Interplanetary Network Directorate

Communication Standards, Who Needs Them?

28 October 2002

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wrong

Some Beliefs About Standards

- They stifle creativity
- They add cost and complexity
- They're cumbersome to use
- They're not right for *my* problem
- …

Rationale (or, Why we need standards)

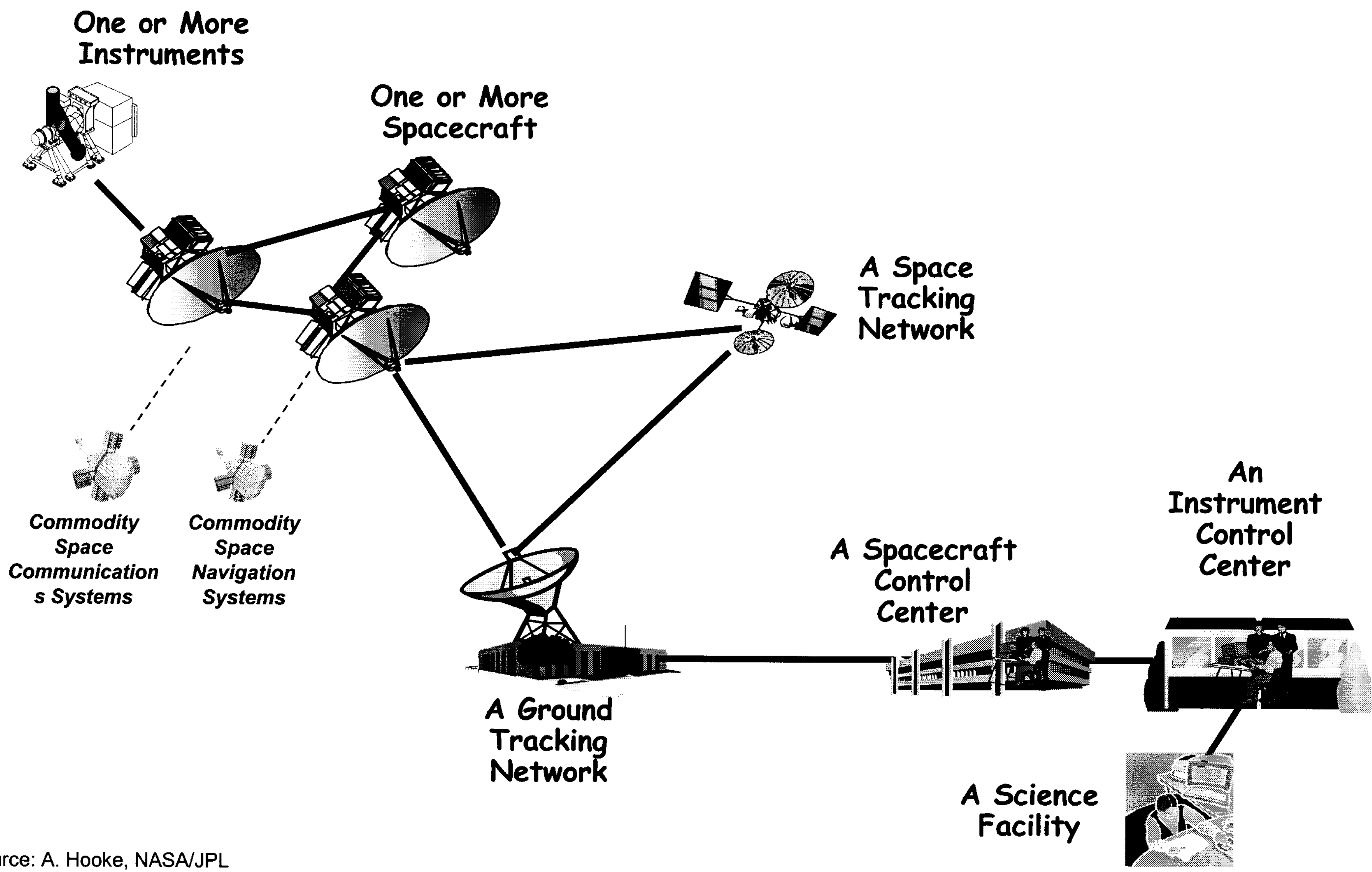
- **Cross-support**
  - Ground assets (e.g. DSN)
  - Space assets (e.g. Mars relay)
- **Interoperability**
  - Multi-agency support agreements
  - Multi-mission support arrangements
- **Reduce costs**
  - Shared (expensive, scarce) resources
  - S/W and H/W reuse
  - Commercial implementations
- **Increase reliability / reduce risks**
  - Through use of well tested local and commercial implementations

Mission Drivers

- **INCREASED SPACE SEGMENT CAPBILITIES**
  - More miniaturization, more missions, more bang for the buck
  - Higher date rates, more powerful onboard processing
  - Constellations and Formation Flying
    - Inter Spacecraft Communications
    - Positioning Relative to Each Other
  - Autonomous Exploration
    - Less reliance on "Joystick Operations."
    - Dynamic Response to Environment (Precision EDL, Rendezvous & Docking)
  - Highly networked
    - Re-configurable web of orbiting and landed sensors for in-situ, long-term and detailed observation, prediction and analysis.
    - Data access, fusion and integration requirements
- **HIGHLY DISTRIBUTED MULTI-ORGANIZATION DESIGN AND OPERATIONS TEAMS**
  - Agency, Academic, and Corporate entities
  - National and International Partnerships

CCSDS:
The Fleet
Space Domain
Spacecraft Platforms
On-Board Systems
Space Qualified ASICs
Astro-E
INTEGRAL
Gravity Probe B
Lunar-A
EOS LAM-2
EOS AM-2
Selene
JASON
CHAMP
SIRTF
ERS-1
EOS PM-2
SolarB
ETS-VII
QuikSCAT
EOS PM-1
SAMPEX (SMEX-1)
Radarsat
EOS LAM-1
Astro-F
Muses-C
EOS CHEM-1
ROSETTA
Spacelab-Deutsche 2
ERS-2
FAST (SMEX-2)
METOP-1
International Space Station (ISS)
EURECA
ISO
Consultative Committee for Space Data Systems
245 missions, and counting
STRV-1 A/B
Cassini
TEAMSAT
YES
Rossi XTE
BeppoSAX
MIR 1 and follow-on missions
NEAR
MGS
EOS AM-1
TOMS EP-1
MPF
TRMM
DS-1
Lunar Prospector
Ground Domain
Commercial Ground Networks
Command & Telemetry Data Processing
http://www.ccsds.org
Space Link Extension Forward and Return Services

Physical View of Space Data System

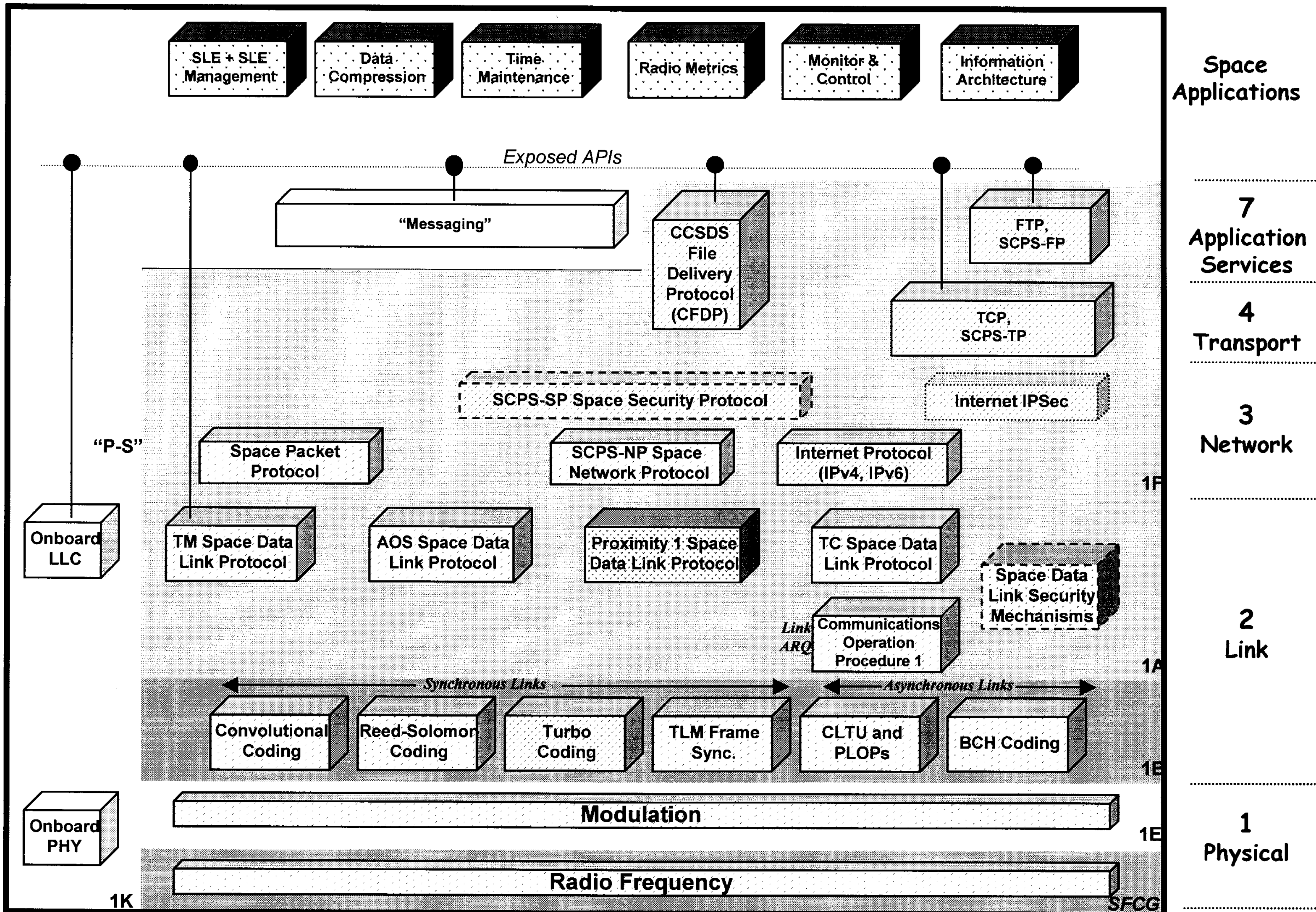


Source: A. Hooke, NASA/JPL

Core Data Transfer Standards

- **Physical & Link Layers**
  - Frequency and modulation
  - Coding gain
  - Logical link between entities
  - Accounting at the link layer
- **Packet Layer**
  - Merging data onto the link
  - Separation and prioritization of multiple data sources
  - Accounting by data source
- **File Delivery Layer**
  - Support for file oriented uplink, downlink and onboard file handling
  - Reliable file transfer across proximate & deep space links

CCSDS Space Communications Standards



Source: Adrian Hooke, JPL

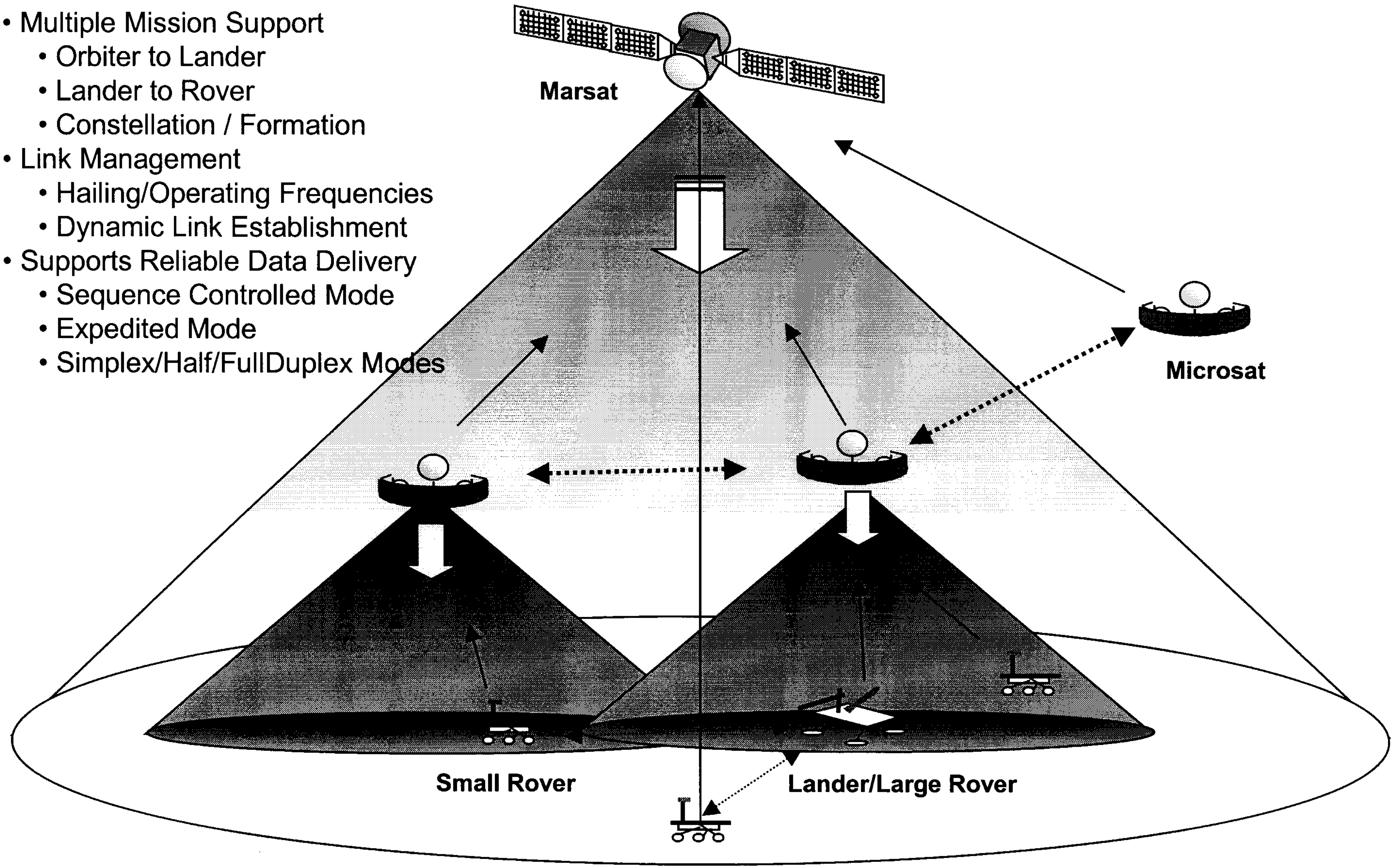
Notable Recent Successes

- **Proximity -1 Link Layer**
  - **Prox-1 consists of three parts:**
    - Link protocol for "near-by" communications, point to point, half / full duplex, simplex
    - Link establishment and management specifications
    - RF, Modulation and Coding specifications
  - **Jointly developed at JPL with Electra, MEPO**

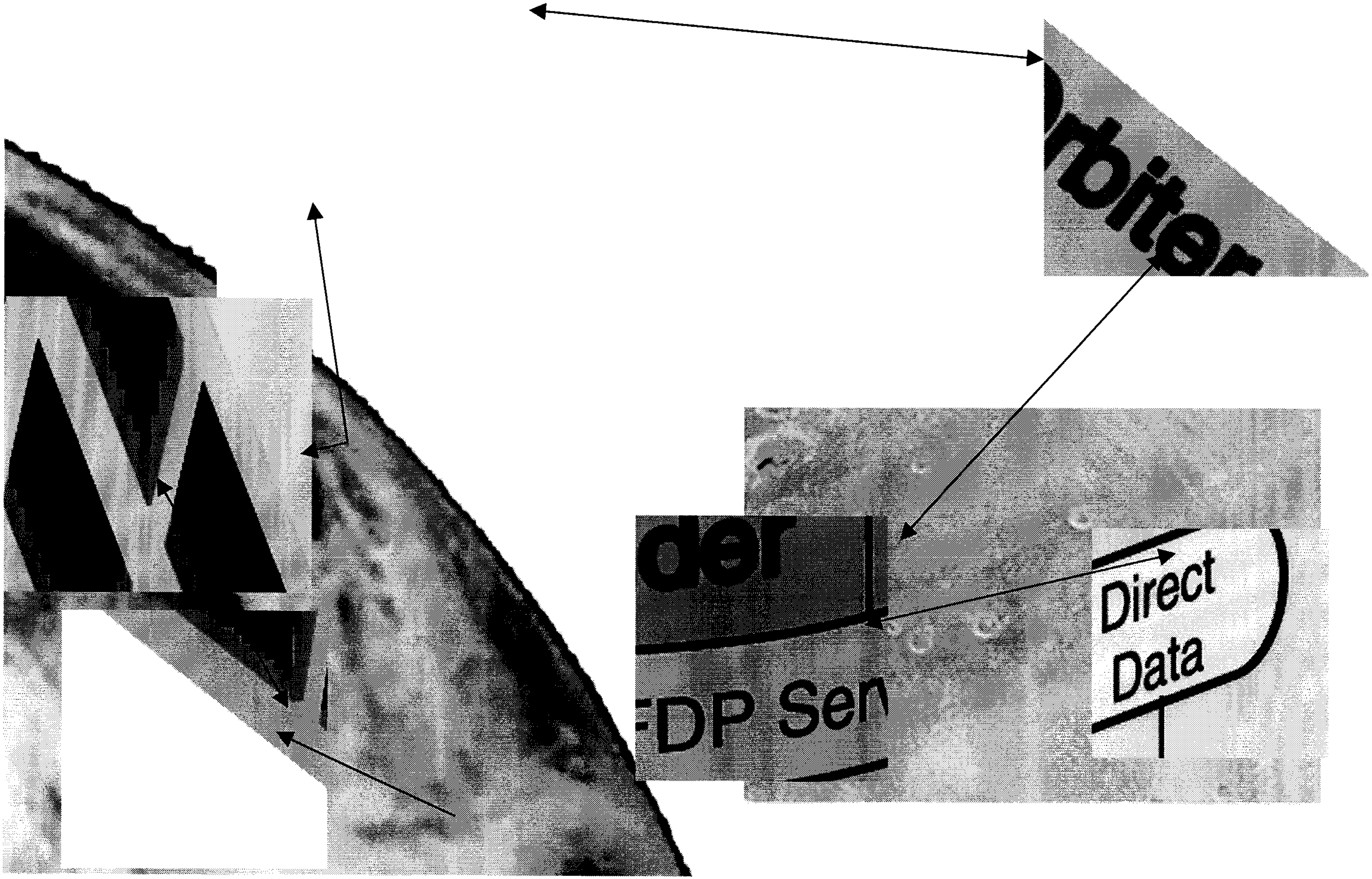
- **CCSDS File Delivery Protocol (CFDP)**
  - **CFDP consists of two parts:**
    - Core Procedures (over single link)
    - Extended Procedures (over multiple links / relay operations)
  - **Jointly developed at JPL by Standards Program and IND Engineering Office, delivered to Ball Aerospace**

Future Potential Mars Environment

- Multiple Mission Support
  - Orbiter to Lander
  - Lander to Rover
  - Constellation / Formation
- Link Management
  - Hailing/Operating Frequencies
  - Dynamic Link Establishment
- Supports Reliable Data Delivery
  - Sequence Controlled Mode
  - Expedited Mode
  - Simplex/Half/FullDuplex Modes



CFDP Multi-hop Scenario (3A)



"Pedigree" of Standards

- Agreed by all ten major space agencies and the 23 observer space agencies
- Supported by an active organization and adopted as ISO and NASA preferred standards
- Implemented by:
  - DSN
  - AMMOS S/W
  - Many commercial products and S/C vendors, see http://ccsds.gst.com/implementations/products.html
- Used by more than 245 space missions

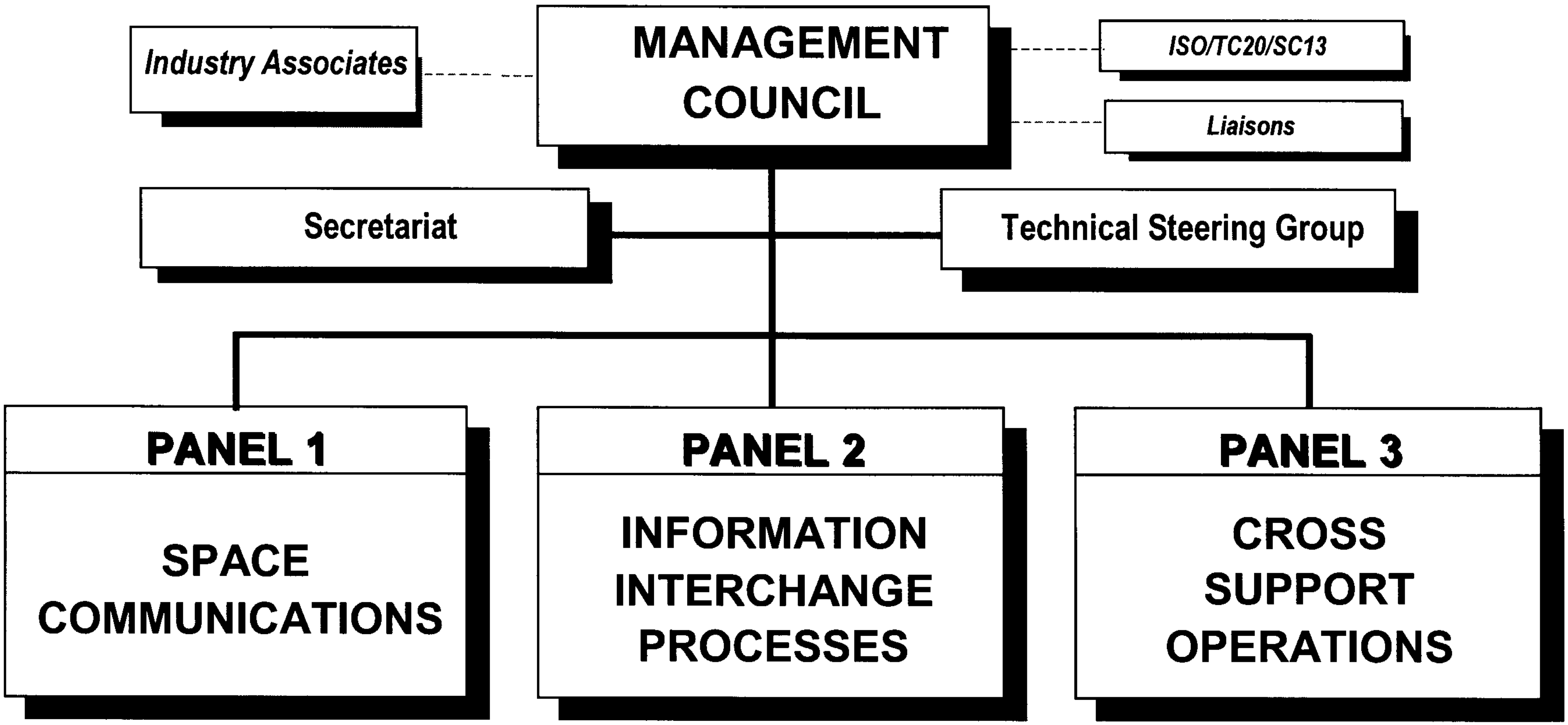
See http://www.ccsds.org

Summary

- **Internationally agreed Standards provide significant mission and program benefits**
  - Reduced risk
  - Reduced costs
  - Improved performance
  - High functionality
- **Standards process is well understood**
  - NASA centers and international partners
  - ISO process for bringing standards into larger venue
- **Process at JPL requires mission involvement**
  - Stakeholders in defining delivered result
  - Active involvement in testbedding, implementing and validating specification
  - Participate in review and approval process

Backup Slides

Consultative Committee for Space Data Systems (CCSDS)



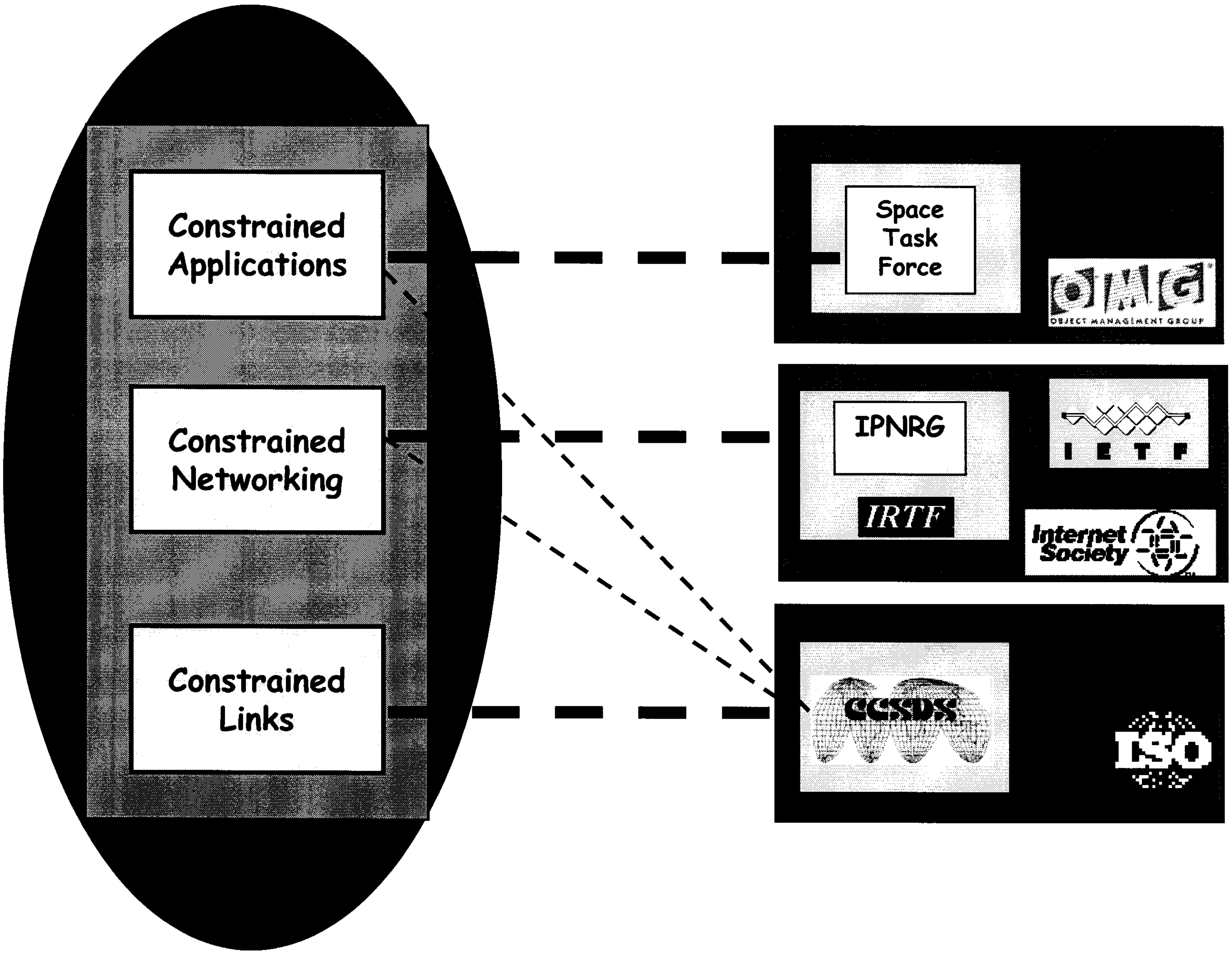
Member Agencies

ASI/Italy	*ESA/Europe*
BNSC/UK	*INPE/Brazil*
CNES/France	*NASA/USA*
CSA/Canada	*NASDA/Japan*
DLR/Germany	*RSA/Russia*

Observer Agencies

ASA/Austria	*CTA/Brazil*	*IKI/Russia*	*NOAA/USA*
CAST/China	*DSRI/Denmark*	*ISAS/Japan*	*NSPO/Taipei*
CRC/Canada	*EUMETSAT/Europe*	*ISRO/India*	*SSC/Sweden*
CRL/Japan	*EUTELSAT/Europe*	*KARI/Korea*	*TsNIIMash/Russia*
CSIR/South Africa	*FSST&CA/Belgium*	*KFKI/Hungary*	*USGS/USA*
CSIRO/Australia	*HNSC/Greece*	*MOC/Israel*	

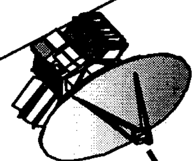
Current Active Standards Tracks



CCSDS Strategic Themes
(JPL Content Indicated)

5. Develop Interoperable Spacecraft Onboard Interfaces

■ "Network Ready" Space Devices and Subsystems



4. Develop Space Missions as Extensions of the Earth's Internet

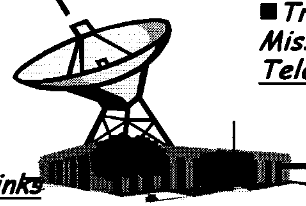
Interface with Near-Earth Constellations
Interface with Commercial Near-Earth Navigation Systems
Interface with Public Media Distribution Systems
Extension of the Internet into Near-Earth Vicinity
■ Extension of the Internet into Deep Space

3. Develop Standard Mission Operations Services

Space Link Access
Spacecraft Monitor and Control
■Ground System Monitor and Control
■Tracking and Navigation Services
Mission Planning Services
Telecommunications Services

1. Develop Highly Efficient Communications in Resource-Constrained Environments

Single Aperture/Multi-User Links
Higher Frequency Communications
■ Efficient Modulation
High Performance Coding
Proximity/In-Situ Communications Links
File Transfer Protocols
■ Security and Privacy
Advanced Data Compression



2. Develop Standard Data Interchange and Archiving Services

Data Management Services
■ Information Architecture for Space Data
Space Data Archiving Techniques

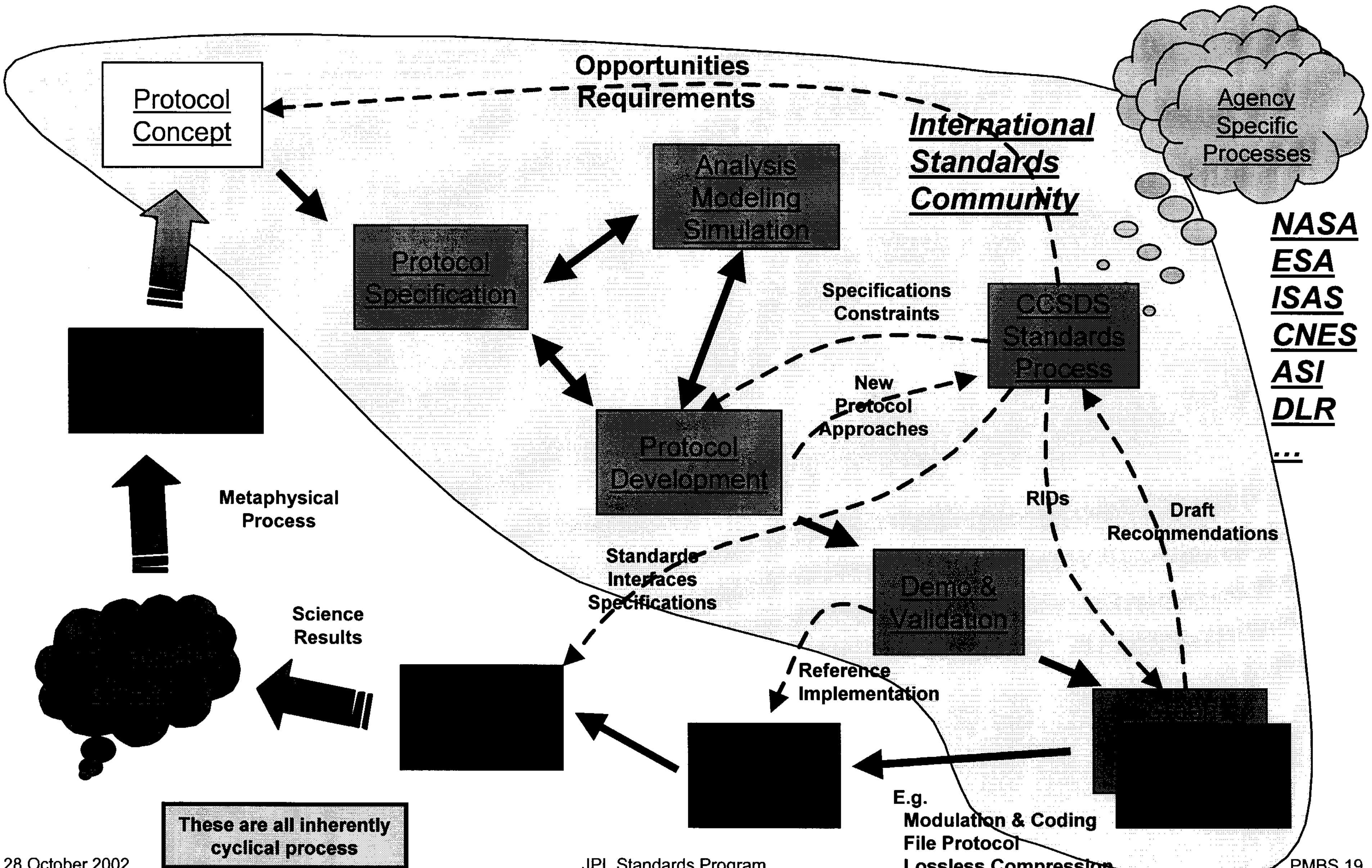
Key:
Underlined items are current JPL work items
♉ Bullets mark newest JPL work items
Some unmarked items are funded at GSFC

- **Develops Leading Standards**
  - "Leading" means the standards do not just document what has been done before, but look toward the future
  - Well-engineered pathways to guide future end-to-end system designs
  - Converge on a common way of doing the routine things that each spacecraft, tracking station, and ground tracking station must do

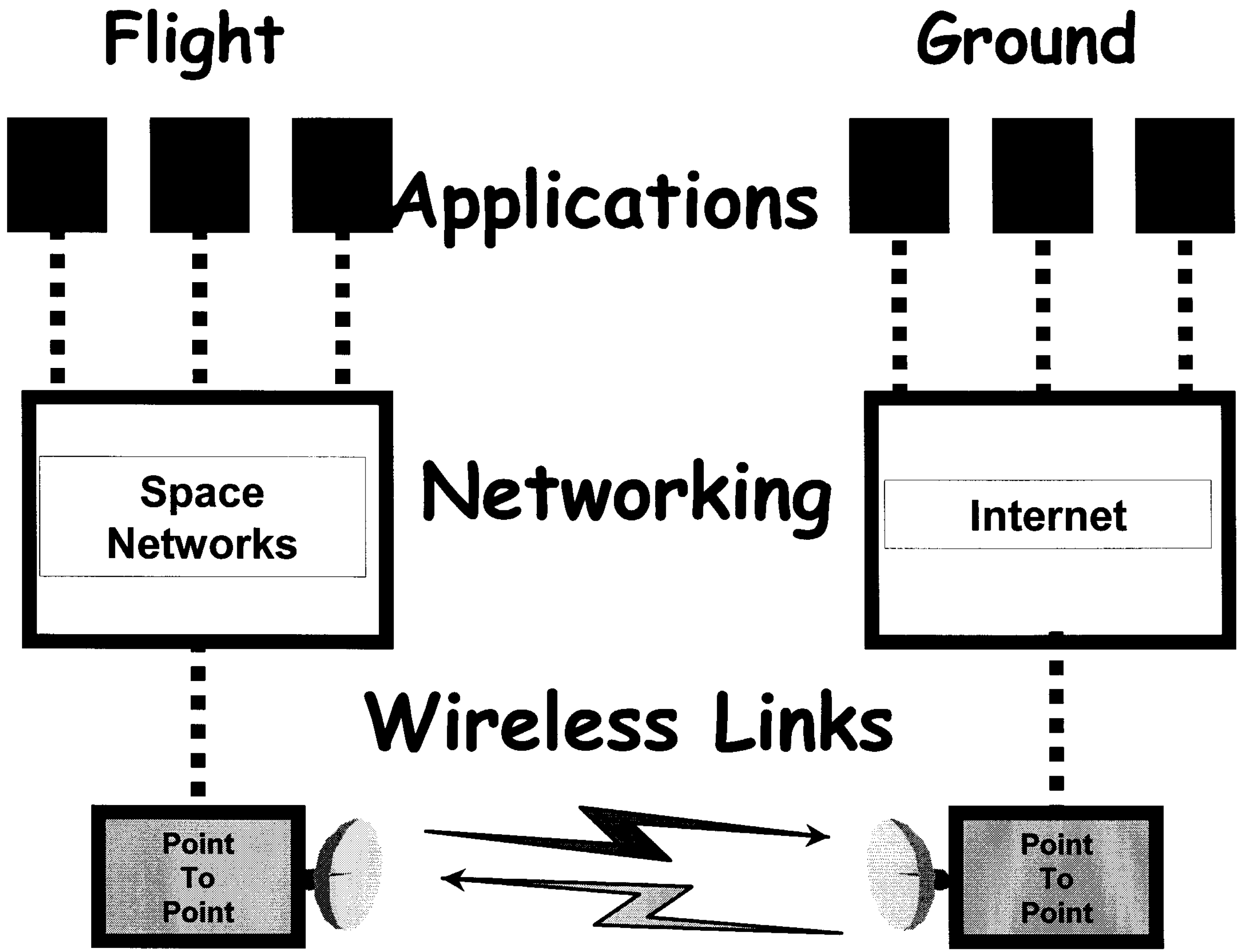
- **Guide future mission designs in areas of common and routine operations**
  - Proportionally less money expended on the functions common to all missions,
  - More money for the mission's non-routine and unique needs

- **Single standards that cover many missions must ..**
  - Deal with ill-defined, aggregate, future mission needs
  - Have flexibility to accommodate needed variations
  - Represent a delicate balance between defining multi-mission functions that are "good enough" and can be done at "reasonable cost"
  - Be defined using good engineering judgment and vision

CCSDS Standards Creation Process

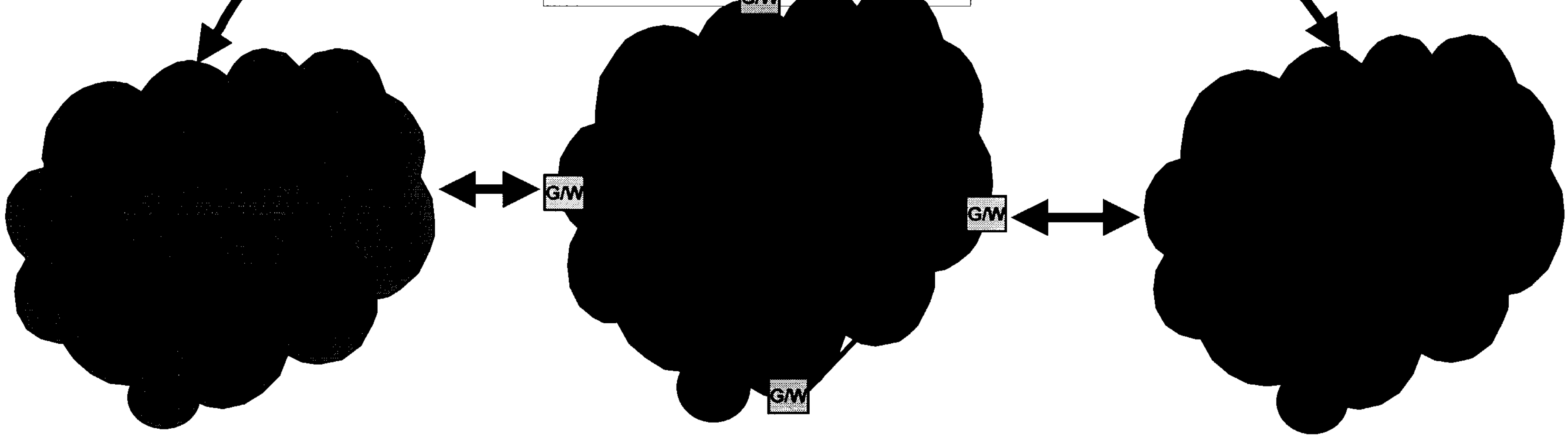


Layered View of Space Data System



Interplanetary Network Global Overview

End-to-End Protocols for IPN
- CFDP baseline completion
- Bundling prototype
- End to End Application framework
- Distributed System Mgmt & Ops
- Security



Internet Technologies
- IS Technologies (XML)
- Visualization
- Immersive environments
- Application component middleware (OMG & others)
- Web based applications
- SLE (transport, mgmt)

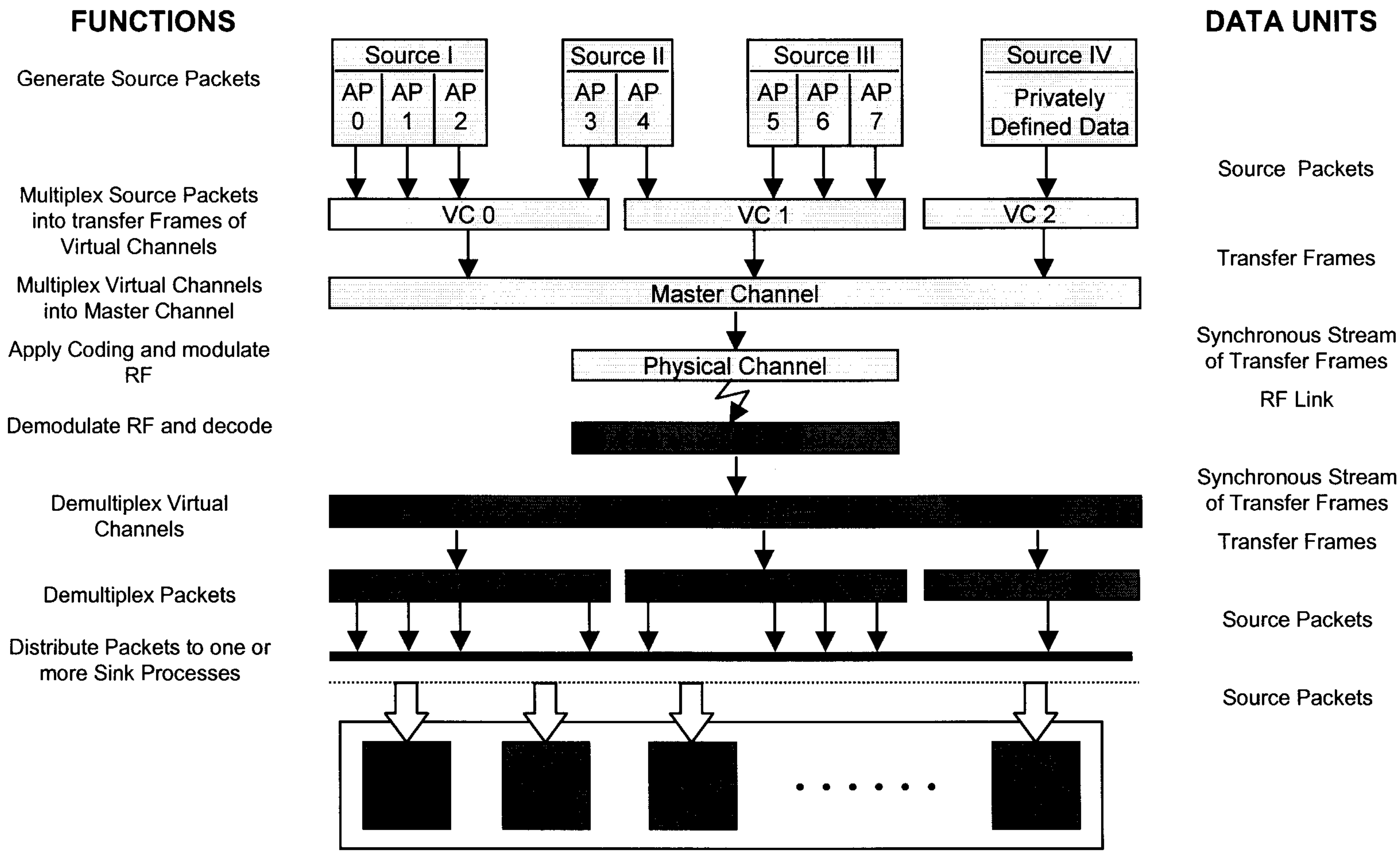
InterPlanetary Network "Backbone"
- RF (coding, modulation)
- Optical (coding, modulation, stds)
- Link (coding, modulation, interop)
- Navigation (stds, interop)
- Time (clocks, time svcs)

"Proximate" Internets
- Local wireless (include constellation & formation)
- Local wired (include S/C & surface)
- Local Internet (include near planet)

Space Communication Protocol Incubator

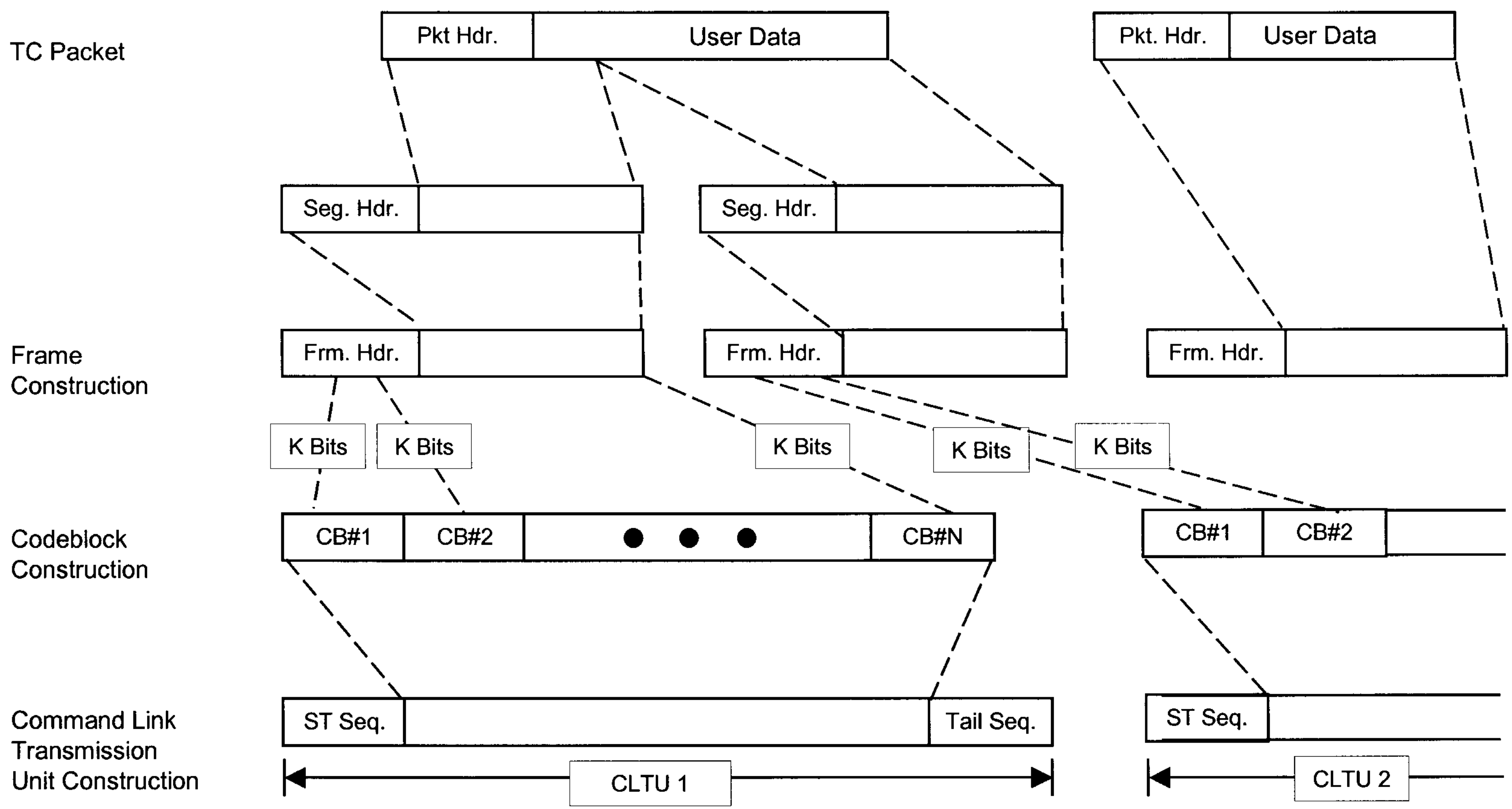
INTERPLANETARY NETWORK DIRECTORATE

Telemetry Data Flow



AVTEC SYSTEMS

Telecommand Packet Transfer Services



NOTE: The data field of each CLTU contains the encoded representation of one or more transfer frames.

Current JPL Program Content

- CCSDS File Delivery Protocol (CFDP)
  - Multi-hop relay, technology prototype
- Proximity 1 Link Protocol
  - Restructured Link Layer Space Protocol Documents
- Space Communication Protocol Standard (SCPS)
  - Internet protocols tuned for space
- Space Link Extension (SLE)
  - Service requests & service management
- Spacecraft Onboard InterFace (SOIF) Definition
  - "Plug and Play" device and application interfaces
  - SOIF Message Layer prototype
- And several other tasks
  - Application "profiles" - how to apply these standards
  - Bandwidth & spectrum efficient coding and modulation
  - Navigation data interchange standards
  - XML Space Application Study
  - IPN Protocol Study Task

Proximity-1 Link Protocol

- Prox-1 consists of three parts:
  - Link protocol for "near-by" communications, point to point, half / full duplex, simplex
  - Link establishment and management specifications
  - RF, Modulation and Coding specifications
- Link Protocol includes:
  - Sequence controlled data delivery over a single link, "go back n" ARQ
  - Expedited data delivery over a single link, command link may be one to many
- Link Establishment and Management includes:
  - Link setup and tear-down
  - Operational parameter negotiation (mode, rate, frequency, modulation, encoding)
- RF, Modulation and Coding includes:
  - RF, hailing channels and working channels, modulation
  - Convolutional code error correction and CRC error detection
- Prox-1 spec has been edited to leave the link protocol, including management functions, in the core spec and to move the RF and modulation sections moved into an Annex prior to moving them into separate Physical Layer documents

Use and Support for Proximity-1

- **Mission Use**
  - JPL Mars missions (Odyssey, MER, MRO, MSL, Mars Scout)
  - Beagle, Netlanders, ASI Telecom orbiter, CNES Premier Science orbiter, Mars Express
- **Flight System Support**
  - CE Radio (partially compliant)
  - Electra (MRO, MSL, ASI Telecom Orbiter, CNES ’07 Science Orbiter)
- **Implementation & Validation**
  - Four independent implementations
  - Initial protocol simulation for validation
  - Evaluations of link throughput at various data rates & margins

CCSDS File Delivery Protocol

- **CFDP consists of three parts:**
  - **Core Procedures (over single link)**
  - **Optional Extended Procedures (over multiple links / relay operations)**
  - **And standard user operations (store & forward overlay, proxy delivery)**

- **Core Procedures include:**
  - **Reliable file delivery over a single "link"**
  - **Simplex file delivery over a single link**
  - **File manipulation & mgmt primitives**

- **Extended procedures include:**
  - **File delivery with multi-hop relay**
  - **Product delivery (store & forward)**

- **CFDP spec now includes the core (with deferred transmission) and the extended procedures, with options of extended protocol for relaying and the product oriented store & forward overlay**

- **CFDP extended procedures are being viewed as a precursor of the "Bundling" protocol that is being created within the IPNRG**

Use and Support for CFDP

- **Mission Use**
  - Deep Impact
    - Ball Aerospace S/W platform
  - Mission Data System (MDS)
  - APL Messenger
  - GSFC NGST

- **Flight & Ground System Support**
  - Aug 01, Common Ground & FSW delivery to Ball
  - Apr '02, TTACS with integrated CFDP
  - Oct '02, first delivery integrated with IND ground system
  - Apr '03, integrated w/ SLE in ground system

- **Implementation & Validation**
  - Bnnn independent implementations
  - Protocol simulation for validation
  - Evaluation of end to end performance at various data rates & margins

ROI: CCSDS File Delivery Protocol (CFDP)

- Background:
  - Spacecraft manage data as "products" using file structure rather than packets. Space-Ground communications using file transfer protocol provide reliable and accountable data product transfer.
- Previous method
  - Uplink and downlink processes were packet-oriented and required many manual steps to construct, validate, transmit, and handle retransmission (to deal with effects of lost or corrupted packets)
  - Turn-around times for packet retransmission requests were measured in hours, not minutes
  - Required 3-4 people for uplink and 2-3 people for downlink
  - In order to use files, most missions developed their own file protocols, with customized software both on spacecraft and on the ground. No standards, an interoperability problem, NRE costs for each mission.
- New method (CFDP)
  - Provides international standard product delivery in both reliable and expedited modes across both short haul and Deep Space links, and recreates the user's product directly for transfer to user's processing
  - Automated protocol improves link utilization and reduces operational costs and complexity (link turn around in 5 minutes vs 6-8 hours, transmit up to 20K files / year vs 2K - based upon DS-1 experience w/ pre-cursor)
  - Tested for interoperability with four space agencies (ESA, BNSC, NASDA, NASA)
  - Adopted by Deep Impact, Messenger, and Next-Generation Space Telescope (mission enhancing, automation, cost savings, cost avoidance)
- Cost Benefit
  1. Mission using CFDP-based file service provided by DSMS
     - Use our core flight/ground software: flight s/w development cost savings to mission $800K, mission operations cost savings 2-4 operations staff $400-800K/year/mission, cost avoidance for DSMS $800K
     - Mission develops their own CFDP: no development cost savings to mission, mission operations cost savings 2-4 operations staff $400-800K/year/mission, cost avoidance for DSMS $800K
  2. Mission relying on two different service providers
     - Mission development cost savings ≥$800K when CFDP is used as the common interface approach
     - Mission operations cost savings 2-4 operations staff $400-800K/year/mission
     - DSMS cost avoidance from single common protocol
- Standards Investment costs - Total $2.42M (DSN - $1.28M, AMMOS - $1.14M)
  - $760K for standard (incl. modeling), $520K for prototype, $1140K for production code development including I&T
  - Compare to SIRTF costs for proprietary downlink only file protocol: design - $100K, implementation - $500K for reliable packet retransmission, $300K file reconstruction. Total 900K.

Mapping CCSDS & Internet Stacks