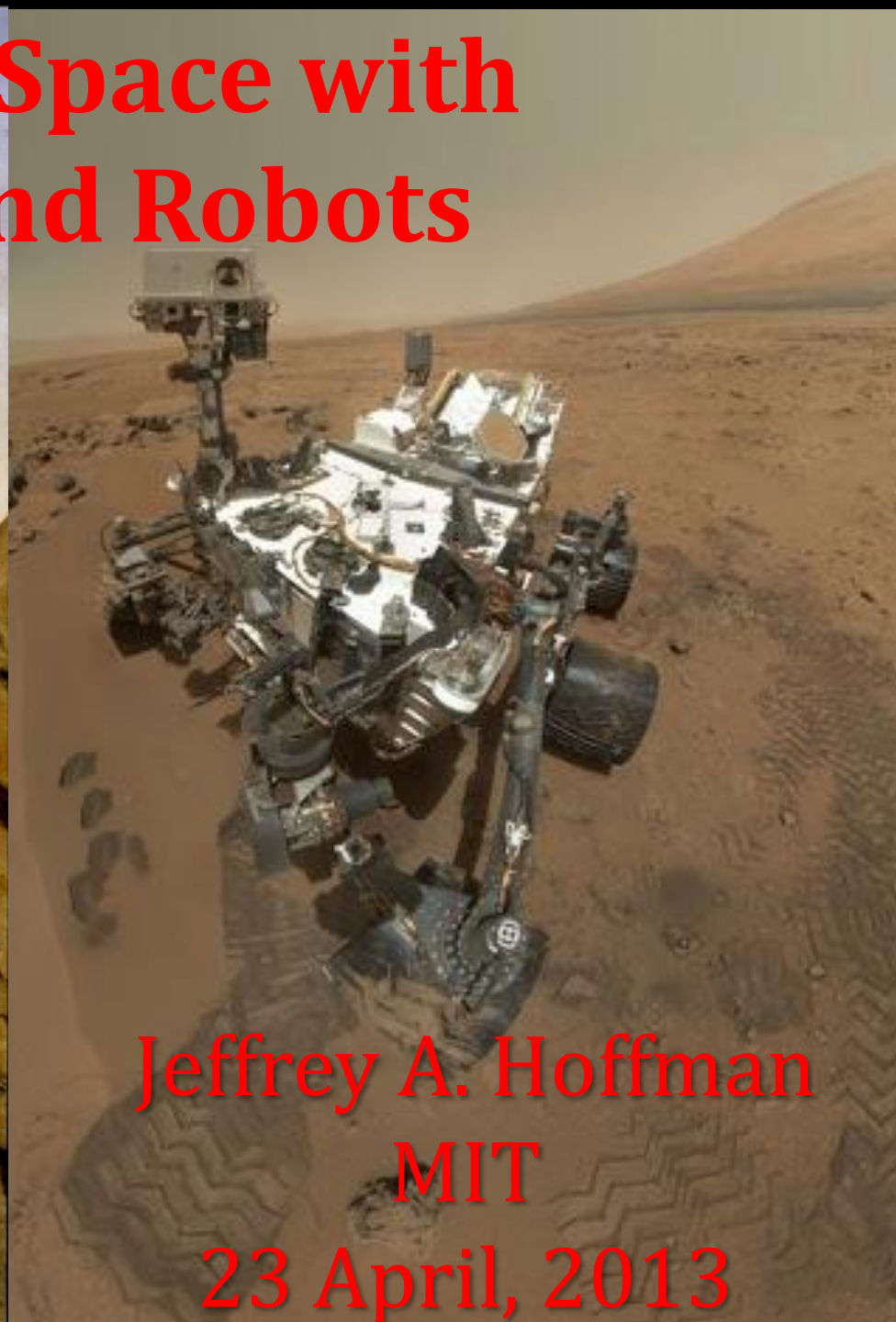
Exploring Space with Humans and Robots

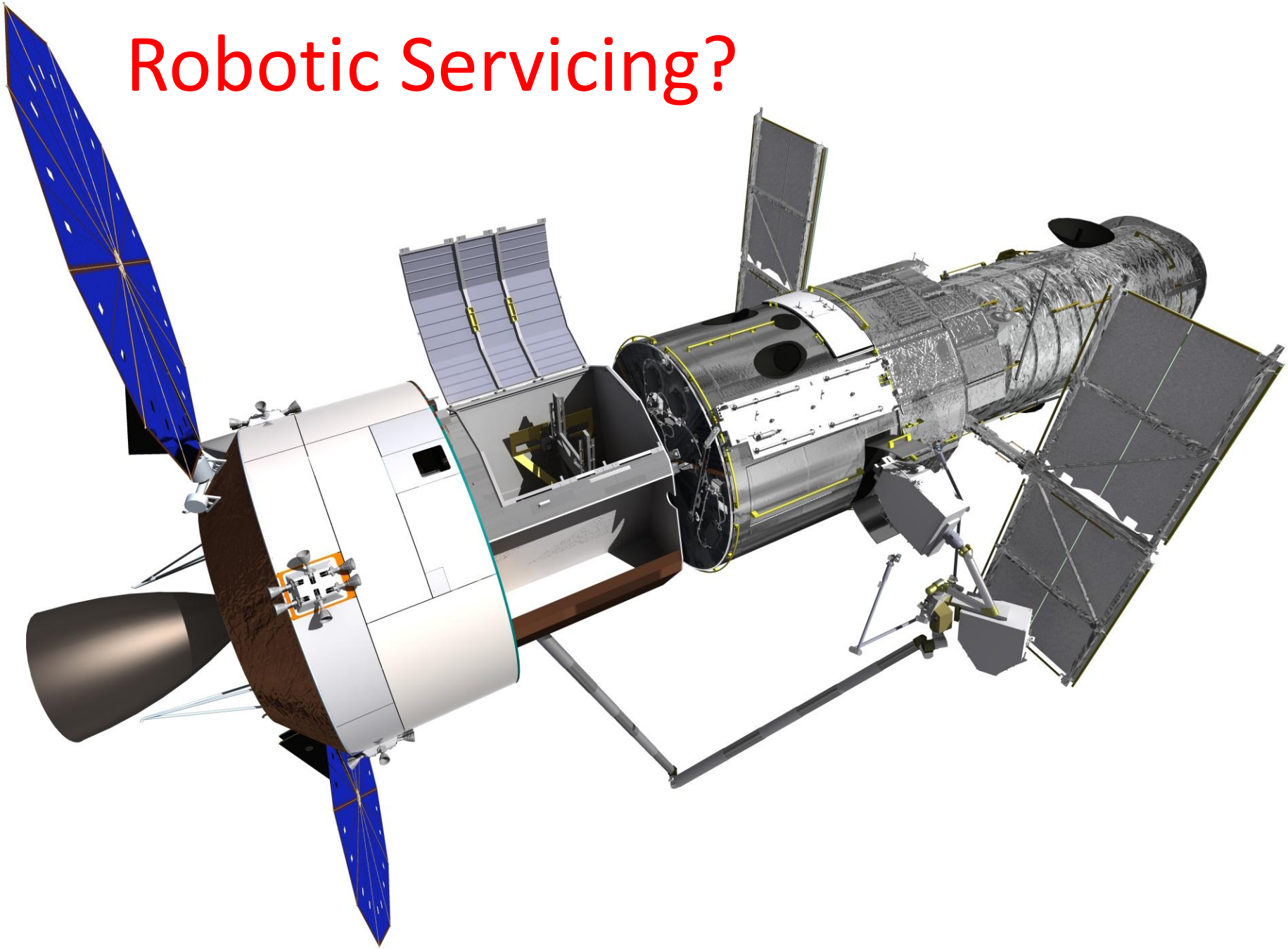


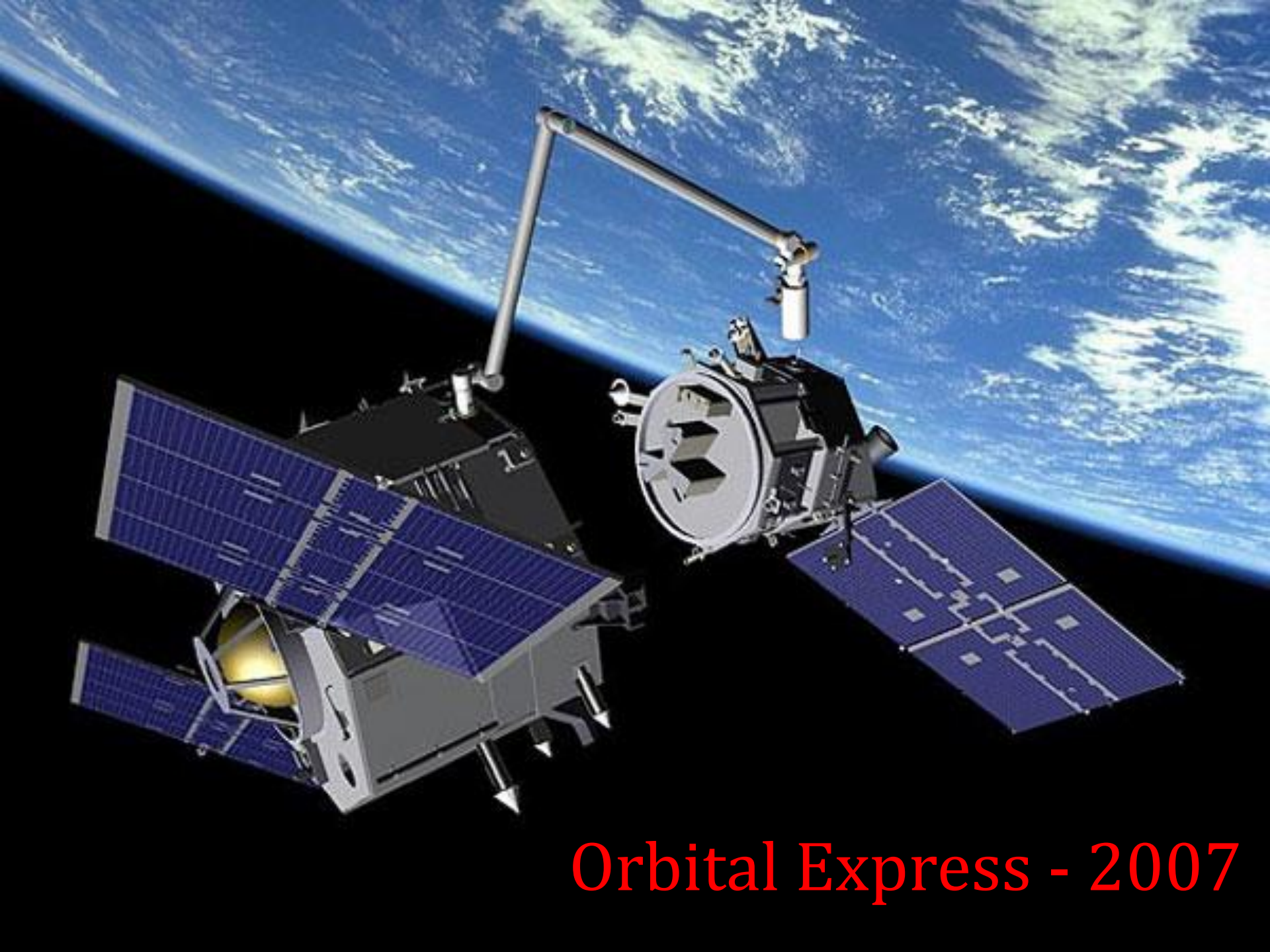


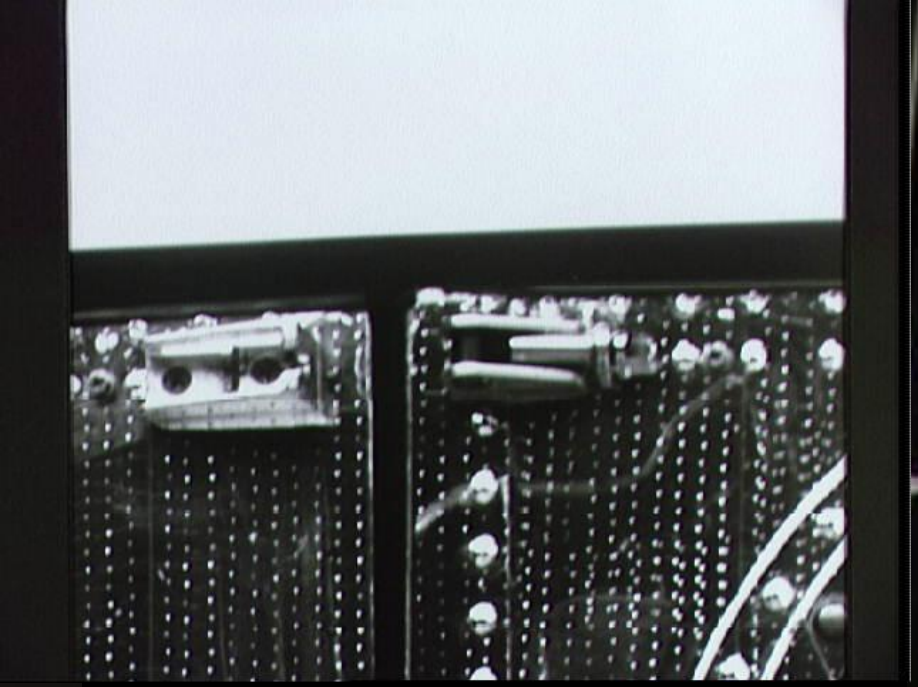
Jeffrey A. Hoffman
MIT
23 April, 2013

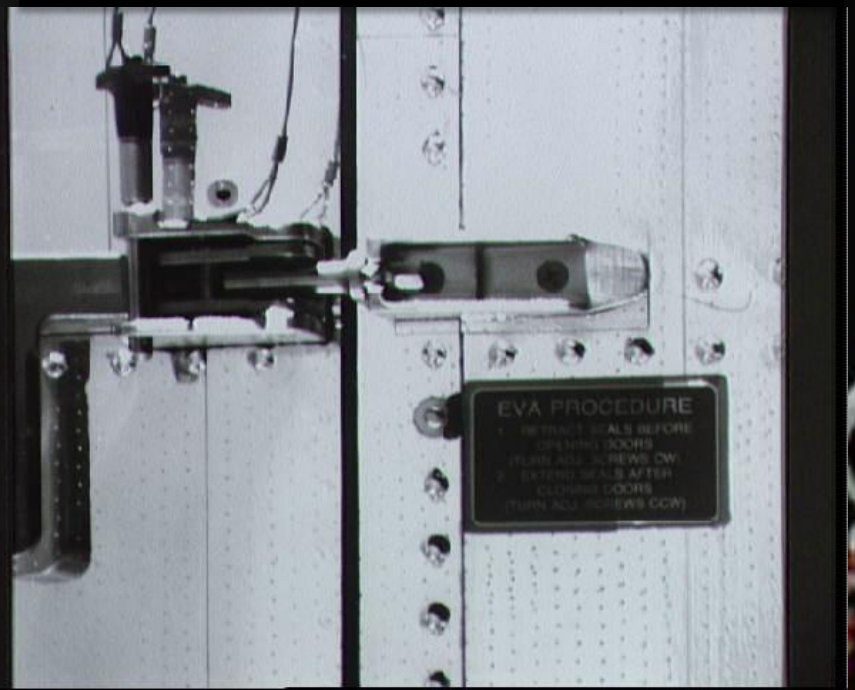
Complexity, Repair, and Servicing

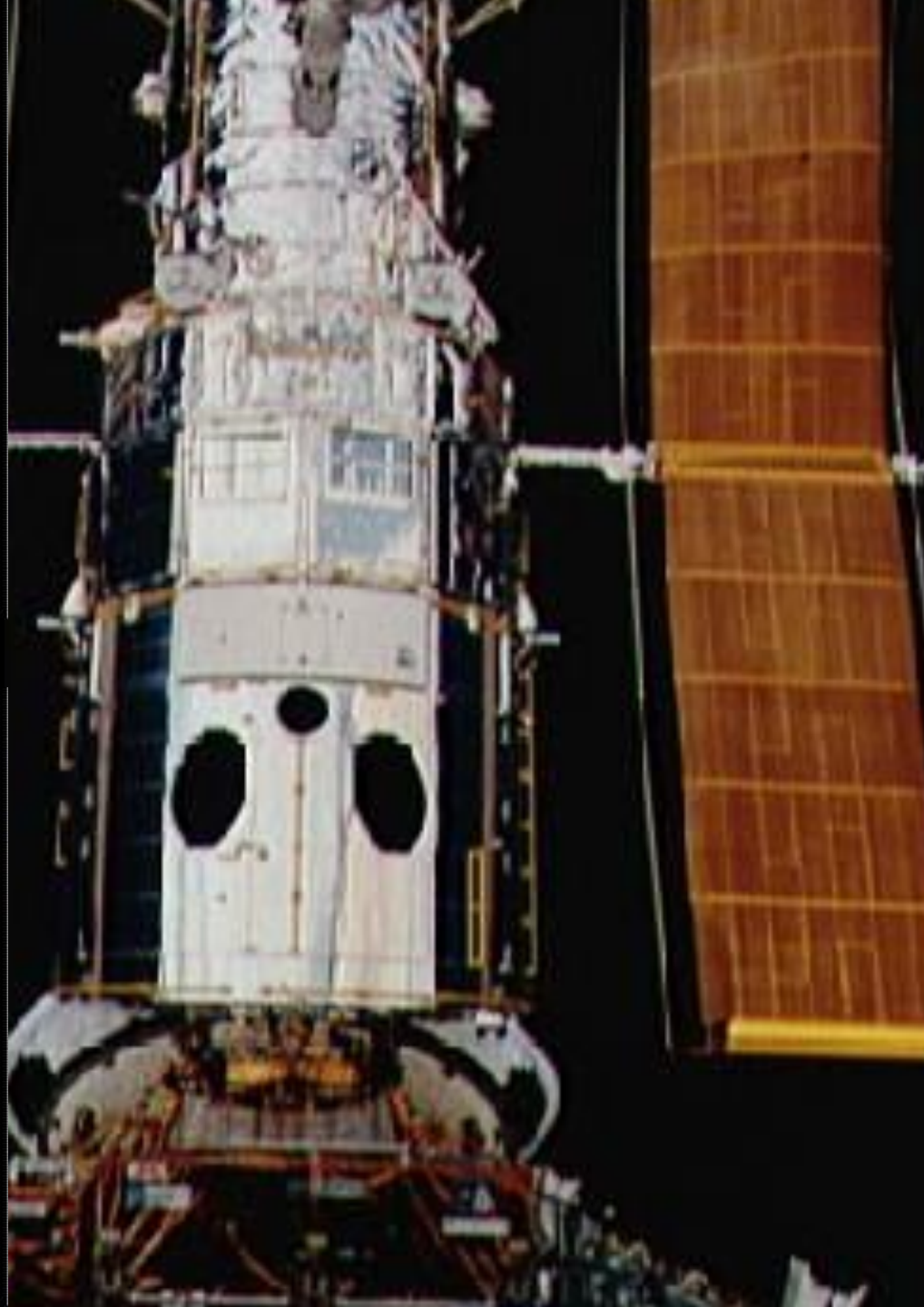
Robotic Servicing?

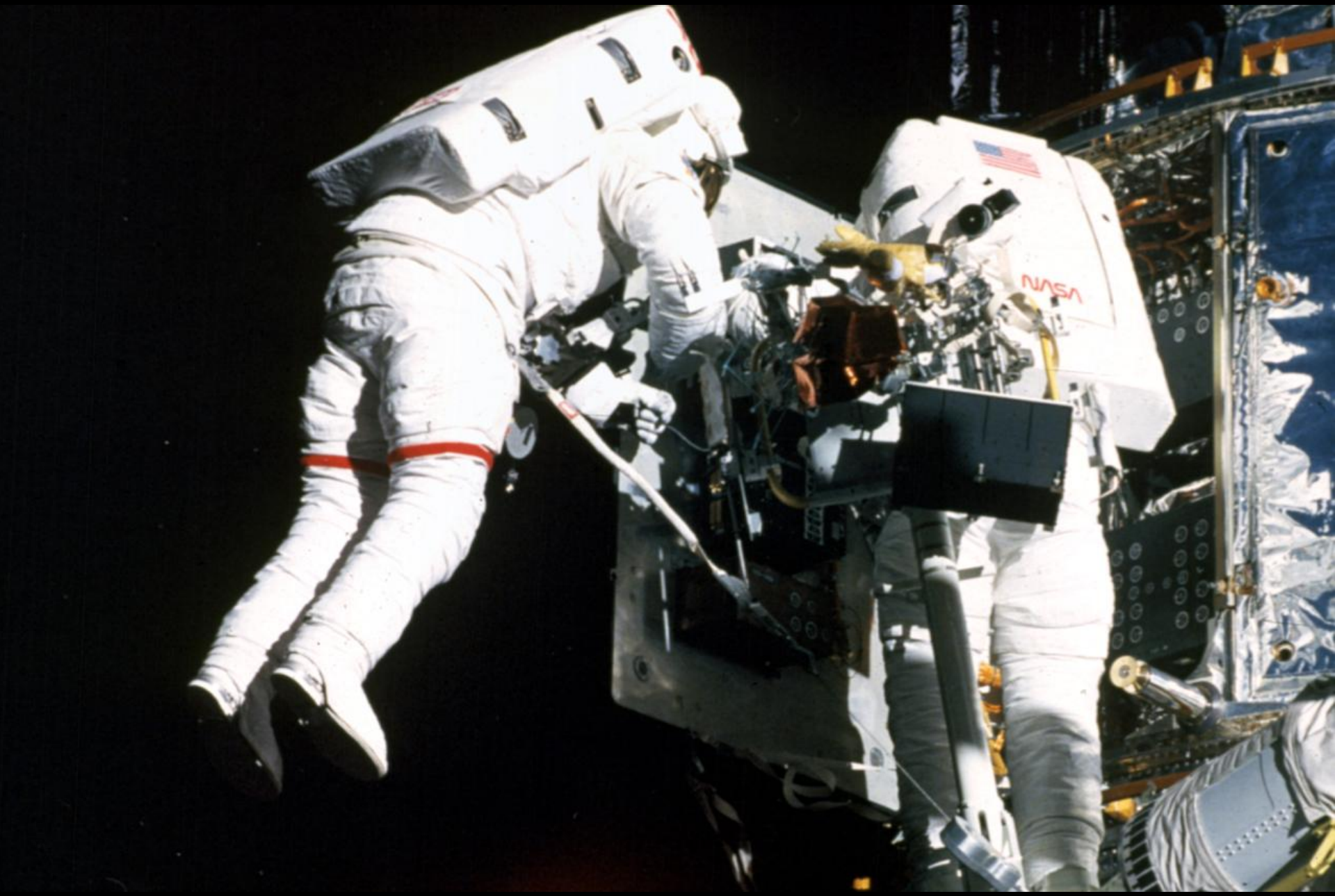



Orbital Express - 2007

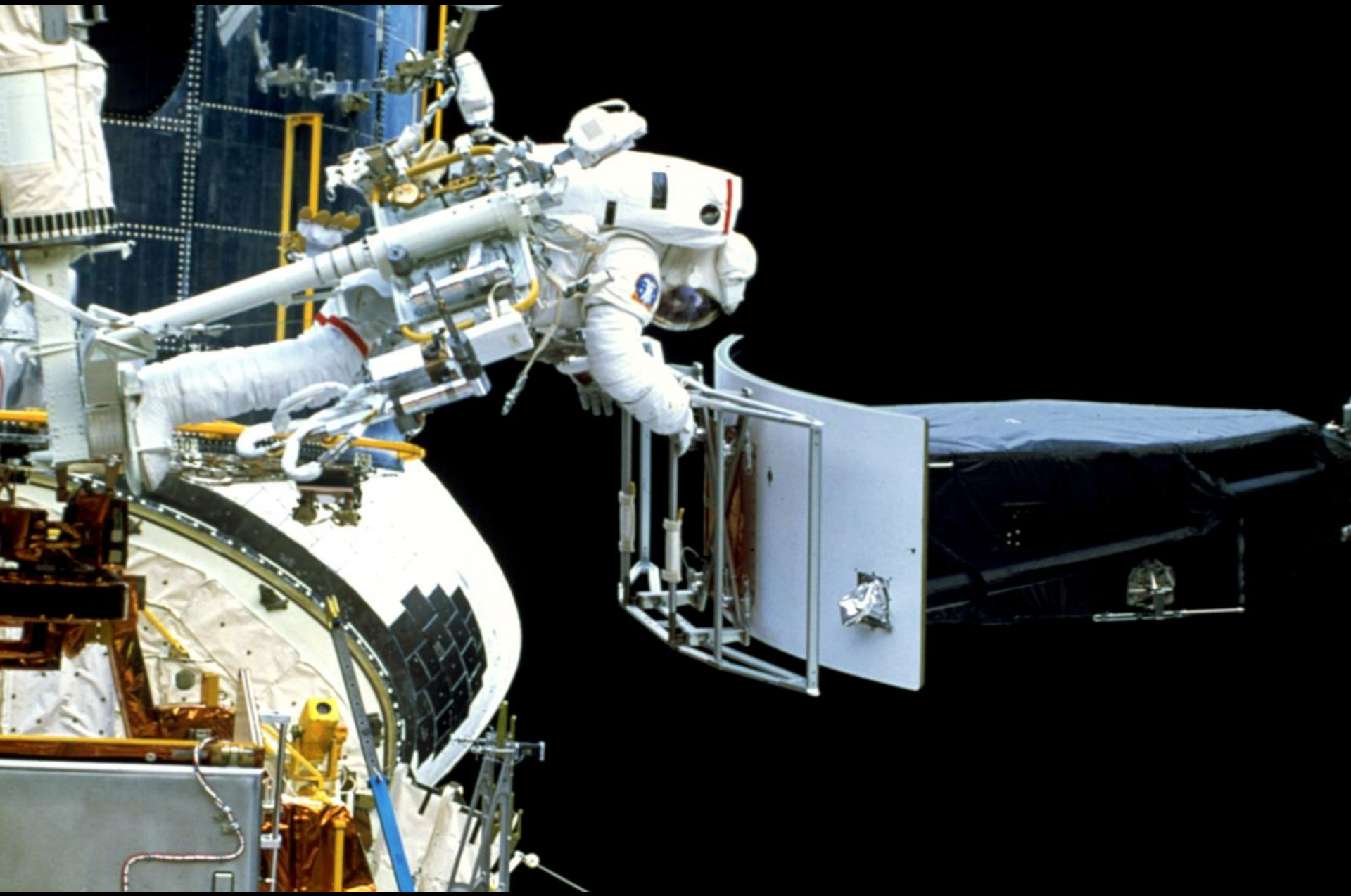


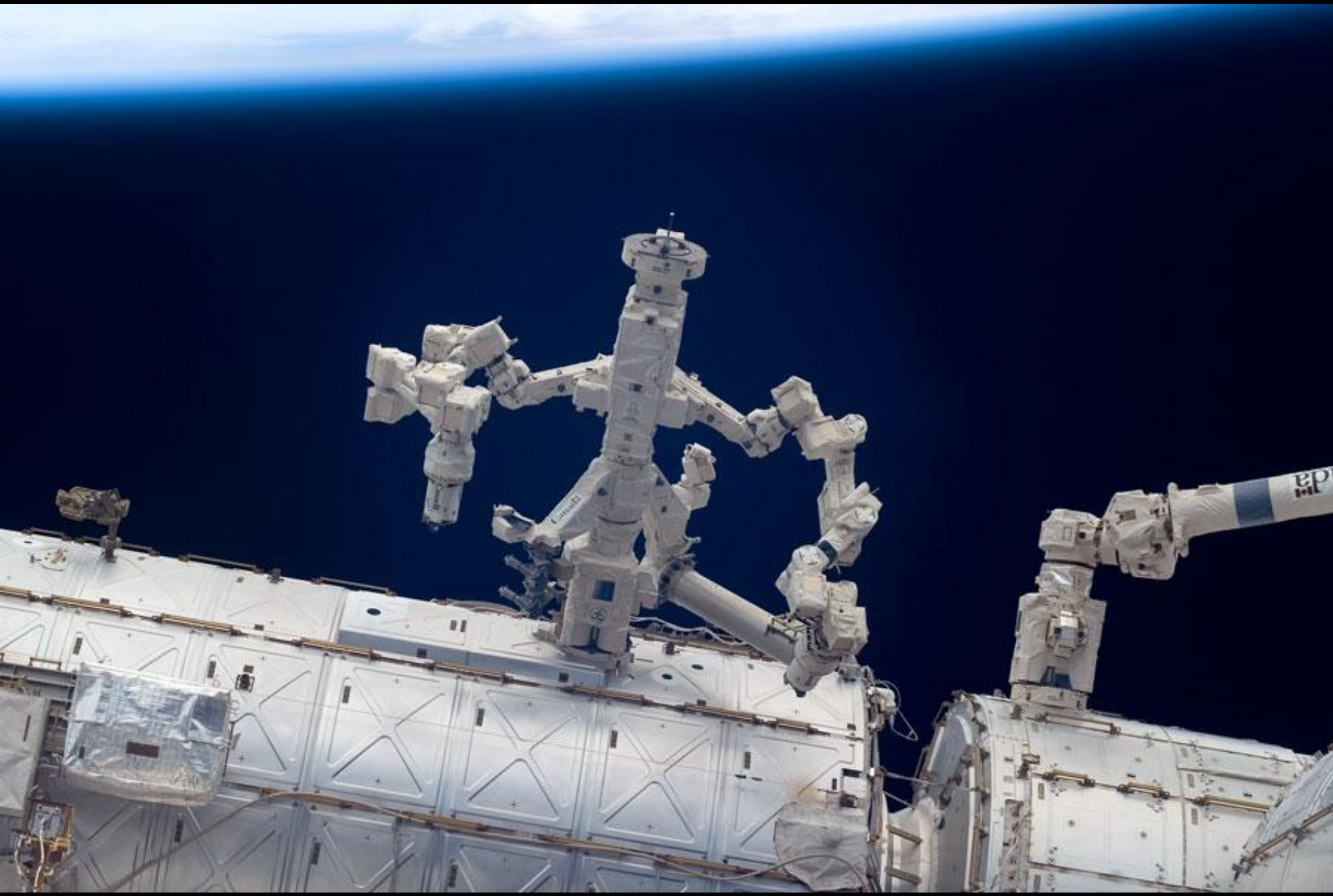

EVA PROCEDURE




NASA


GE2000350
SN 1008
GE2000350
SN 1005

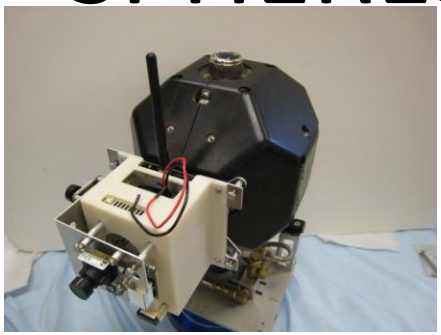





SPHERES

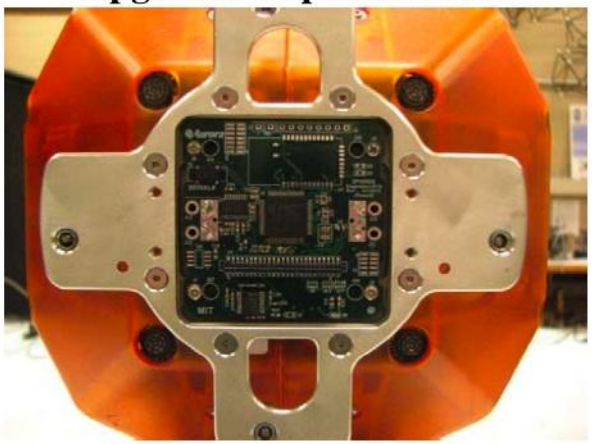

DECK

SPHERES: ISS National Laboratory



VISION-BASED NAVIGATION

Upgraded Expansion Port

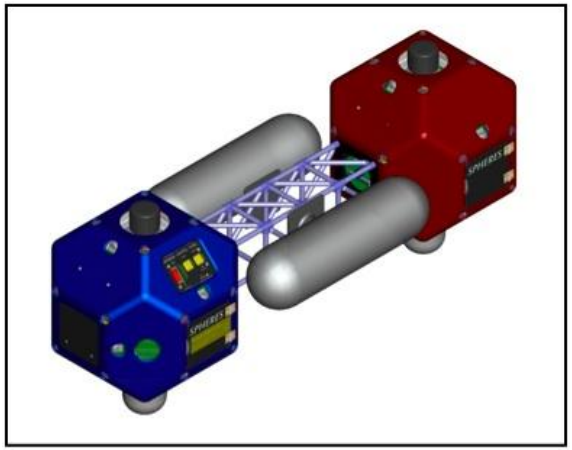


EXPANSION PORT

ELECTRO-MAGNETIC ACTUATION

TETHERED FORMATIONS

EXO-SPHERES



FLUID SLOSH

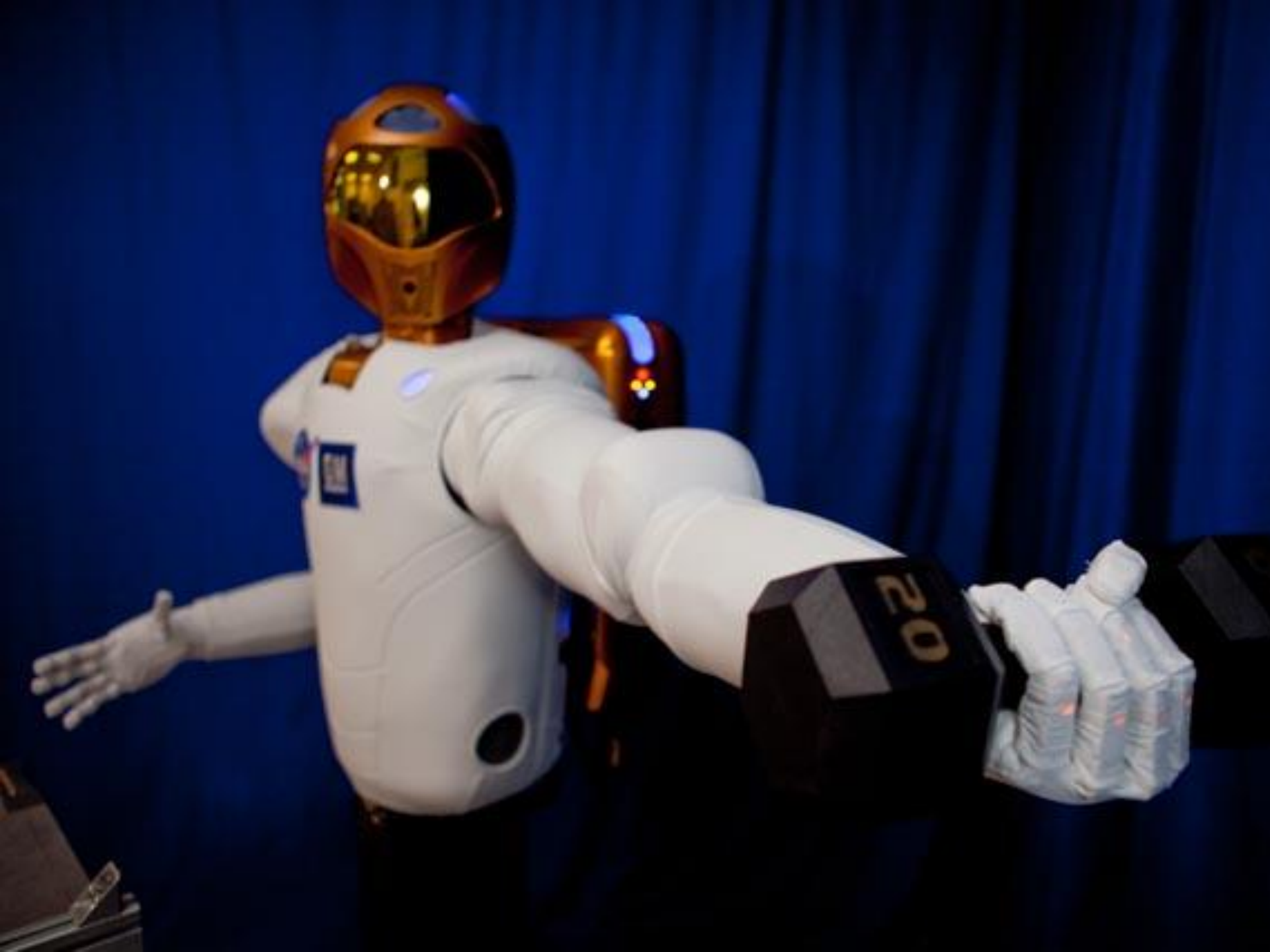
SPHERES: Zero Robotics

- A competition designed to allow Middle- and High-school students unprecedented access to the International Space Station

- Teams of students work to *program* the SPHERES satellite to win an MIT-designed game

- The teams go through multiple elimination rounds; the top teams see their code tested aboard the ISS

A "complementary" software Competition in the Fall, similar to the FIRST Robotics HW in Spring.


20

0-G Climbing

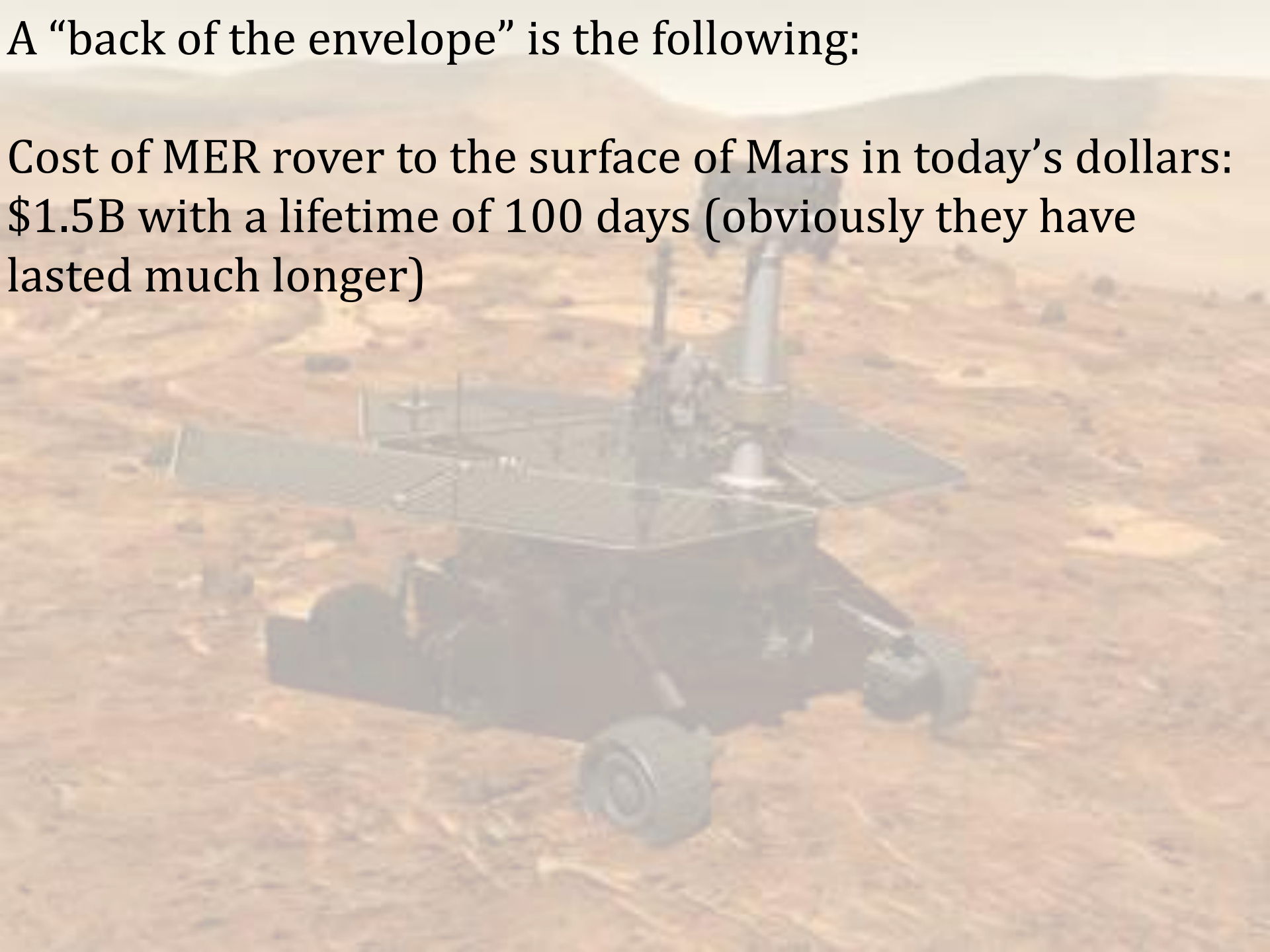

NASA

COST vs. SCIENCE RETURN

A “back of the envelope” is the following:

A “back of the envelope” is the following:

Cost of MER rover to the surface of Mars in today’s dollars: $1.5B with a lifetime of 100 days (obviously they have lasted much longer)



A “back of the envelope” is the following:

Cost of MER rover to the surface of Mars in today’s dollars: $1.5B with a lifetime of 100 days (obviously they have lasted much longer)

Cost of Human crew to Mars in today’s dollars: $150B
(estimate of minimal mission to achieve a short stay surface mission)

A “back of the envelope” is the following:

Cost of MER rover to the surface of Mars in today’s dollars: $1.5B with a lifetime of 100 days (obviously they have lasted much longer)

Cost of Human crew to Mars in today’s dollars: $150B
(estimate of minimal mission to achieve a short stay surface mission)

The science for the 100-day mission would be accomplished by a human crew in about 4 hours
(Steve Squyres estimate, confirmed by many planetary scientists)

A “back of the envelope” is the following:

Cost of MER rover to the surface of Mars in today’s dollars: $1.5B with a lifetime of 100 days (obviously they have lasted much longer)

Cost of Human crew to Mars in today’s dollars: $150B
(estimate of minimal mission to achieve a short stay surface mission)

The science for the 100-day mission would be accomplished by a human crew in about 4 hours
(Steve Squyres estimate, confirmed by many planetary scientists)

So roughly speaking a crew of 6 would perform at least 100x the science of the robot for 100x the investment.

Typically, well-trained humans make discoveries that robots cannot, so the actual scientific return is even higher.

Humans can set up robotic equipment to function long after humans leave, and with human intervention, more complex robotic systems are possible.

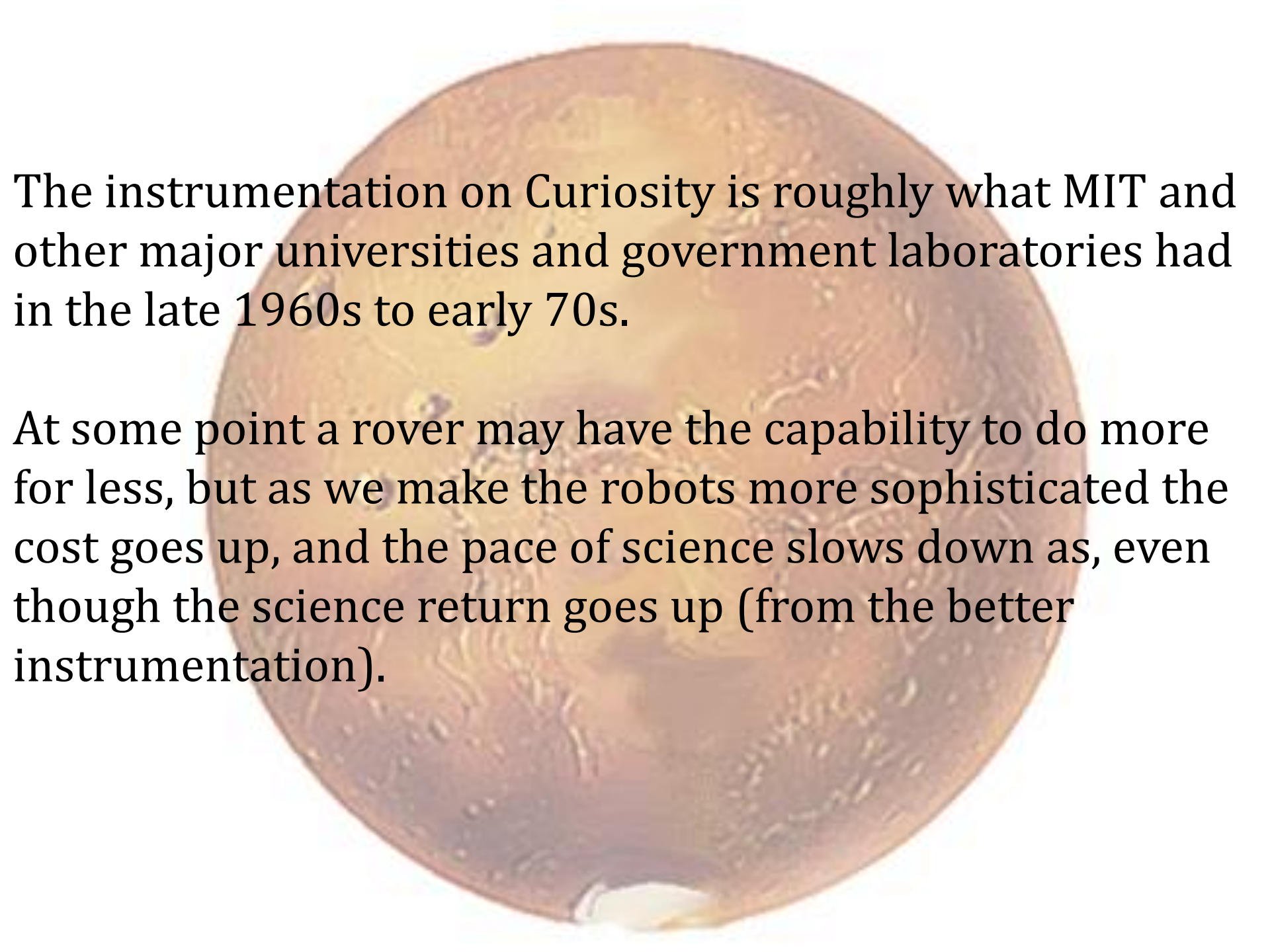
For Curiosity we have a $2.5B rover, and 6 months of a 2-year mission or $0.6B invested. A senior scientist on the team again reiterated that he could have done the science we've achieved so far in less than 1 day.

Assuming 40 days on the surface with a team of 6: 40 *6 * 0.6B/day = 144B, again showing that the cost /unit science is about the same.

For Curiosity we have a $2.5B rover, and 6 months of a 2-year mission or $0.6B invested. A senior scientist on the team again reiterated that he could have done the science we've achieved so far in less than 1 day.

Assuming 40 days on the surface with a team of 6: 40 *6 * 0.6B/day = 144B, again showing that the cost /unit science is about the same.

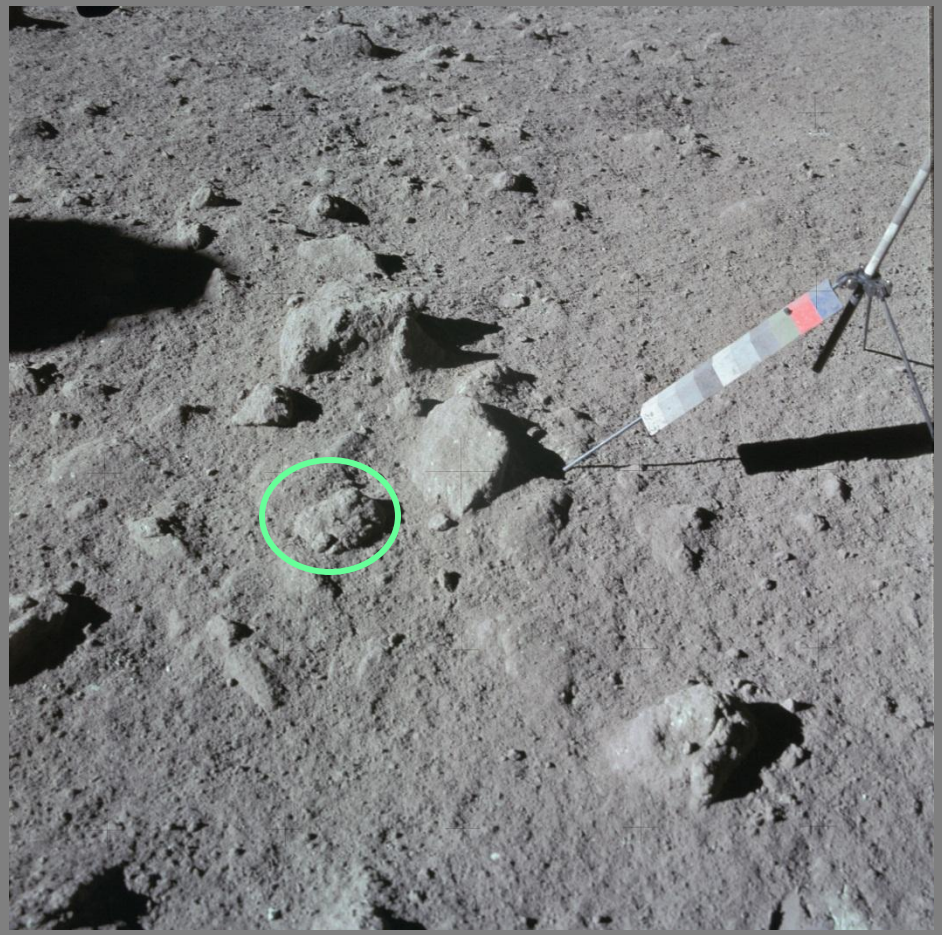
The reason we are currently sending robots rather than people is that we do not want to spend 100x the cost for 100x the science.



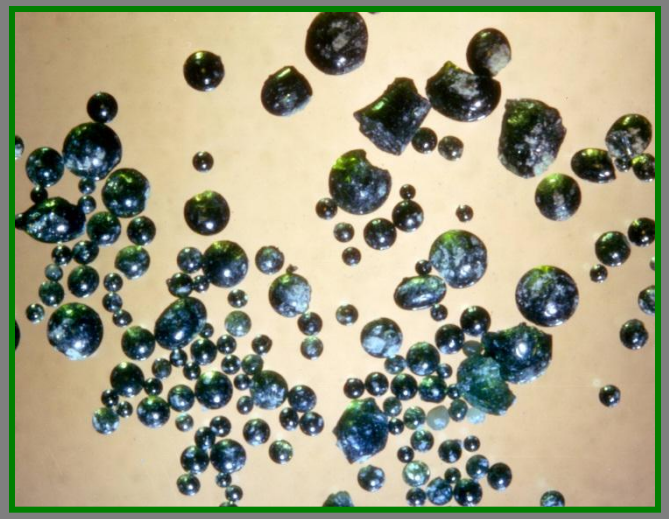
The instrumentation on Curiosity is roughly what MIT and other major universities and government laboratories had in the late 1960s to early 70s.

At some point a rover may have the capability to do more for less, but as we make the robots more sophisticated the cost goes up, and the pace of science slows down as, even though the science return goes up (from the better instrumentation).

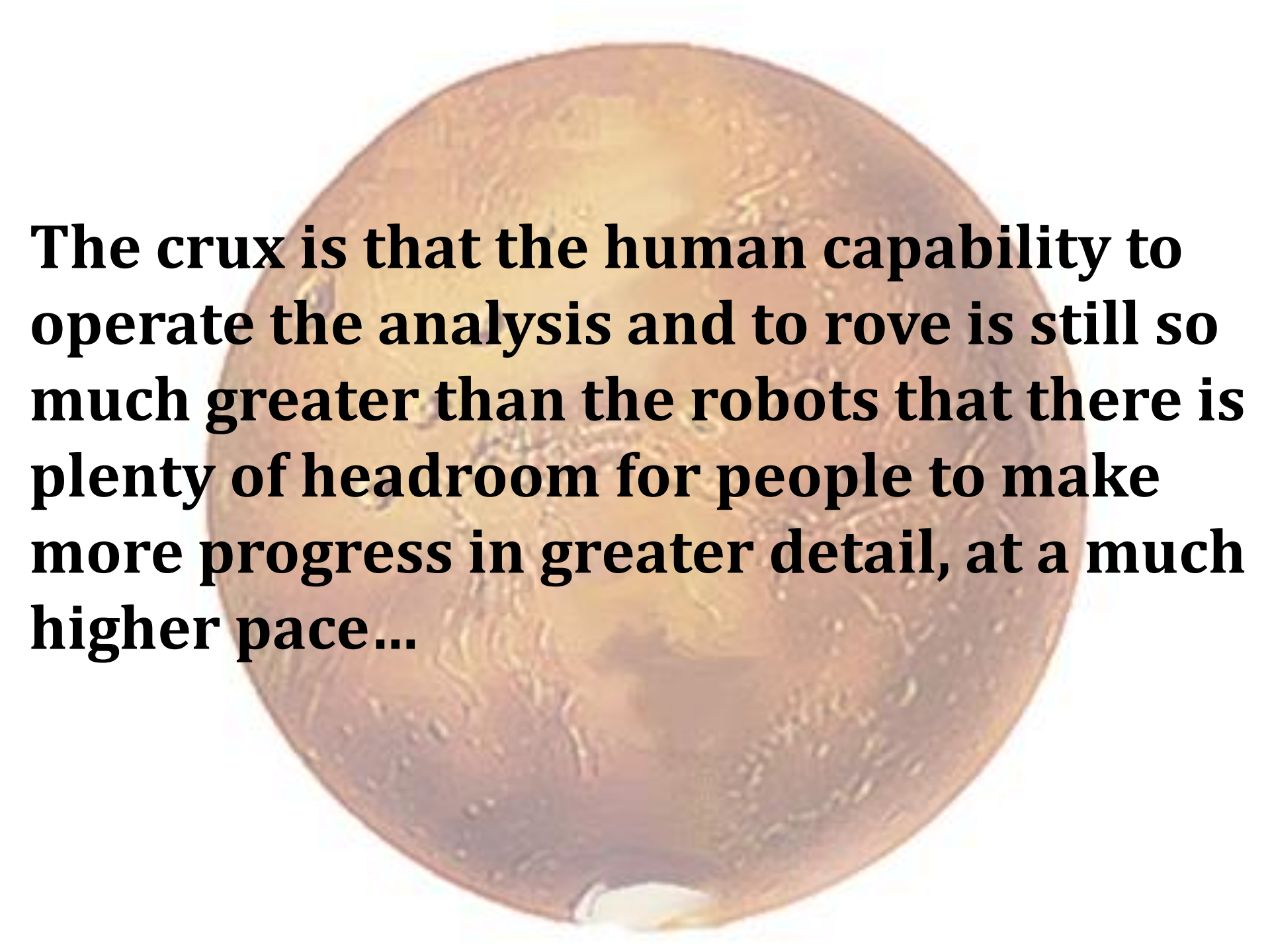
Apollo 15 -- Green Rock -- 15425



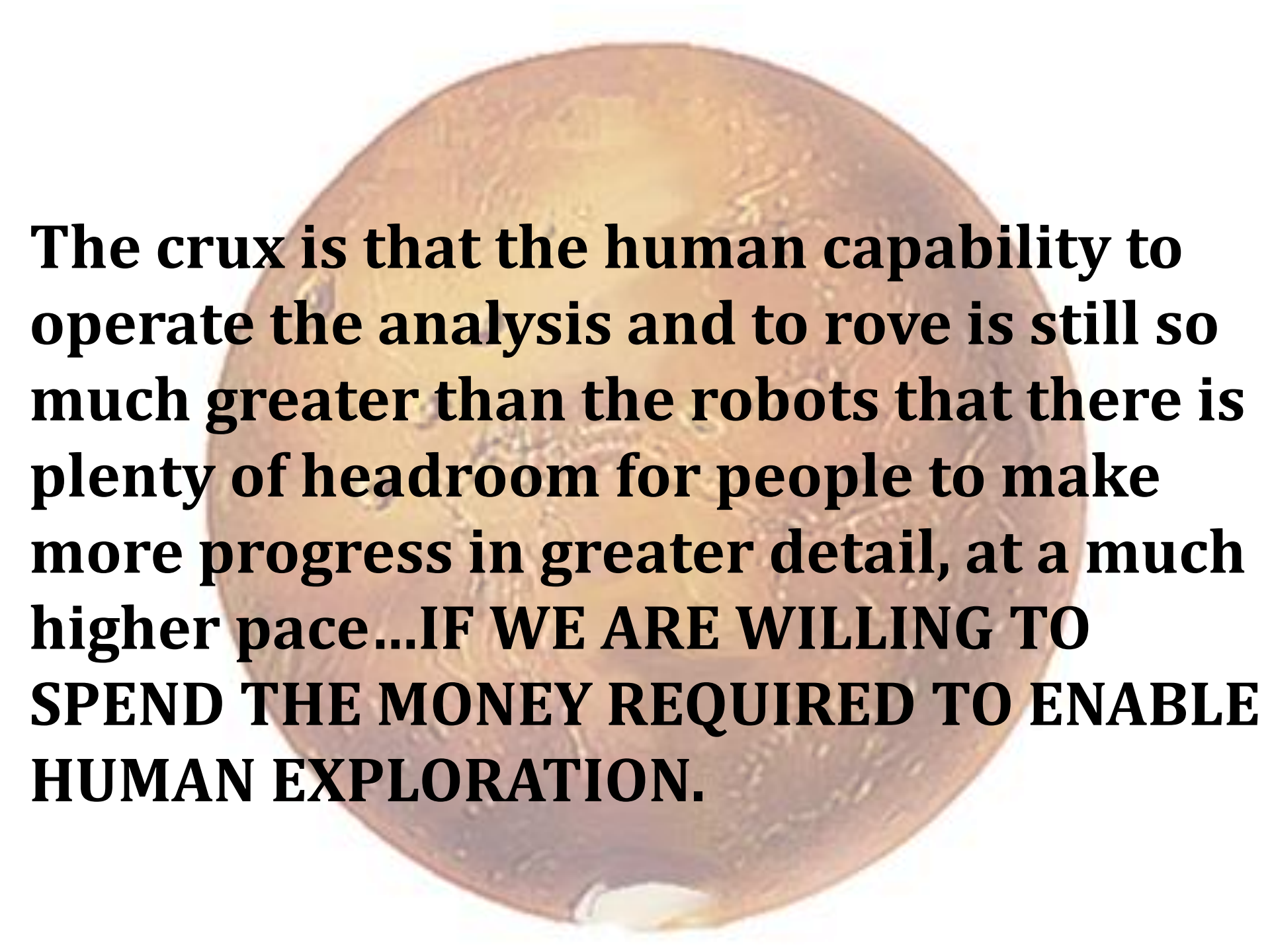
Green Glass Clods -- 15425 -15427
~ 500 grams



Green Glass Beads
40 – 250 microns



The crux is that the human capability to operate the analysis and to rove is still so much greater than the robots that there is plenty of headroom for people to make more progress in greater detail, at a much higher pace…



The crux is that the human capability to operate the analysis and to rove is still so much greater than the robots that there is plenty of headroom for people to make more progress in greater detail, at a much higher pace…IF WE ARE WILLING TO SPEND THE MONEY REQUIRED TO ENABLE HUMAN EXPLORATION.

Foundations

- *Exploration* is the expansion of human experience.

Foundations

- *Exploration* is the expansion of human experience.

"WHAT IS IT LIKE IN SPACE?"

Foundations

- *Exploration* is the expansion of human experience. **"What is it like in space?"**
- Explorers should share the experience of exploring as well as the environment being explored.

Foundations

- *Exploration* is the expansion of human experience. **"What is it like in space?"**
- Explorers should share the experience of exploring as well as the environment being explored.

  VIRTUAL REALITY tools should be part of every exploration mission.

Foundations

- *Exploration* is the expansion of human experience. **"What is it like in space?"**
- Explorers should share the experience of exploring as well as the environment being explored. **Virtual Reality**
- Our exploration of the universe expands in three stages:

Foundations

- *Exploration* is the expansion of human experience. **"What is it like in space?"**
- Explorers should share the experience of exploring as well as the environment being explored. **Virtual Reality**
- Our exploration of the universe expands in three stages: **Direct, Remote, Passive**

Three Stages of Exploration

- *Direct, with ability to interact with the local environment in real-time.*

  Can include teleoperation, if sufficient feedback
- *Remote (robotic), with speed-of-light impact on speed of interaction with the local environment*
- *Passive, with all knowledge of the environment comes from receiving radiation or particles.*


esa