Consultative Committee
CCSDS
for Space Data Systems

Comm and Data Standards For Future Human Spaceflight

SpaceOps Workshop at APL
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Consultative Committee for Space Data Systems

Agenda

- ✦ CCSDS Background
- ✦ CCSDS Architecture
- ✦ Ongoing CCSDS projects that support future human spaceflight
- ✦ Gaps: Areas where new CCSDS work is needed
- ✦ Special Topic: DEM/PUS/SM&C

- ✦ Note: Because this session is on Human Spaceflight, the robotic side is not in focus… but it is no less important, and is generally ***more*** serviced by CCSDS standards teams.

The Essential Message

CCSDS:

Advancing Technology

through international standardization

What could be more important?

- Right now, between major human spaceflight and robotic programs, it is critically important to prepare for the upcoming international missions.
- History shows that waiting until the program starts is too late to develop effective and capable cross-support technology.
- New missions are bringing new communications needs; new technology is becoming available; therefore, the standardization process is more important than ever.

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.

On CCSDS Standards

MYTH

Standards stifle innovation

FACT

CCSDS stimulates advanced technology by adopting, adapting, developing and solidifying innovations with exposure to a wider community

When an innovative technology is rapidly brought to the standards community, it is vetted with a larger user base, facilitating widespread adoption of innovative technology.

This **reduces the risk** of new technology with "more eyes on the problem."

MYTH

Standards delay implementation

FACT

Not if the innovation is brought into the standards process early. Delays result from reluctance to standardize, not from standardization

This **spreads the cost** of technology development over a larger user base.

This **enables joint missions**, for cost sharing and increased capabilities.

This **improves operations**, with familiar interfaces and more options for contingency recovery.

CCDS Overview - Participation

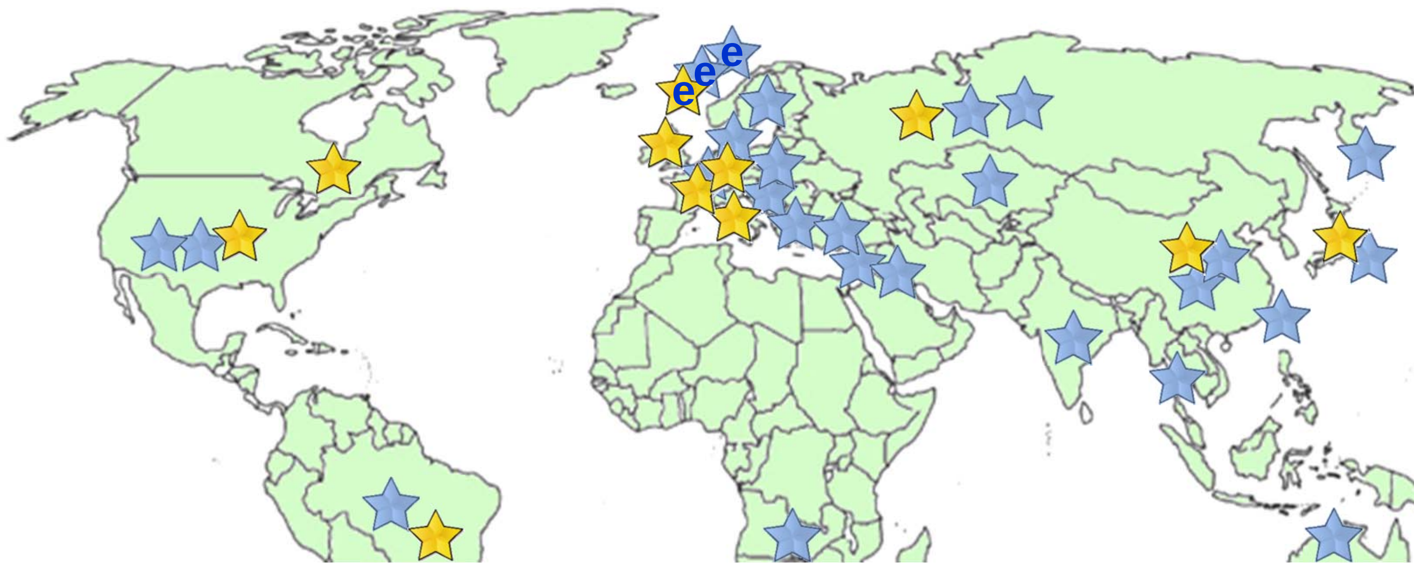
- CCSDS – An Agency-Led International Committee
  - Currently 11 Member agencies
  - Currently 28 Observer Agencies
  - Agencies represent 26 nations
  - Currently 141 Commercial Associates
  - ~160-180 attendees at Spring/Fall meetings
- Also functions as an ISO Subcommittee
  - TC20/SC13 - Space Data & Info Transfer Systems
  - Represents 20 nations

MEMBER AGENCIES

ASI/Italy
CNES/France
CNSA/China
CSA/Canada
DLR/Germany
ESA/Europe
FSA/Russia
INPE/Brazil
JAXA/Japan
NASA/USA
UKSA/UK

OBSERVER AGENCIES

ASA/Austria
BFSPO/Belgium
CAS/China
CAST/China
CLTC/China
CSIR/South Africa
CSIRO/Australia
DCTA/Brazil
DNSC/Denmark
EUMETSAT/Europe
EUTELSAT/Europe
GISTDA/Thailand
HNSC/Greece
IKI/Russia
ISRO/India
KARI/Korea
KFKI/Hungary
MOC/Israel
NCST/USA
NICT/Japan
NOAA/USA
NSARK/Kazakhstan
NSPO/Taipei
SSC/Sweden
SUPARCO/Pakistan
TsNIIMash/Russia
TUBITAK/Turkey
USGS/USA



Consultative Committee CCSDS for Space Data Systems

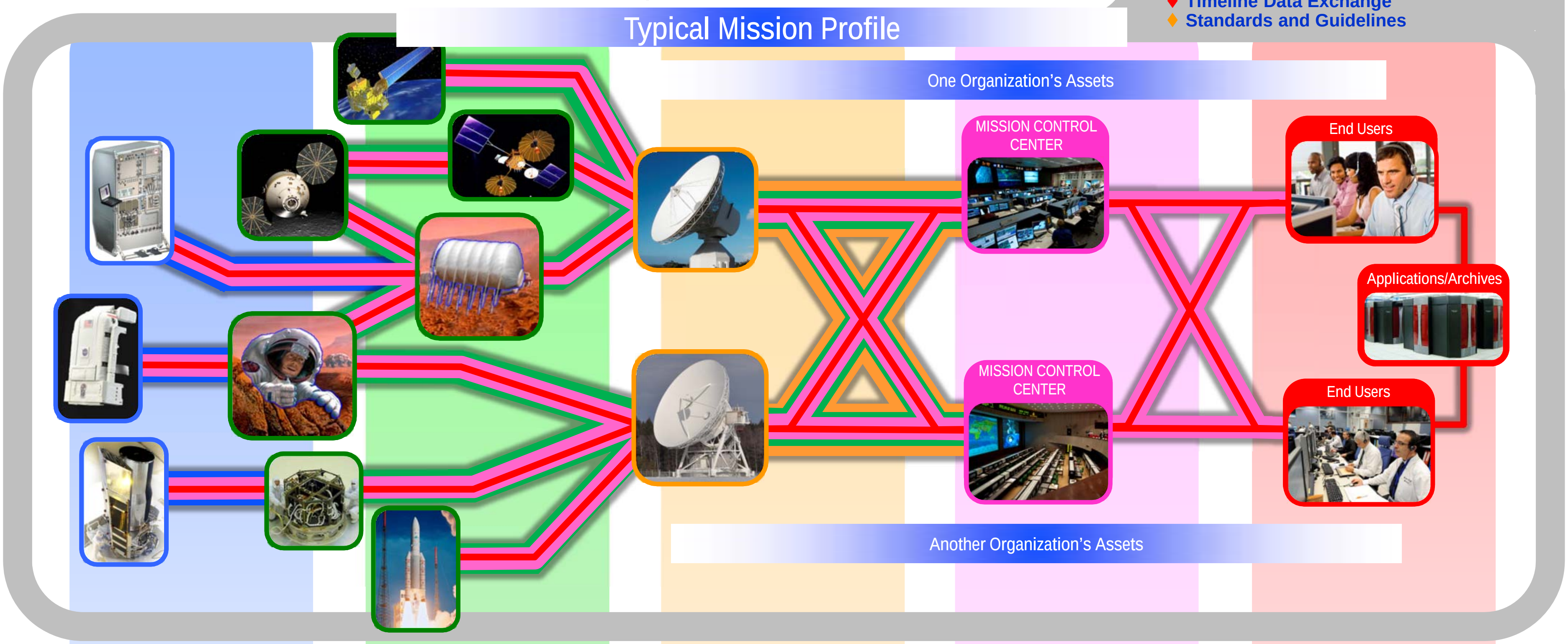
CCSDS Overview
End-to-End Architecture

Six Areas
Twenty-Eight working groups

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

Systems Engineering

- ♦ Security
- ♦ Space Assigned Numbers Auth.
- ♦ Delta-DOR
- ♦ Timeline Data Exchange
- ♦ Standards and Guidelines



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
- ♦ Planetary Communications
- ♦ Optical Coding and Mod

Cross Support Services

- ♦ CS Service Management
- ♦ CS Transfer Services
- ♦ Cross Supt Service Arch.

Space Internetworking Services

- ♦ Asynchronous Messaging
- ♦ Motion Imagery & Apps
- ♦ Delay Tolerant Networking
- ♦ Voice
- ♦ CFDP over Encap

Mission Ops & Info Mgt Services

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

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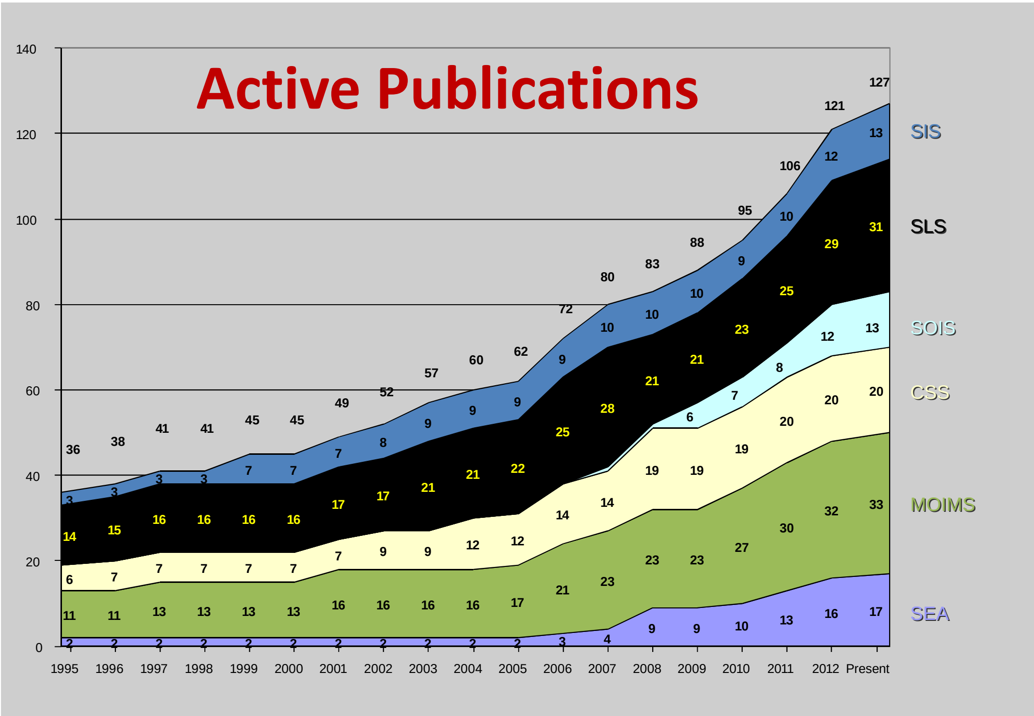
CCSDS Overview
Adoption by Missions



Currently Active Publications: 127

Normative: 78

Informative: 49

Downloadable for free from www.ccsds.org

All major pubs since 1982: 275

Some were historical mission needs or superseded technology

609 space missions have adopted and used various CCSDS standards

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Cumulative Missions	108	155	205	221	271	308	330	371	387	416	435	461	544	596

Future Mission Drivers

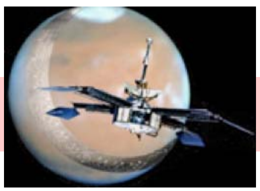
PAST → **PRESENT** → **DRIVERS FOR THE** → **FUTURE**

Shuttle/SpaceLab
CCSDS packets

International Space Station
Adv. Orbital Sys (AOS)
Early DTN Prototyping

In Situ Exploration
- Human Expeditions
- Long Duration, High Reliability
- Mobile comm protocols
- Voice, Video, Medical handling
- Onboard Autonomy
- Highly integrated ops

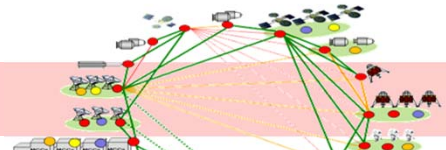
Asteroid/Surface Exploration
Autonomy, High bandwidth
Multi-Agency Mission Ops



Brief Recon Flyby,
Short-Lived Probes
Direct-to-Earth links

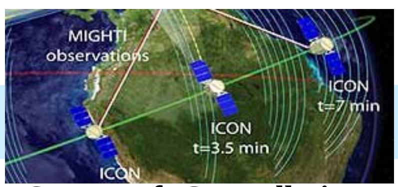
Missions designed for orbital relays,
Longer duration

Complex Deep Space Missions
- Human ***or*** robotic exploration
- Longer Duration
- Mobile comm protocols
- Fully automated routing
- Network-Managed DTN
- Optical Communications



Complex human or robotic
Scenarios for remote surface missions
Fully automated Space Internetworking

Single-Spacecraft
Survey/Sensors

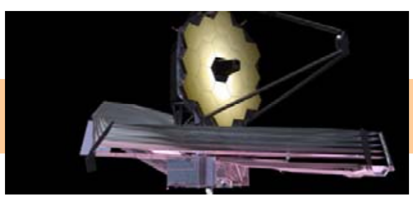


Spacecraft Constellations
and formation flying

Orbital Remote Sensing
- Long Duration, high bandwidth
- High Spatial, Spectral, & Temporal Resolution
- Low Latency Comm
- Complex link topologies
- *SensorWebs for synchronized remote sensing*

Multi-Discipline and
Multi-Resource SensorWebs

Single-Spacecraft
Observatories in LEO



Greater Distances
Higher bandwidth

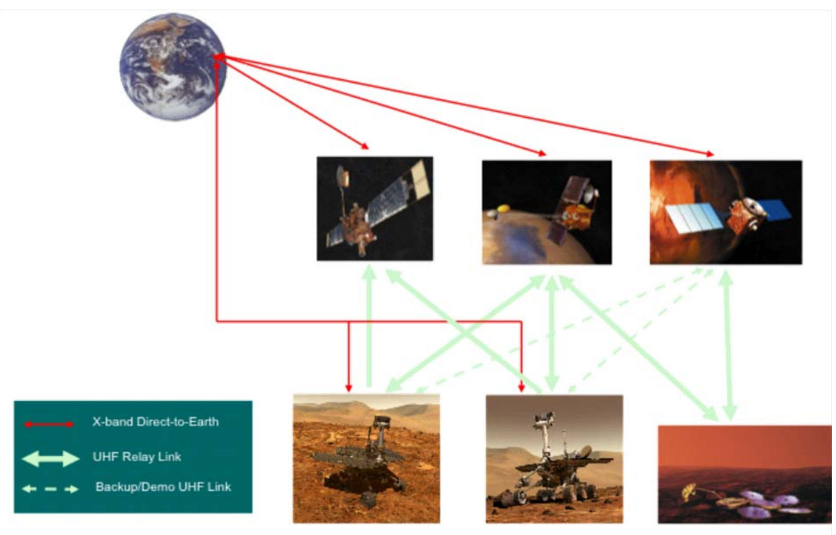
Next Generation Observatories
- More Capability
- Multiple Spacecraft drive network needs
- Even Greater Capacities require new coding schemes
- Located Even Farther from Earth

Next Generation
Observatory Complexes

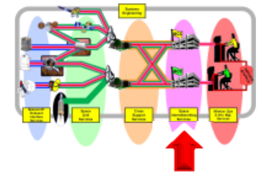
Ongoing CCSDS Projects
That Are Needed for Human Spacefight

Delay/Disruption Tolerant Networking

- The DTN Working Group is laying the foundation for the Solar System Internet (SSI)
  - Provides automated routing in space (like terrestrial Internet), but compared to current IP technology:
    - Adds Delay/Disruption tolerance for deep space environment
    - Delivers more data, faster in disrupted near-earth environment
- Past Progress and Current Work
  - Green book establishes rationale, develops scenarios, explores candidate technologies
  - Due to be approved/published this year: SSI Architecture Document, DTN Bundle Protocol (BP) specification and Licklider Transmission Protocol (LTP) Blue Books.
- Future work – Complete Solar System Internet (SSI) infrastructure with
  - Network Management
  - Contact Graph Routing
  - File Delivery Protocol (CFDP)



Asynchronous Message Service (AMS)



- The AMS Working Group recently completed standardizing messaging middleware for flight mission communications.
  - AMS provides "message bus" functionality for flight missions, including both publish/subscribe and client/server interaction models.
  - Unlike JMS or DDS, AMS is *a wire protocol rather than a service spec*
    - Conformant implementations are interoperable, no gateways needed.
  - Unlike AMQP, AMS is *peer-to-peer, not reliant on a message broker*
    - High performance, fault tolerant.
  - Unlike RTPS, AMS is *designed to run efficiently over space links*
    - Uses a built-in delay-tolerant and disruption-tolerant multicast tree.
- Overall benefit: Flight-system capable, loosely-coupled, simplified interfaces
  - Overall reduction in interface complexity
- Completed publication of Blue Book, and closed Working Group
- Reference implementation is available as open source, included in JPL's "ION" software distribution at: http://www.openchannelfoundation.org/projects/ION/

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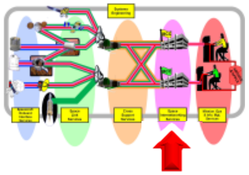
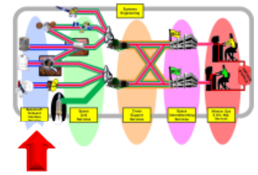
Onboard Wireless Working Group



- Overview of Onboard Wireless activity
  - Provides standards-based resources to achieve interoperable wireless network communication
  - For basic spacecraft design, reduces launch mass of vehicles
  - For operations concepts, allows untethered mobility of crew and instruments
  - On the ground, potential utility for standards in test and integration
- Approved documents:
  - Green Book: *Wireless Network Communications Overview for Space Mission Operations*
    - Examines the possibilities and advantages of the application of *wireless communications technology* to space missions
  - Magenta Book: *RFID-Based Inventory Management Systems*
    - Improve ground system and spaceflight vehicle inventory tracking & visibility
  - Magenta Book: *Low Data-Rate Wireless Communications for Spacecraft Monitoring and Control*
    - targeted towards low data-rate and low-power applications transmitting in the 850 MHz – 950 MHz and 2.45 GHz (ISM) radio frequency band

Spacecraft Monitor and Control



- Emphasis is on standardizing service interfaces for common functions that are in every mission, at the ***application level***
  - Early emphasis is for ground-to-ground interfaces
  - Starting testing for flight systems interfaces as well
- Capitalizes on industry-accepted approach of a Service Oriented Architecture (SOA)
  - Standardizing interactions of providers and consumers of service
  - Includes discovery of services (auto-configuring interfaces)
  - Plug-n-play characteristics
  - Provides application portability as well as interoperability
- Progress to date:
  - Basic framework (Message Abstraction Layer, etc.) is published.
  - First applications (Telemetry, Command, common services) is published
  - Alerts (alarm limits, etc.) currently in review cycle
  - Some future work will be spin-offs (Telerobotics, Planning, etc.)
- New Development: IOAG committee considering oversight of MO Services
- More to come: Interaction with other standards to be discussed shortly.

Other New Work Areas

- Optical Coding and Modulation SIG (Special Interest Group)
  - Considering whether it is time for an Optical Comm standard
  - Would support Mars-Earth, LEO-GEO, LEO DTE scenarios
  - Interesting work in optical coding and modulation for interoperability
- Voice and Video WGs
  - Classic problem of Voice/Video degradation from analog/digital conversions during cross support
  - Digital video adds more complexity
  - Plan to establish “profiles” of cross-supported commercial standards
  - Addressing both ground systems (between MCC’s) and flight systems interoperability
- Telerobotics WG
  - Seeking to develop standardized protocols for operating space-borne robotic sstems
- Planning Systems (Future BOF)
  - Seeking to develop standardized interfaces for exchange of Mission Operations Planning Data, for both robotic and human spaceflight programs.

GAPS:
Areas Needing Work
for Future Human Spacefight Missions

CAVEAT: These are only thought-joggers for today's session on future human spaceflight needs.

They do not represent positions of either NASA or CCSDS.

Consultative Committee CCSDS for Space Data Systems

Planetary Communications

- Current Prox-1 standard (Mars orbit-to-surface) has some problems
  - Spectrum not usable in cislunar space (terrestrial interference)
  - Capacity/bandwidth inadequate for new human missions
  - No GPS-like tracking/position/nav functions provided
  - Special Interest Group has been studying approaches, but new standard not yet underway
- Surface-to-Surface (802.X-like WiFi) not yet addressed
  - Obviously significant need for Cx-like habitat operations (lunar/Mars)
  - Probably also for LaGrange or Asteroid retrieval missions
- Currently a SIG (Special Interest Group) is discussing these topics in CCSDS.
- Ultimately, working groups will “spin off” to develop new standards documents.

EVA Communications

- Currently comm for EVA suits are incompatible between agencies (US, Russia, China)
- Envision operations scenarios:
  - Multi-national exploration of an asteroid at a LaGrange point
  - Other surface (lunar/Mars) EVA exploration around a habitat
- In these cases integrated multinational EVA compatible comm is needed
  - Certainly for contingency, if not for nominal ops
- Potential standards include:
  - Digital Voice
  - Digital Helmet Video
  - EVA Telemetry
  - General Wireless Data capability (IEEE 802.X standards)
- Expected applicability: EVA suit-to-spacecraft and suit-to-suit (suit-to-ground not expected)
- What about more general proximity communications… a broadly applicable proximity network for spacesuits *and* other suit-like devices?
  - Robonaut or Spheres (robotics), free-flying cameras and smallsats, etc.
  - external wireless sensors and effectors, the “comm nodes” discussed earlier
  - Applicable to other agencies besides those that build spacesuits.

Implications of Lightspeed Time Delays

- For time-delayed deep space international human missions, what does the ***time delay*** imply for ***potential*** future standardization needs between agencies' systems?
- A study on time-delayed communications on human exploration was conducted by NASA and culminated in a TIM in October 2012.
- The following list of factors and data types imply new needs for standardization between facilities conducting deep-space human exploration. (note – they are mostly application level)
  - Legitimacy, value of text messages was verified; new application level function
  - Text, email and delayed voice recordings require unique additional metadata features, such as message alerts, grouping/threading, auto-tagging, etc.
  - Situational awareness on the ground was a major issue. Video/voice/text metadata is one aid, but more TBD technology solutions are needed.
  - Predictive and actual comm capacity and outages, as operations management data
  - In the case where there's a habitat or large spacecraft of multi-agency modules, onboard systems management and automation *across* multi-agency systems
  - Planning, timeline and data archive/curation is already in the standardization process, but maybe not in a way that factors in requirements driven by time delayed mission communications.

“Around the World” MCC rotation

- In the early ISS program, a concept was briefly considered where the Mission Control function would be passed from control center to control center based on day shift hours
  - Each of (at least) three MCCs would have an 8-hour shift
  - Eliminated the need for any one agency to bear 24 hour operations
- Concept was abandoned as being politically and technically unfeasible
- Politics aside, consider what would enable this technically (?)
  - With deep-space time delays, realtime MCC responses are less achievable anyway; offline MCC concepts may be more adaptable to this ops scenario.
  - Application level service interfaces (CCSDS MO Services)
  - Cloud-based applications accessible to all MCC’s

SPECIAL TOPIC:
Avoiding conflicting standards
For Human Spaceflight
DEM/PUS/SM&C

Background

- This issue has been raised in the CCSDS community
- The function can be characterized as application-level characteristics (telemetry, command, planning, etc.) as manifested in packet transport mechanisms.
- ESA does this with their Packet Utilization Standard (PUS)
  - Widely adopted by European programs.
  - In the past they have attempted to bring this forward as a candidate CCSDS standard.
  - NASA did not support this concept.
- NASA does this with the Data Exchange Message (DEM) as a program-internal standard for the MPCV/SLS/KSC programs only.
  - DEM is a component of the larger C3I Architecture specification
  - C3I = Command, Control, Communications, and Information
- It is also possible that the ongoing work in the CCSDS Spacecraft Monitor and Control (SM&C) Working Group on Mission Ops Services can perform this function. (SM&C and MO Services are equivalent)
- Purpose of this discussion: Explore ways forward for future international human spaceflight programs, for this function.

Background (cont.)

- Actually, there is significant (but not 100%) overlap of three standards:
  - ESA's PUS (ca. 1994)
  - NASA's DEM/C3I (Cx era, but continues in MPCV/SLS/KSC projects)
  - CCSDS SM&C Mission Operations Service protocols (started ~2003)
- The Constellation program and new NASA human spaceflight projects (MPCV/SLS/KSC) do not have formal international interoperability requirements.
  - Hence, C3I and DEM has not been surfaced in international ICDs, etc.
  - However, future international human programs would likely need to come to agreement on an interoperable interface for this function.
- Recently CCSDS asked NASA to bring DEM forward to CCSDS for discussion on standardizing either DEM or PUS for this application-layer function.

Background (cont.)

- Open question: Should we consider only NASA's DEM or full the full NASA C3I specification for this discussion?
  - Direct comparison of PUS and SM&C Mission Ops Services to DEM only doesn't reflect full MPCV approach.
  - Other C3I protocols/services will need to be factored in to compare all functionality apples-to-apples.

Comparison of PUS, MO Services, DEM, C3I

PUS services	Mission Ops Services	DEM Only	*C3I (defined in vol 8) and DEM (vol 5)
Telecommand verification	M&C / Action	Telemetry	Command Response DEM
Device command distribution	M&C / Action	Command	Command DEM
Housekeeping & diagnostic data reporting	M&C / Aggregation & Parameter	Not Defined	Telemetry DEM
Parameter statistics reporting	M&C / Statistics	Not Defined	Scripting engine
Event reporting	M&C / Alert	Not Defined	Caution & Warning and Event-driven telemetry DEM
Memory management	Software Management - TBD	Not Defined	Dump uses telemetry DEM or to a file, Load uses files and commands, CFDP
Function management	M&C / Action	Not Defined	Command DEM
Time management	Time TBD	Not Defined	Time in telemetry and sync via NTP, GPS, USCCS w/ commands
On-board operations scheduling	Scheduling TBD	Not Defined	Time & event triggered command DEMs
On-board monitoring	M&C / Parameter & Check	Not Defined	Event-driven telemetry and scripting engine
Large data transfer	Data Product Management TBD	Not Defined	CFDP
Packet forwarding control	Remote buffer Management TBD	Not Defined	DEM forwarding and IP routing
On-board storage and retrieval	Remote buffer Management TBD	Not Defined	Data recording and CFDP
Test	M&C / Action	Not Defined	Command BIT tests with results in telemetry
On-board operations procedure	Automation TBD	Not Defined	Crew procedures, Automation, & Scripting Engine
Event-action	Automation TBD	Not Defined	Scripting Engine
Not Defined	M&C / Alert	Not Defined	Crew notifications via Caution & Warning
Not Defined	CCSDS Voice Std.	Not Defined	Audio: RTP/G.729 (same as ISS Ku-band)
Not Defined	CCSDS MIA Std.	Not Defined	Video: RTP/H.264 (same as ISS Ku-band)

Considerations

- Positive factor for SM&C MO Services evolution:
  - Full C3I did broad adoption of other standards
    - NTP, GPS, H.264, CFDP, etc.
  - It should be just as easy for those same “external standards” to “ride on” C3I as on DEM.
  - However, working that into SM&C will require more participation from the NASA C3I experts to get engaged with SM&C to evolve it in that direction.

Comparison

- Historically, C3I has been designed single-agency, single-program. PUS and MO Services were developed and designed in multi-agency forums (PUS only European multi-agency).
- SM&C MO Services has strong pick-up in:
  - NASA's human program (MCC-Houston)
  - ESA's robotic (unmanned) program.
- Other complications in making apples-to-apples comparison:
  - PUS and MO Services handle those data types in an integrated way, within one spec.
  - C3I is not so tightly integrated, lots of external references
  - C3I includes more variables (less standardization), more flexibility (Scripting engines, etc.)
  - PUS is more ridged (less flexible) compared to C3I

More Background on PUS

- ESA has been using PUS since 1994
  - Pervasive across European missions
  - Not only as ESA, but as DLR, CNES, ASI, UKSA, etc.
  - European Cooperation for Space Standardization (ECSS) approved standard
- ESA has strong support for migrating to SM&C MO Services for ground systems.
- ESA direction for flight systems is still being discussed.
- Other agencies (besides NASA and European) weighing in right now could influence both the NASA and ESA long-term direction
- Alternatively, failure to resolve before the next major international human program could result in imposing DEM or PUS for on other agencies, or the requirement to build converter/gateway functions.

Proposed position on DEM/PUS/SM&C

- Neither DEM nor PUS should be promoted as long-range international interoperable standards.
- For the long-range interoperability of these functions, CCSDS should develop those functions fully specified by the SM&C protocol stack and Mission Ops Services.
- NASA and ESA should participate in CCSDS in developing DEM/C3I-like and PUS-like functions in SM&C
- Eventually SM&C will replace DEM and PUS in systems long-rage.
  - Probably not too difficult for future ESA Human Spaceflight programs because ESA ISS systems don’t use PUS or DEM.
  - Probably very difficult for ESA robotic spaceflight programs, but any such transition can be *very* long-range.
  - Probably also difficult for NASA MPCV/SLS/KSC programs.
- There is no implied “due date” for such a transition.
- However, when the next major human spacefight program establishes international exchange of these formats, the choice of interface should be SM&C Mission Operations Services.

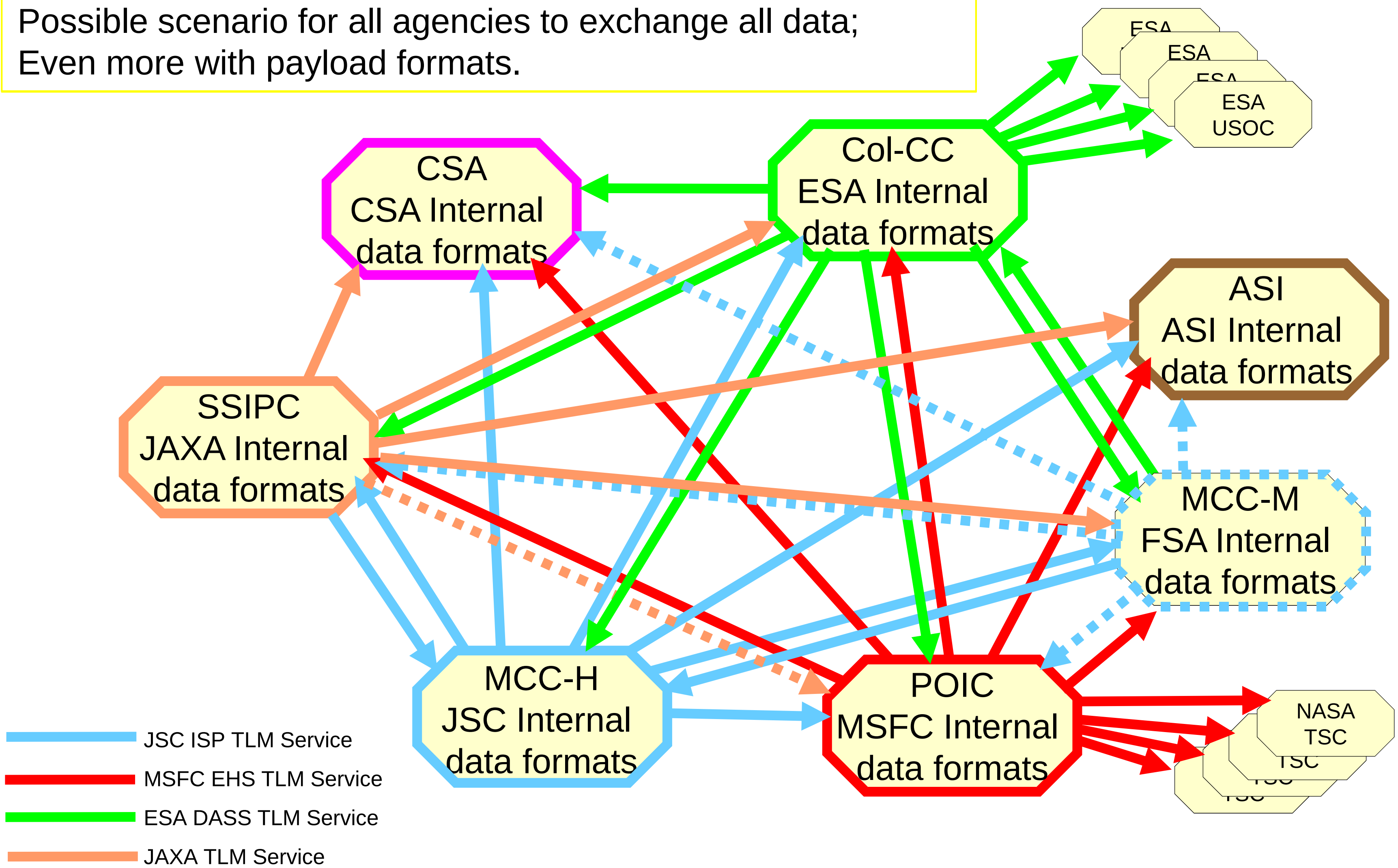
CCSDS Summary

- Take-home message: Still much work to be done
  - Enabling interoperability between international agencies for future missions – both Earth-Orbital and Exploration
  - Long-range vision – automated routing and delay tolerant networking for deep space crosslinks between spacecraft and surface systems
  - Near-term need – evolutionary approach to sustain cross-support agreements with other agencies.
- Organizations with a stake in the future of ***human spaceflight*** and the expertise to contribute to CCSDS should become engaged.

BACKUP

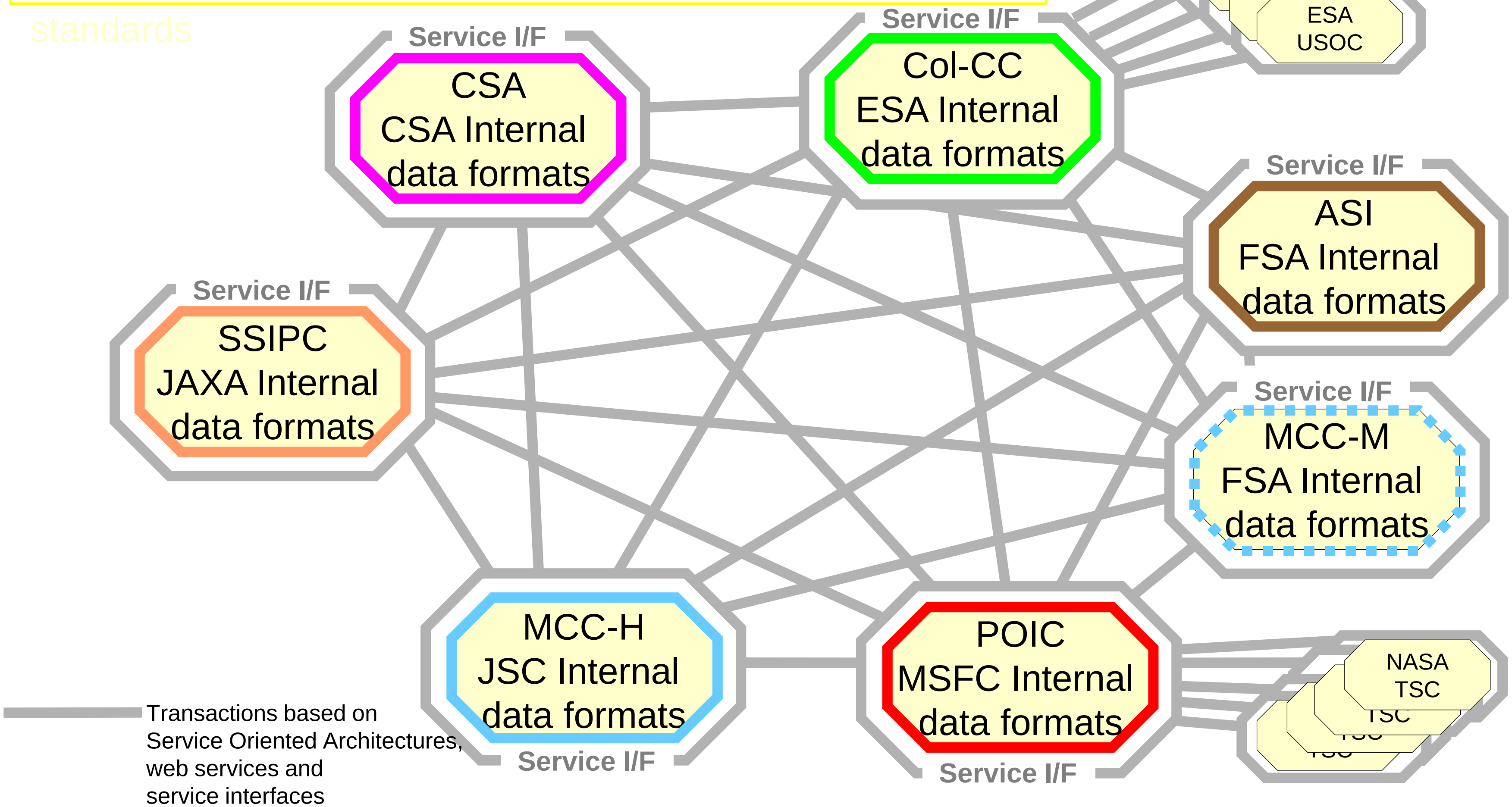
Mission Ops TLM Services – ISS Current formats

Possible scenario for all agencies to exchange all data;
Even more with payload formats.



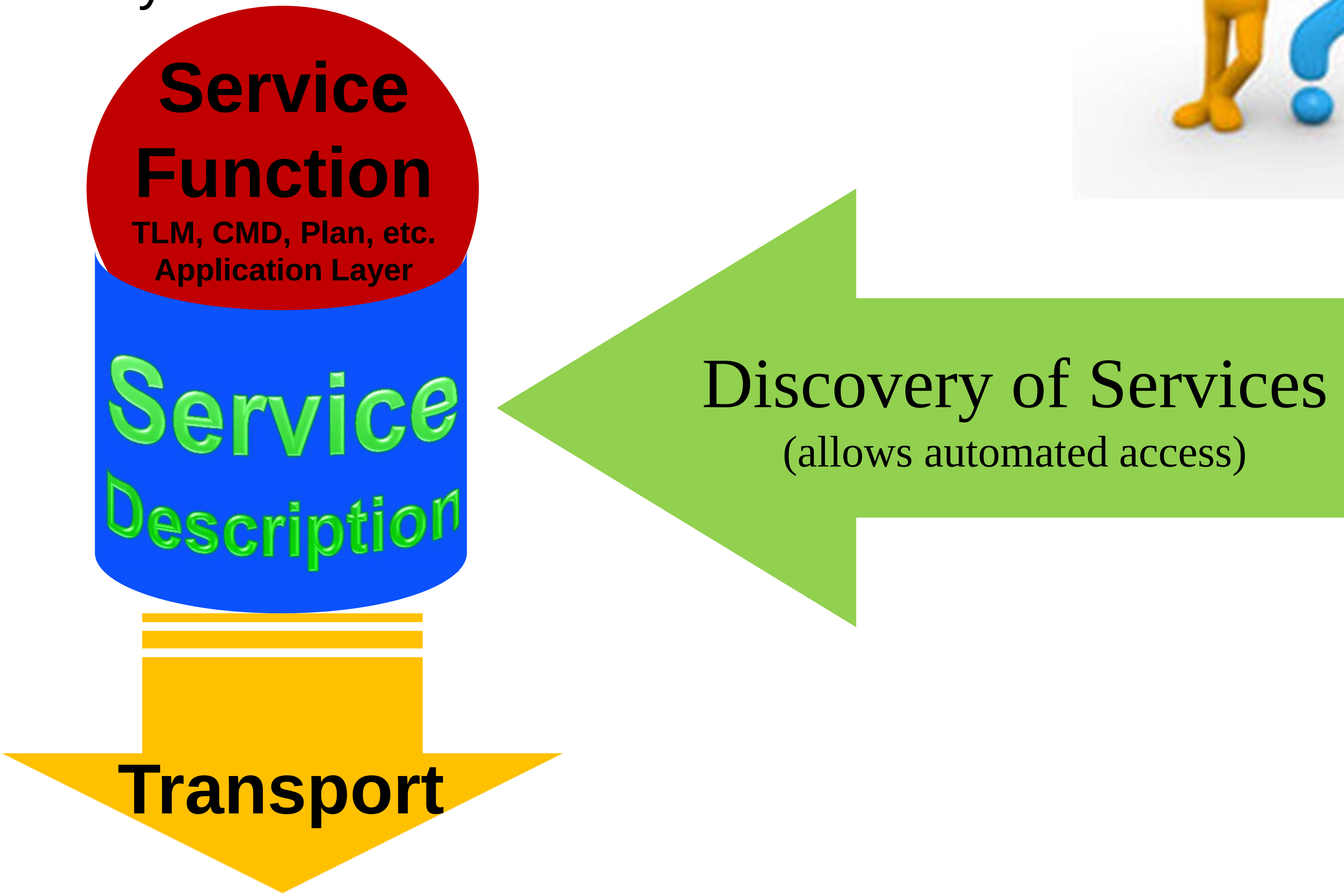
Mission Ops TLM Services – ISS Current formats

Possible scenario for all agencies to exchange all TLM data;
Even more with payload formats. And this is TLM only.



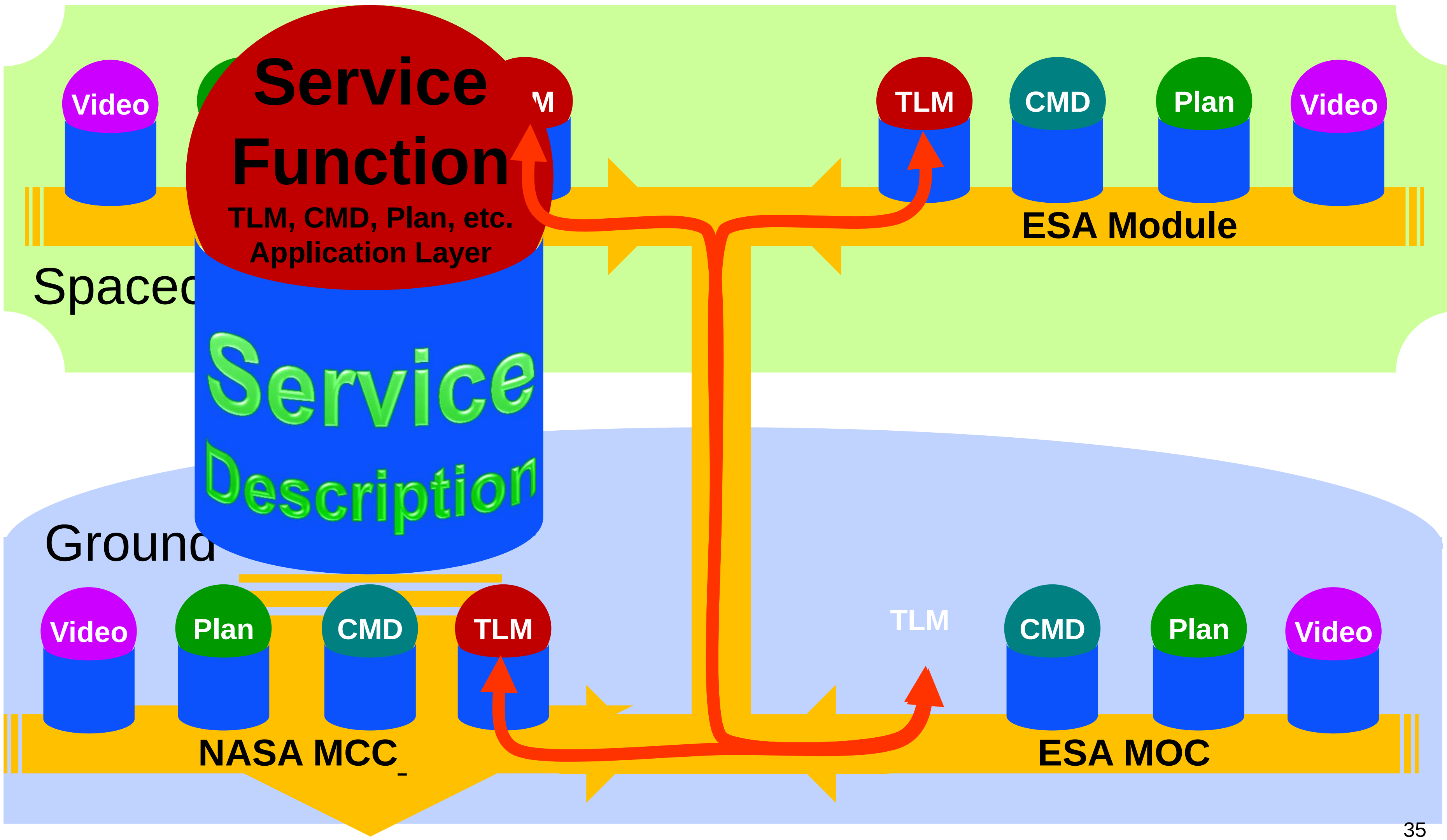
How Does This CCSDS MO Service Architecture Work?

Service Oriented Architecture
→widely used in other industries

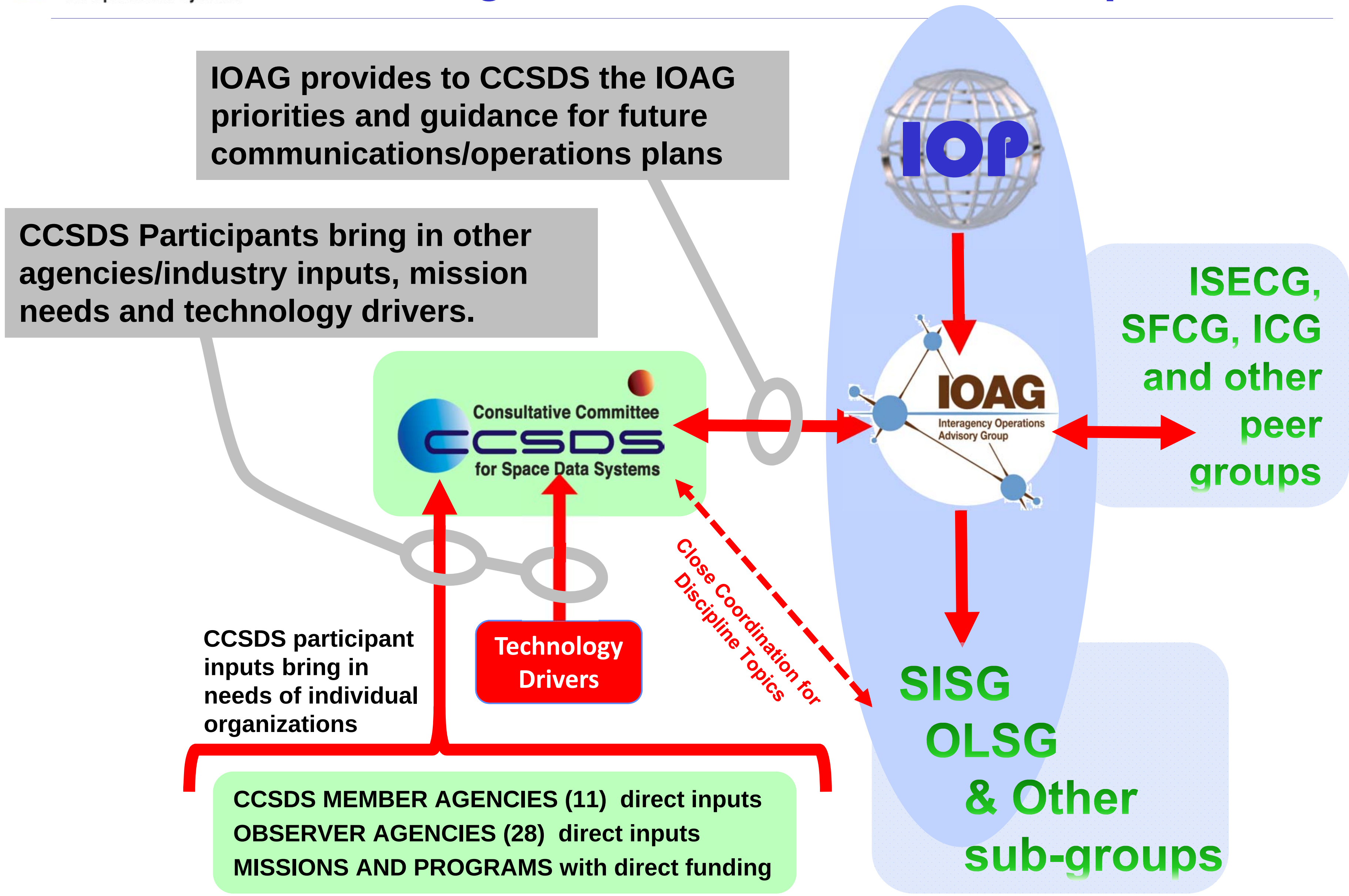


How Can This CCSDS MO Service Architecture Work?

Cross-support is based on *operational configuration and on security*
→ *NOT* on a new software development project.



CCSDS Overview
Organizational Interrelationships



Field Guide to CCSDS Book Colors

BLUE BOOKS

Recommended Standards

Normative and sufficiently detailed (and pre-tested) so they can be used to directly and independently implement interoperable systems (given that options are specified).

MAGENTA BOOKS

Recommended Practices

Normative, but at a level that is not directly implementable for interoperability. These are Reference Architectures, APIs, operational practices, etc.

GREEN BOOKS

Informative Documents

Not normative. These may be foundational for Blue/Magenta books, describing their applicability, overall archtecture, ops concept, etc.

RED BOOKS

Draft Standards/Practices

Drafts of future Blue/Magenta books that are in agency review. Use caution with these… they can change before release.

ORANGE BOOKS

Experimental

Normative, but may be very new technology that does not **yet** have consensus of enough agencies to standardize.

YELLOW BOOKS

Administrative

CCSDS Procedures, Proceedings, Test reports, etc.

SILVER BOOKS

Historical

Deprecated and retired documents that are kept available to support existing or legacy implementations. Implication is that other agencies may not cross-support.

PINK BOOKS/SHEETS

Draft Revisions For Review

Draft Revisions to Blue or Magenta books that are circulated for agency review. Pink Books are reissues of the full book, Pink Sheets are change pages only.