National Aeronautics and Space Administration

A Space Data System Standard for Telerobotic Operations

SpaceOps 2014: 13th International Conference on Space Operations

9 May 2014

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Agenda

- Introduction: Global effort to define standards for telerobotic operations
- Organization: The CCSDS Telerobotic Operations Working Group
- Approach: Philosophical approach to standards definition
- Structure: Technical approach to standards definition
- Services: Current status of the service catalog
- Conclusion: Invitation to participate

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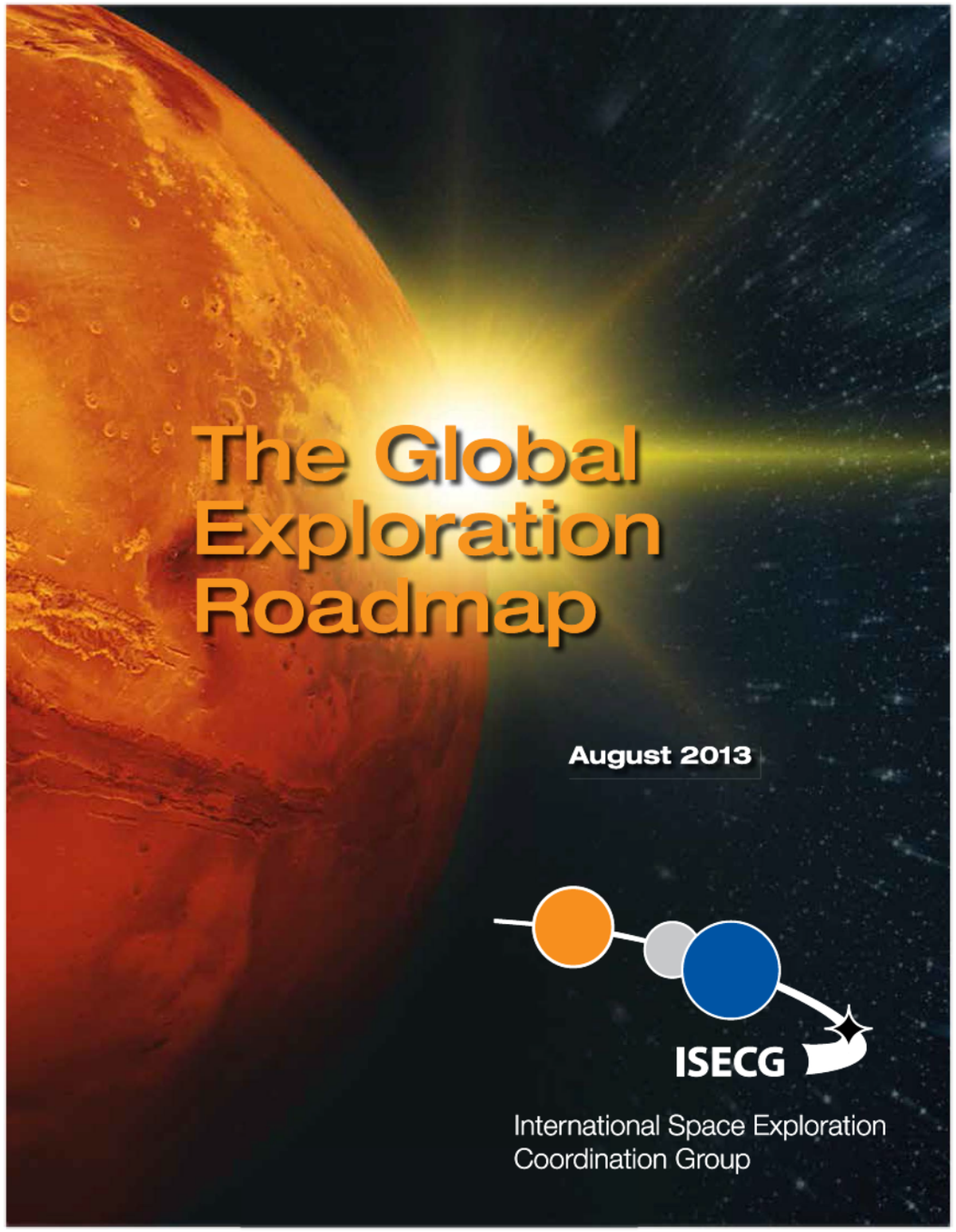
The Global Exploration Roadmap



The Global Exploration Roadmap highlights the efforts of agencies participating in the ISECG to prepare for human and robotic exploration of destinations where humans may someday live and work. Enabling humans to explore the surface of Mars in a manner that is sustainable, affordable, and productive is a long-term goal that we will use to help shape our near-term activities. This goal informs capability evolution and technology investments. The pathway to Mars extends human presence to enable exploration of multiple destinations, including the Moon and near-Earth asteroids.

The Global Exploration Roadmap

Standards to Promote Interoperability

Partnerships among agencies in which each provides capabilities on the critical path to completion of mission objectives have become common, as mission complexity has increased and interagency relationships have strengthened. This is true for both human and robotic exploration initiatives. Large multinational exploration missions will require agencies to accept and manage interdependency at different levels: architecture, mission, infrastructure, and systems. The nature of human exploration beyond low-Earth orbit will necessitate acceptance of, and commitment to, a level of interdependency that is beyond our current experience and that will increase interoperability across the architecture.

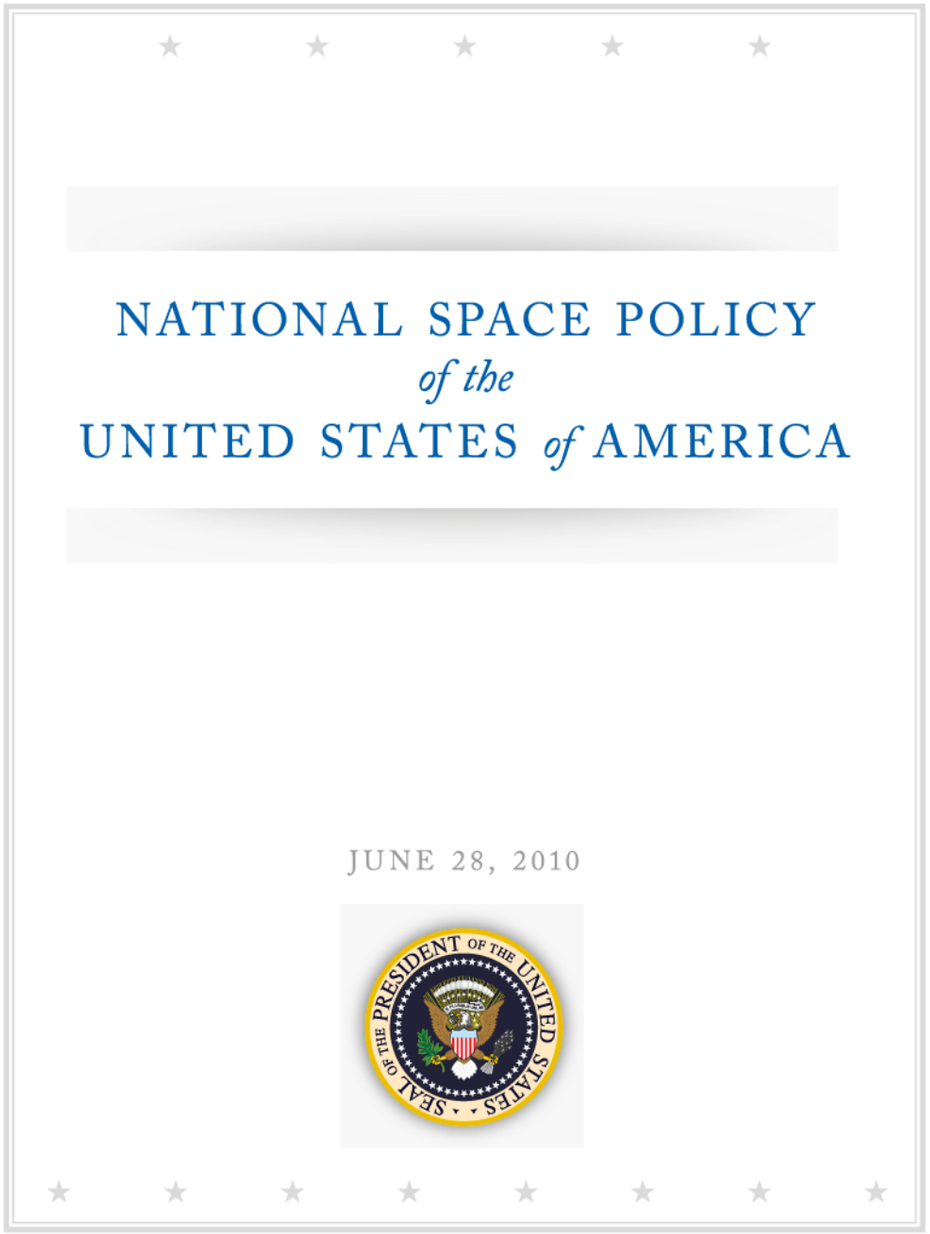
Efforts to promote future interoperability of space systems are critically important. Pursuing interoperability initiatives, such as international standards and common interfaces, will ensure different systems and nations can work together in exploring the solar system. This is a proven approach to lowering the cost and risk of complex exploration missions.

Agencies participating in the Interagency Operations Advisory Group (IOAG), Space Frequency Coordination Group (SFCG), and the Consultative Committee for Space Data Systems (CCSDS) have collaborated on establishing data communications and mission operations architectures, coordinating spectrums for space communications, and technical standards for cross support which take advantage of current and anticipated state-of-the-art technologies.

Most of that work is already underway. These teams have developed service catalogs and technical standards which respond to the anticipated needs of future exploration missions. These services and standards will enable highly internetworked mission operations and facilitate the integration of new partners into complex human space exploration missions. More information about these international organizations is available at: www.ioag.org, www.sfcgonline.org, and www.ccsds.org.

In addition to the efforts in communications and operations, onboard systems standards are equally important. For example, initiatives such the International Docking System Standard and Onboard Data Interface Standards are essential for fostering onboard interoperability. Work on such standards continues. By applying them, vehicles developed by many nations can conduct missions such as those shown in the ISECG Mission Scenario and increase robustness in space exploration endeavours.

US National Space Policy Goals



NATIONAL SPACE POLICY
of the
UNITED STATES *of* AMERICA

JUNE 28, 2010

Expand international cooperation on mutually beneficial space activities to: broaden and extend the benefits of space; further the peaceful use of space; and enhance collection and partnership in sharing of space-derived information.

Pursue human and robotic initiatives to develop innovative technologies, foster new industries, strengthen international partnerships, inspire our Nation and the world, increase humanity's understanding of the Earth, enhance scientific discovery, and explore our solar system and the universe beyond.

Promote appropriate cost- and risk-sharing among participating nations in international partnerships;

ISECG Mission Scenario

2020 2030

Low-Earth Orbit

International Space Station

Commercial or Government-Owned Platforms

Beyond Low-Earth Orbit

Test Missions

Robotic Mission
Human Mission
Cargo Mission

Near-Earth Objects

Rosetta
Hayabusa2 (Sample Return)
OSIRIS-REx (Sample Return)
Asteroid Redirection
Apophis
Explore Near-Earth Asteroid

Lunar Vicinity

Extended Duration Crew Missions

Staging Post for Crew to Lunar Surface

Potential Commercial Opportunities

Moon

LADEE
Luna 25
Chandrayaan-2
Luna 26
Luna 27
RESOLVE
SELENE-2
Luna 28/29 (Sample Return)
SELENE-3
Human-Assisted Sample Return

Humans to Lunar Surface

Potential Commercial Opportunities

Mars

MAVEN
ISRO Mars Orbiter Mission
ExoMars 2016
InSight
ExoMars 2018
Mars 2020
JAXA Mars Precursor

Human-Assisted Sample Return

Mars Sample Return Mission Opportunities

Human Scale EDL Test Mission Opportunities

Sustainable Human Missions to the Mars System

Multi-Destination Transportation Capabilities

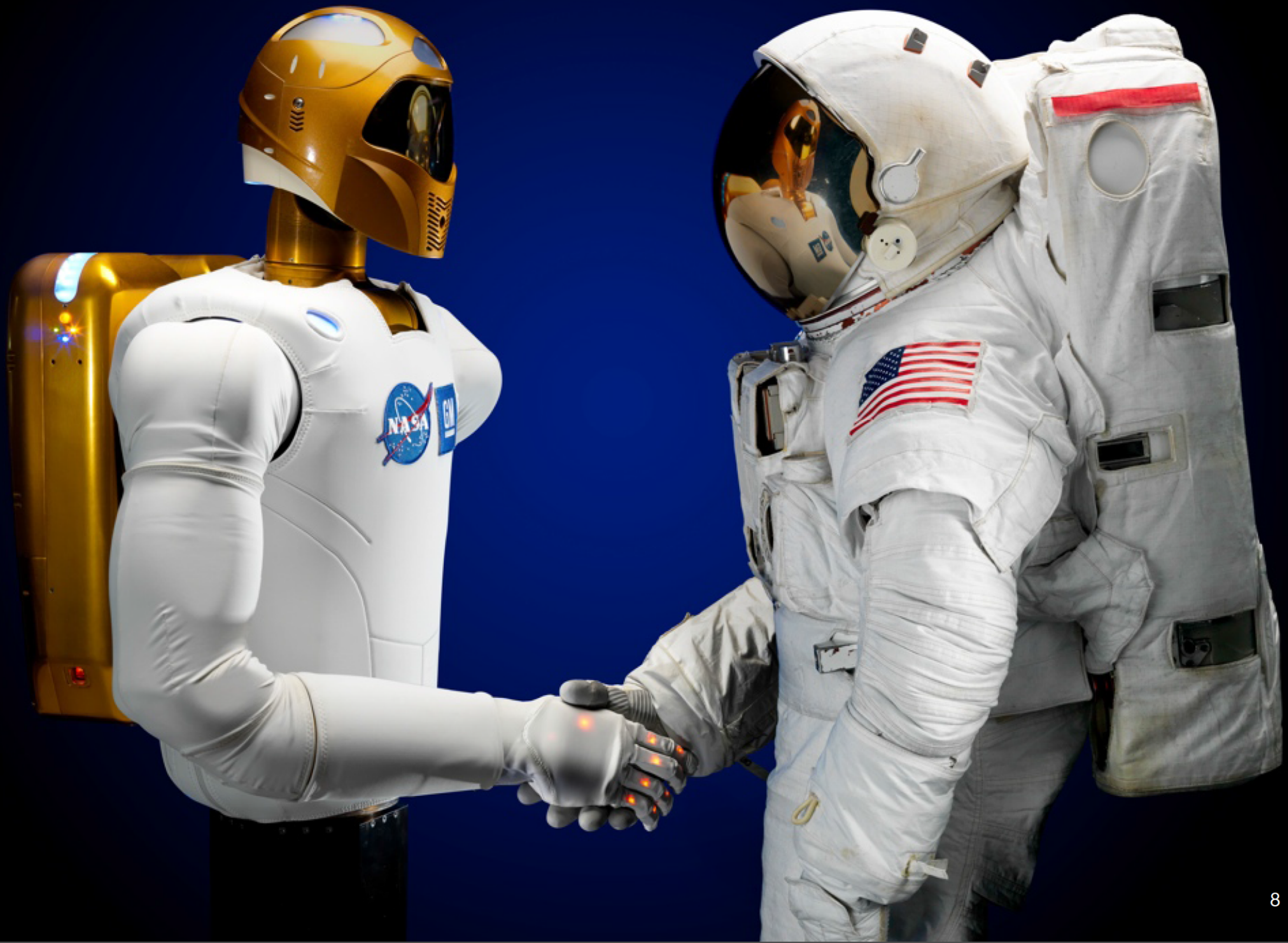
(Planned and Conceptual)

Orion & SLS
Russian Piloted System
Advanced Electric Propulsion
Evolvable Deep Space Habitat
Orion & SLS (Upgrade)
Initial Cargo Delivery
Small Cargo Lander
Human Surface Mobility
Crewed Lunar Lander
Orion & SLS (Upgrade)

Icon indicates first use opportunity.
Commercial/institutional launchers not shown.

Robots for Dull, Dirty, and Dangerous Tasks

Humans and Robots in Partnership



CCSDS – Scope and Origins

- CCSDS = The Consultative Committee for Space Data Systems
- The primary goal of CCSDS is ***interoperability*** between communications and data systems of space agencies' vehicles, facilities, missions and programs.
- Of all of the technologies used in spaceflight, standardization of ***communications and data systems*** brings the most benefit to multi-agency interoperability.
- CCSDS Started in 1982 developing standards at the lower layers of the protocol stack. The CCSDS scope has grown to cover standards throughout the entire ISO communications stack, plus other Data Systems areas (architecture, archive, security, XML exchange formats, etc.

Six Technical Areas, Twenty-Seven Teams

- Working Group (producing standards)
- Birds-Of-a-Feather stage (pre-approval)
- Special Interest Group (integration forum)

Systems Engineering

- Security
- Delta-DOR
- Timeline Data Exchange
- XML Standards and Guidelines

Typical Mission Profile

Spacecraft Onboard Interface Services

- Onboard Wireless WG
- Application Supt Services (incl. Plug-n-Play)

Space Link Services

- RF & Modulation
- Space Link Coding & Sync.
- Multi/Hyper Data Compress.
- Space Link Protocols
- Next Generation Uplink
- Space Data Link Security
- Optical Coding and Mod

Cross Support Services

- CS Service Management
- CS Transfer Services
- Cross Supt Service Arch.
- Generic Gnd-to-Gnd File Transfer

Space Internetworking Services

- Motion Imagery & Apps
- Delay Tolerant Networking
- Voice
- CFDP over Encap
- CFDP Revisions

Mission Ops & Info Mgt Services

- Data Archive Ingestion
- Navigation
- Spacecraft Monitor & Control
- Digital Repository Audit/Certification
- Telerobotics


CCSDS.ORG
The Consultative Committee for Space Data Systems
A few of the more than
300
missions
... that fly with
CCSDS

The Standard in Space Telerobotic Operations

- The development and use of telerobotic operations standards can **decrease the cost and risk of telerobotic technology development** and integration through earlier and more thorough testing opportunities, and **decrease the cost of operations** through cross-support and elimination of duplication of effort.

- The development of the component technologies required to extend human presence and capability into space is accelerating rapidly, and there are **emerging requirements for telerobotics interoperability** between International civil space agencies.

- A common framework for telerobotic operations would allow diverse robotic assets to collaborate on mission goals and realize **cost-savings from the cross-support** provided by participating Agencies.

CCSDS Standards Tracks

NORMATIVE TRACK

NON-NORMATIVE TRACK

CCSDS CONCEPT PAPER

Hard Requirement

Prospective Requirement

CCSDS Proposed Practice ("White")

CCSDS Proposed Standard ("White")

CCSDS Draft Practice ("Red", "Pink")

CCSDS Draft Standard ("Red", "Pink")

CCSDS Draft Informational

CCSDS Experimental ("Orange")

Hard Requirement

CCSDS Recommended Practice ("Magenta")

CCSDS Recommended Standard ("Blue")

CCSDS Informational Report ("Green")

MISSION DEPLOYMENT

EXPERIMENTAL DEPLOYMENT

Minutes, procedures, charters, plans, etc.

CCSDS Record ("Yellow")

CCSDS Historic ("Silver")

DECOMMITTED DEPLOYMENT

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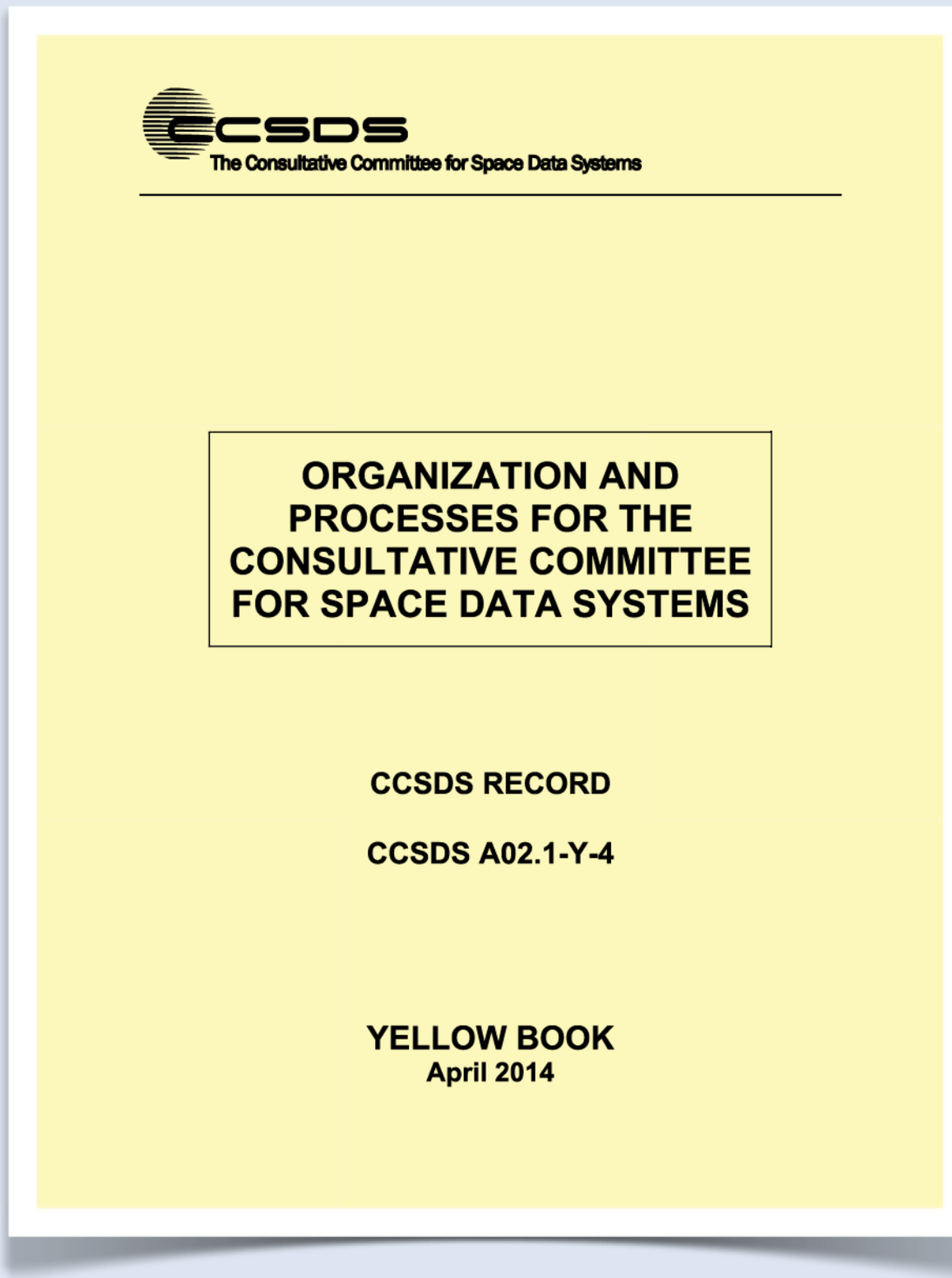
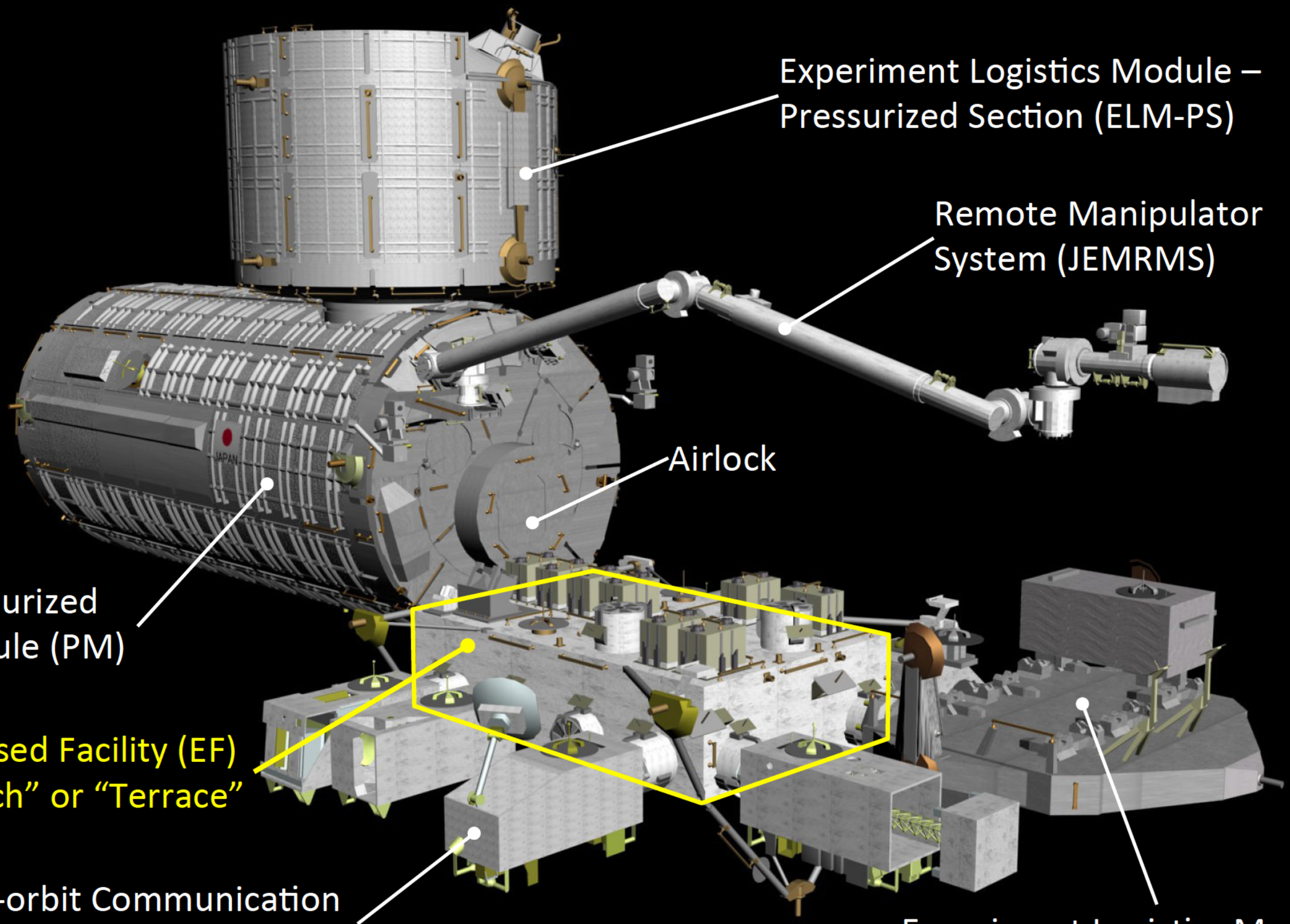
Organizational Processes



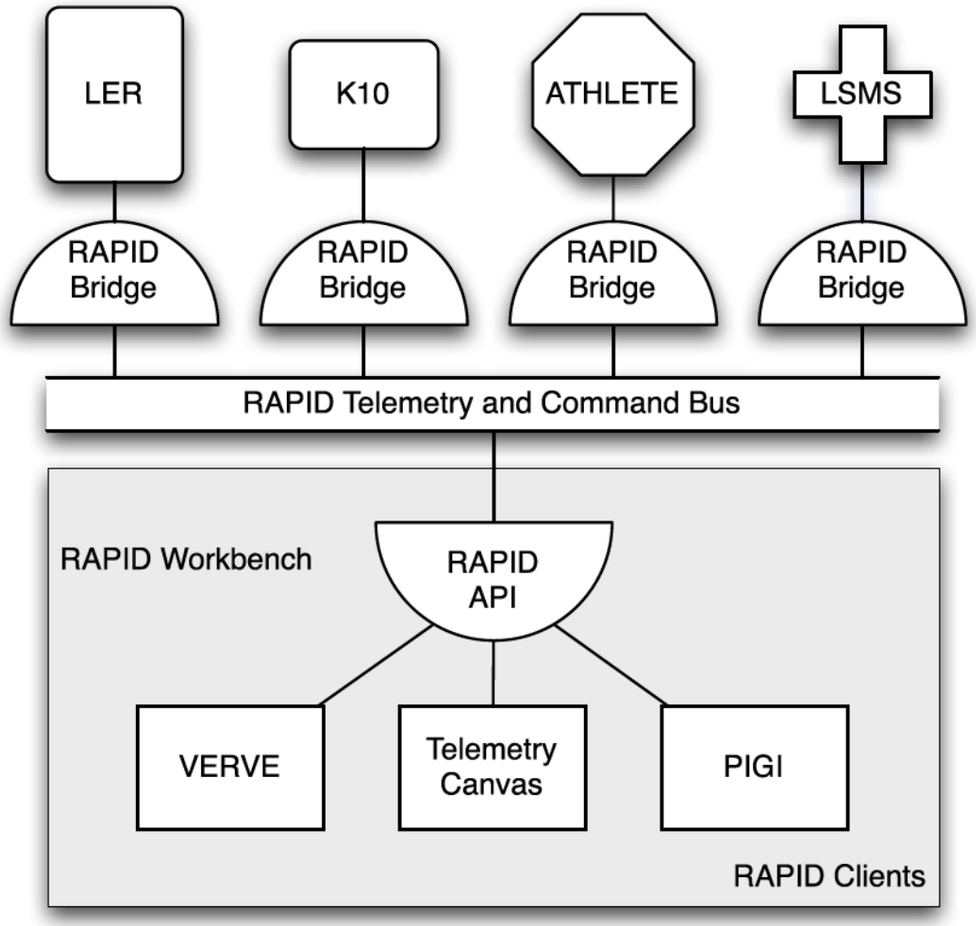
The CCSDS Management Council has patterned the CCSDS organization to adopt what is perceived to be the best common structural features of the World Wide Web Consortium (W3C) and the Internet Engineering Task Force (IETF) organizations, i.e., highly focused product-oriented "Working Groups" collected into functional "Areas" that cluster within broad discipline-oriented "Domains."

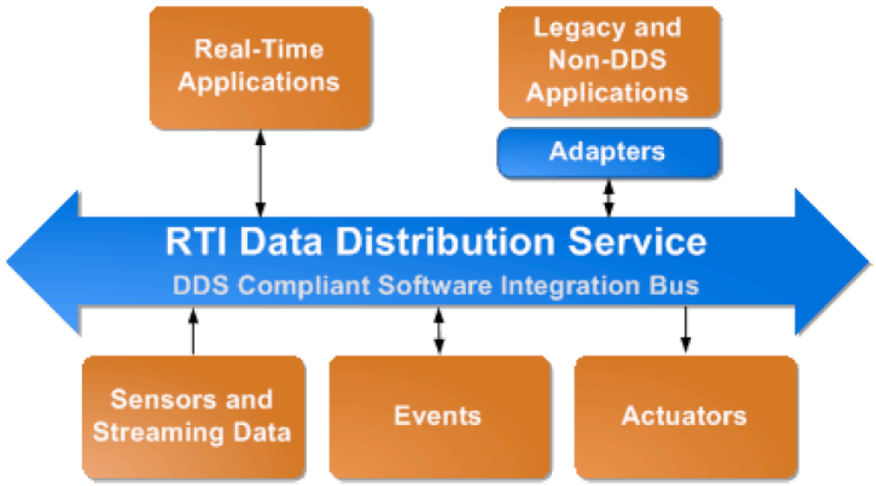
Japanese Experiments Module (JEM)“Kibo” Module



RAPID: A Lesson in Multi-Robot Collaboration

- Provides Message Definitions & API
- Provides Common Services API
- Open Source Release ARC-16368-1 (NASA)
- Partner Centers include JPL, JSC, ARC, LaRC, GRC, KSC and ESA/ESTEC.
- Based on Data-Distribution Service, an open, international standard for publish-subscribe communications.
- RTI DDS is an implementation platform, not a reference platform. RAPID ≠ Middleware!





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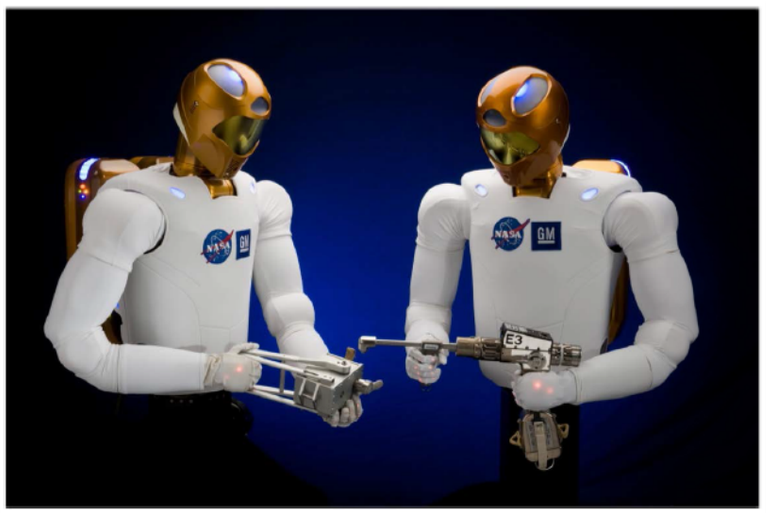
A RAPID Family Album

JPL's ATHLETE

JSC's SEV

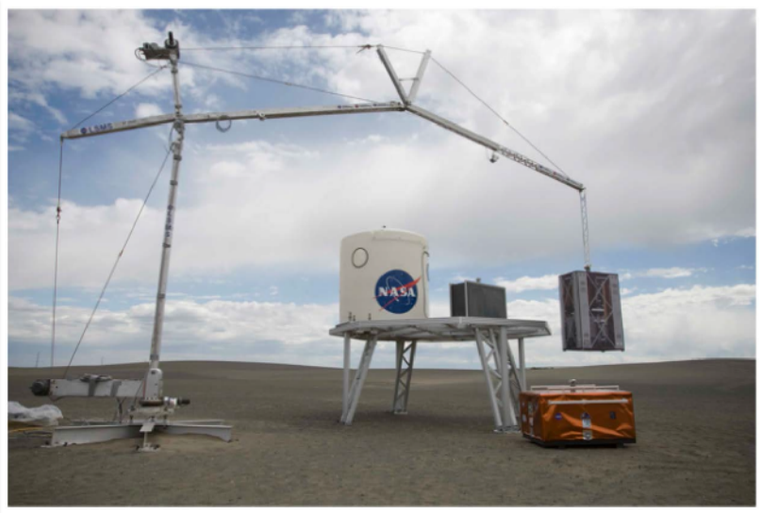
JSC's Centaur 2

GRC's EVAIS

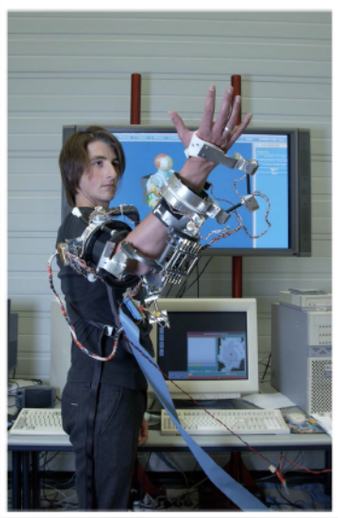


JSC's Robonaut 2

ARC's K10



LaRC's LSMS Crane

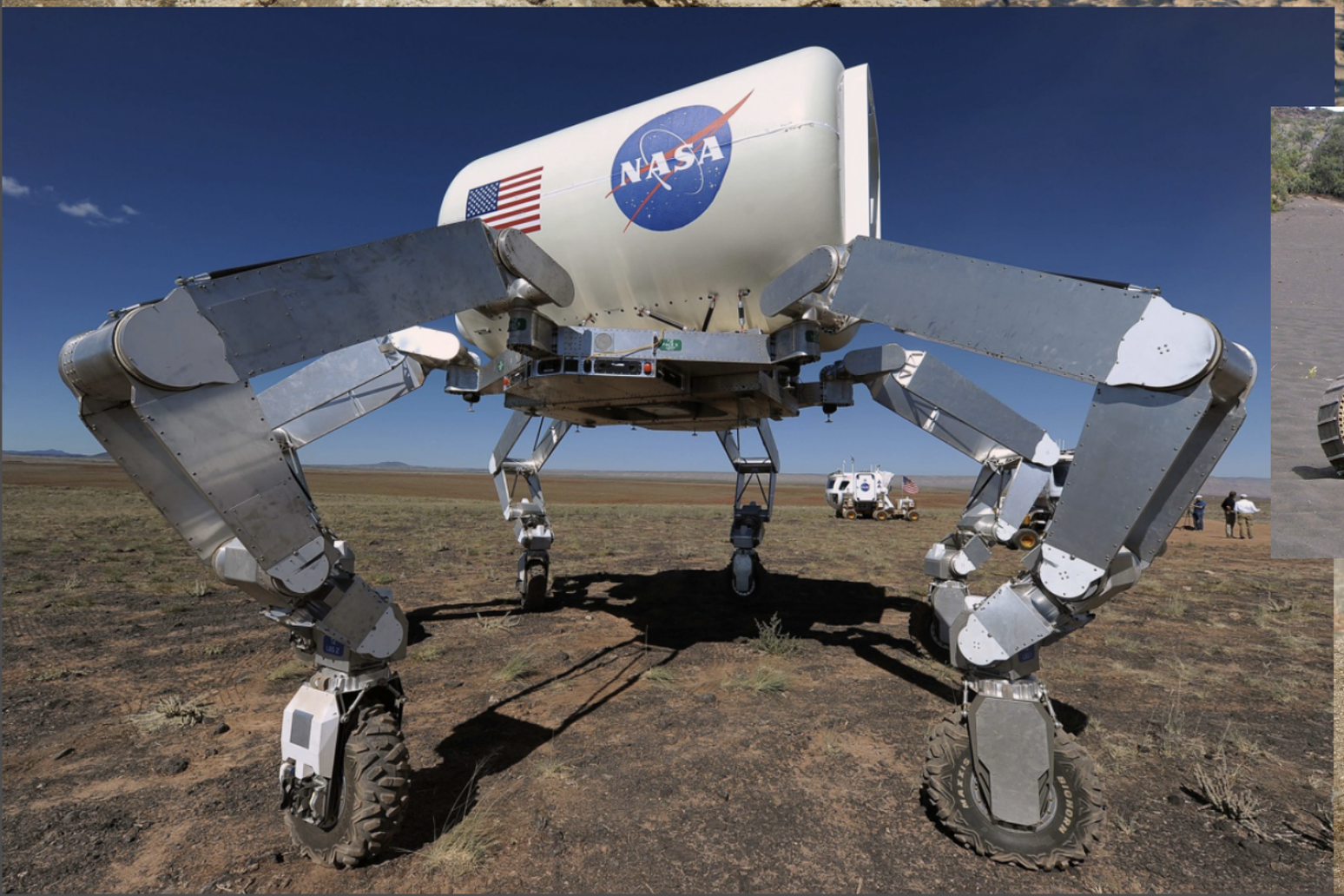


ESA/ESTEC's EXARM

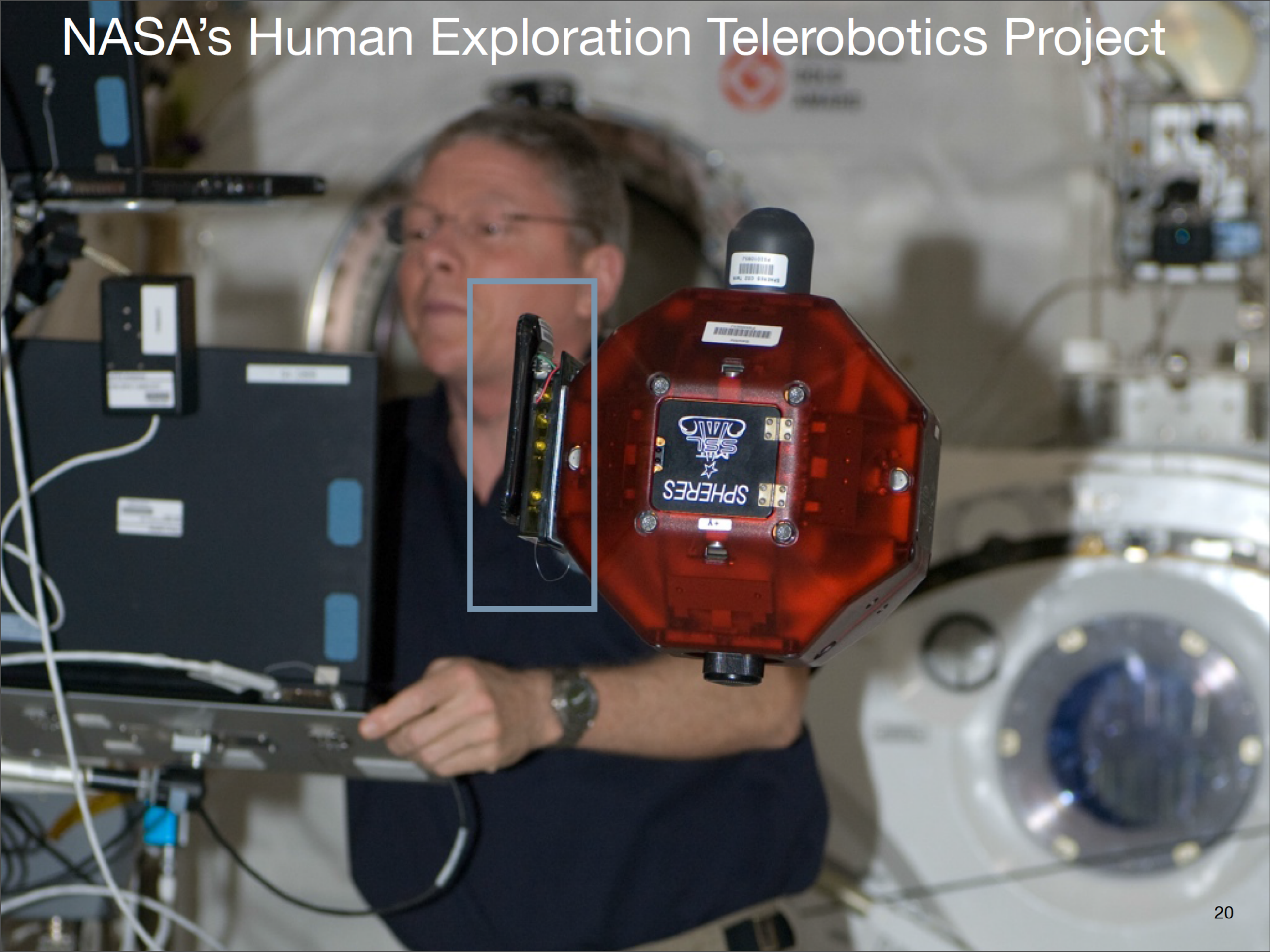
Technology Development Applications

- Object Recognition and Pose Estimation
- Fusing vision, tactile and force control for manipulation
- Achieving human-like performance for piloting vehicles
- Access to extreme terrain in zero-, micro- and reduced-gravity
- Grappling and anchoring to asteroids and non-cooperating objects
- Exceeding human-like dexterous manipulation
- Full immersion, telepresence with haptic and multi modal sensor feedback
- Understanding and expressing intent between humans and robots
- Verification of Autonomous Systems
- Supervised autonomy of force/ contact tasks across time delay
- Rendezvous, proximity operations and docking in extreme conditions
- Mobile manipulation that is safe for working with and near humans

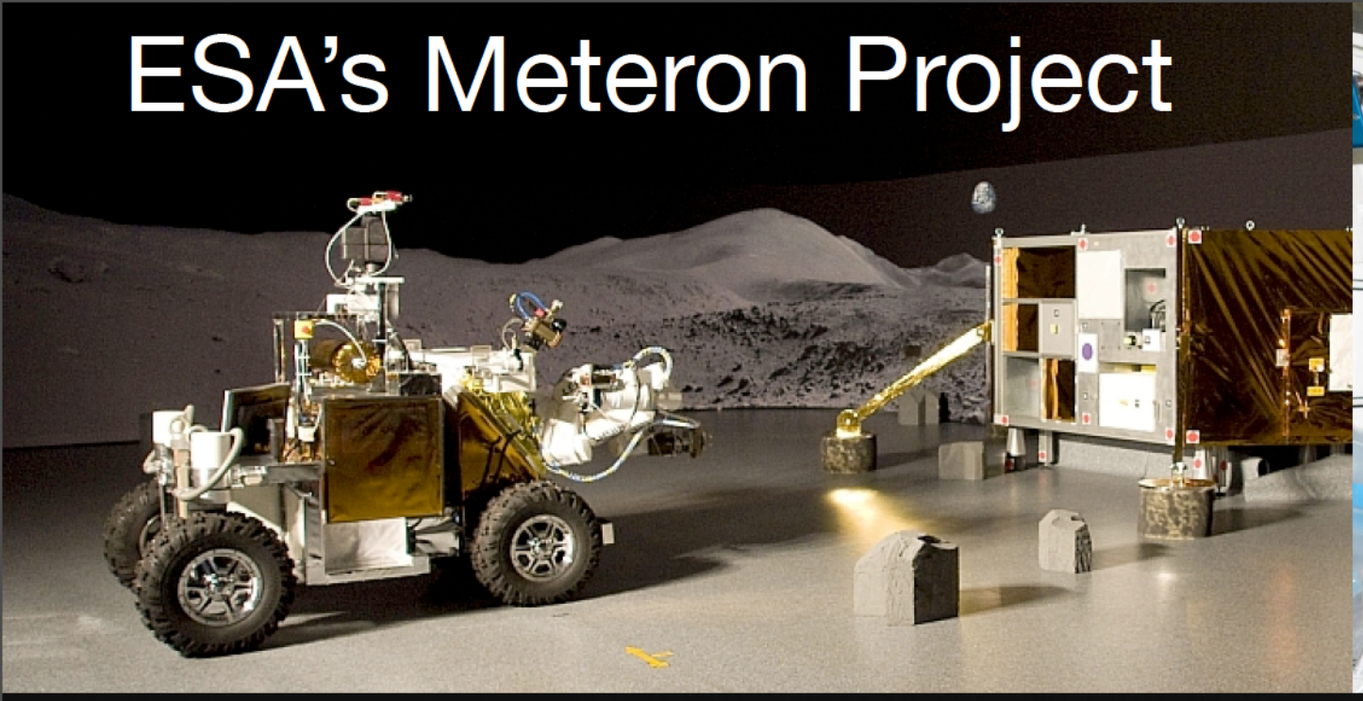
NASA's Human Robotics Systems Project



NASA's Human Exploration Telerobotics Project



ESA's Meteron Project



DLR Robotik und Mechatronik Zentrum

ROBODRIVE

Justin

DLR

Justin

Collaborative Analog Field Testing

ESA

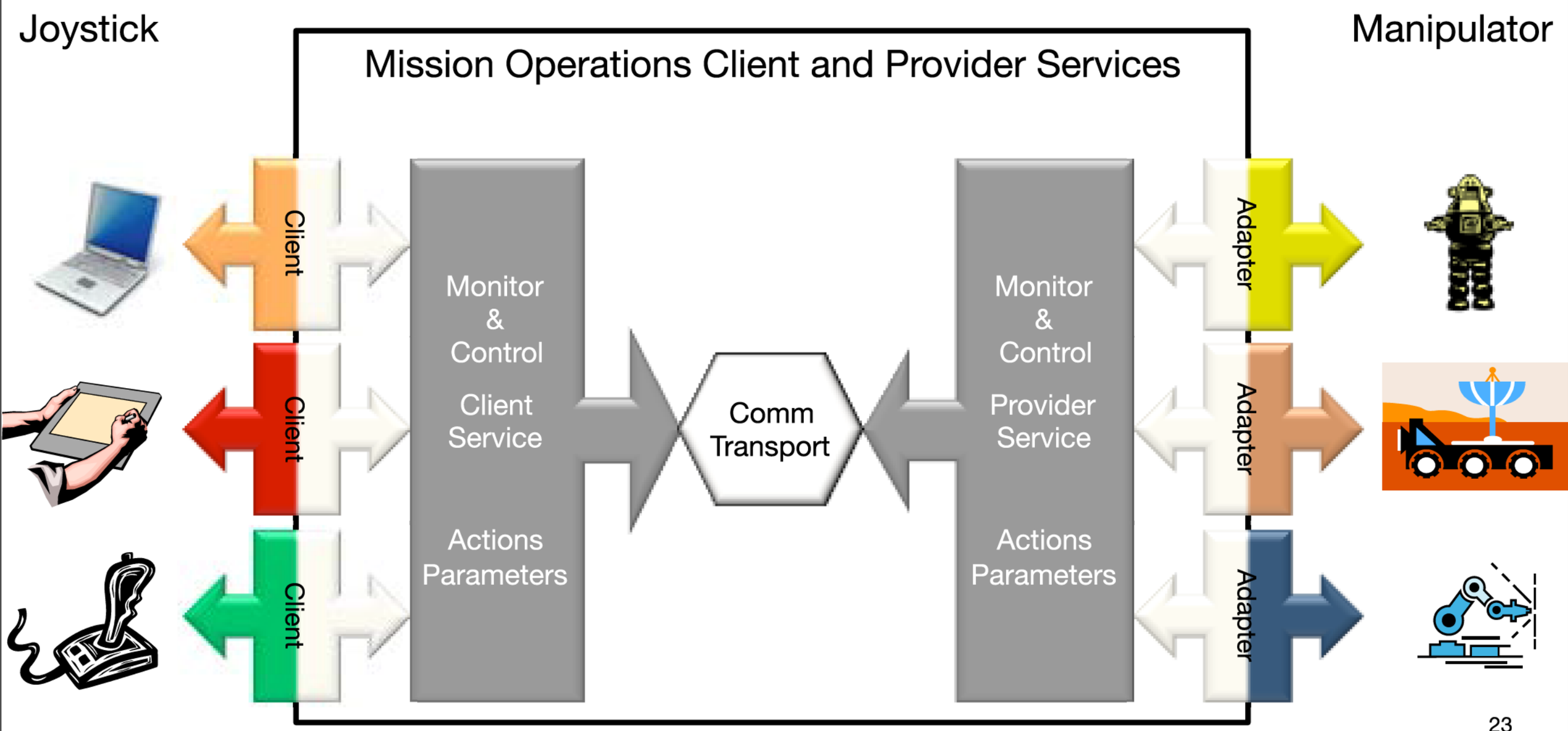
NASA/CSA

NASA/CSA/ESA

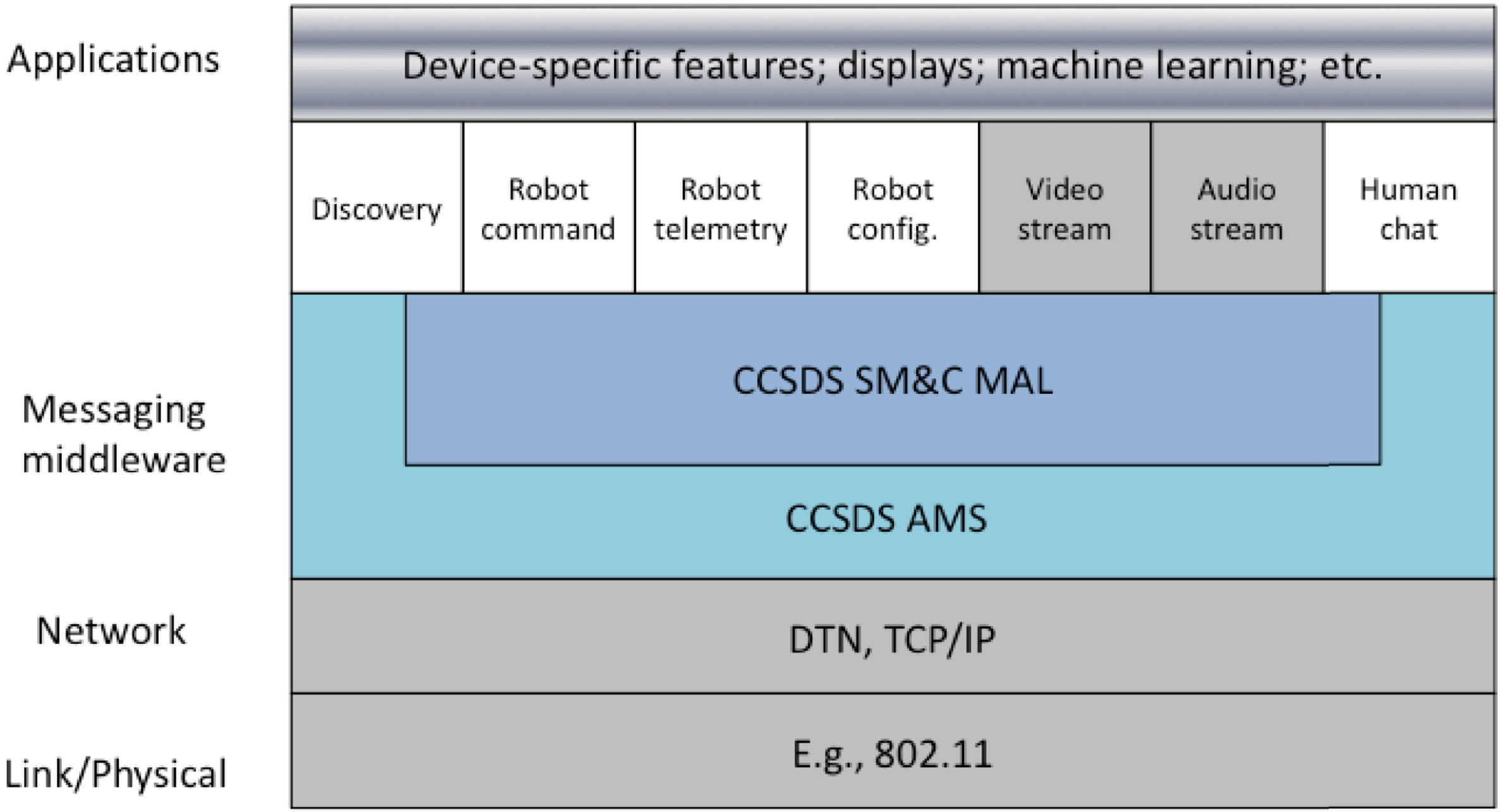
Service-Oriented Architecture

<u>Human Interface</u>
Computer
Tablet
Joystick

<u>Robotic Agent</u>
Humanoid
Vehicle
Manipulator



A Straw Man Gap Analysis



A Strawman Gap Analysis for US-TRSIG. Scott Burleigh. Pasadena, California: NASA Jet Propulsion Laboratory, April 14, 2011. (Chart)

Telerobotic Operations Service Catalog

- **Manipulation Service**
- Sequencer Service
- **Frame Store Service**
- Asynchronous File Transfer Service
- **Access Control Service**
- **Transfer of Control Service**
- Interaction Service
- **Imaging Service**
- **Video Service**
- Special Command Service
- Data Product Service
- **Discovery Service**
- Administrative Service
- **Location Service**
- **Mobility Service**
- **Configuration Service**
- Command Service

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Manipulation, Location, Mobility, Configuration

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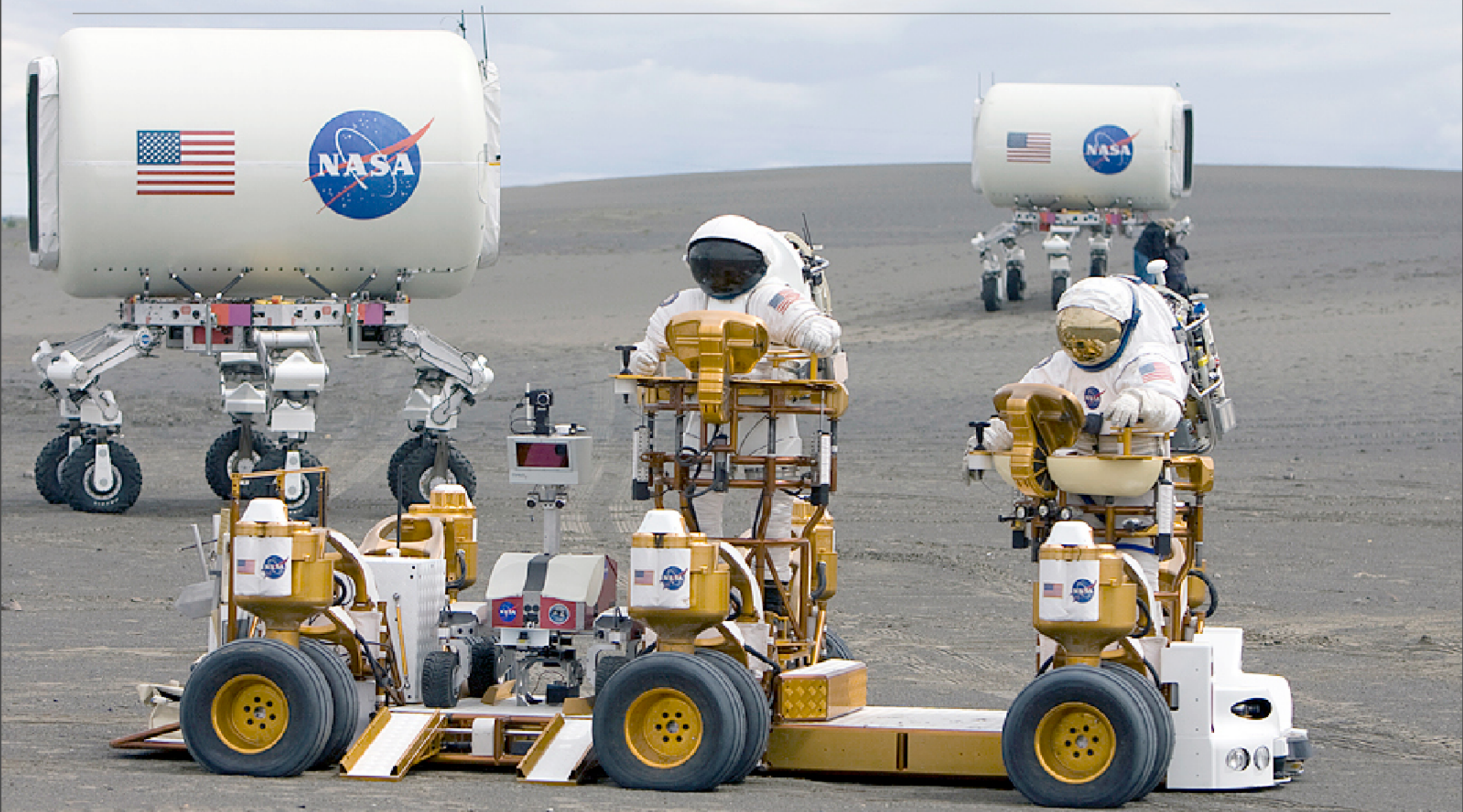
Frame Store, Transfer of Control, Discovery



Imaging, Video

Invitation to Participate

http://public.ccsds.org/

Click CWE to see a map of working groups and access information to contact working group chairs.

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