Looking Ahead to the Solar System Internetwork

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Outline

- What is the Solar System Internetwork (SSI)?
- Objectives of the SSI initiative
- Architecture of the SSI
- Technology: how Delay-Tolerant Networking (DTN) enables SSI
- SSI deployment functional timeline
- Features of the SSI concept
- Benefits of deploying SSI
- Some deployment scenarios
- Outlook and conclusions

What's a Solar System Internetwork?

- 1999 – First Interoperability Plenary meeting of national space flight agencies (IOP-1). Interagency Operations Advisory Group (IOAG) is formed to promote mission cross-support.
- 2007 – IOAG charters Space Internetworking Strategy Group (SISG) to reach international consensus on an approach for network-centric space mission operations.
- 2008 – SISG submits preliminary *Operations Concept for a Solar System Internetwork (SSI)* to IOP-2.
- 2010 – SISG submits final SSI Ops Concept and asks the Consultative Committee for Space Data Systems to draft an architecture.
- 2013 – CCSDS completes SSI Architecture "Green Book".

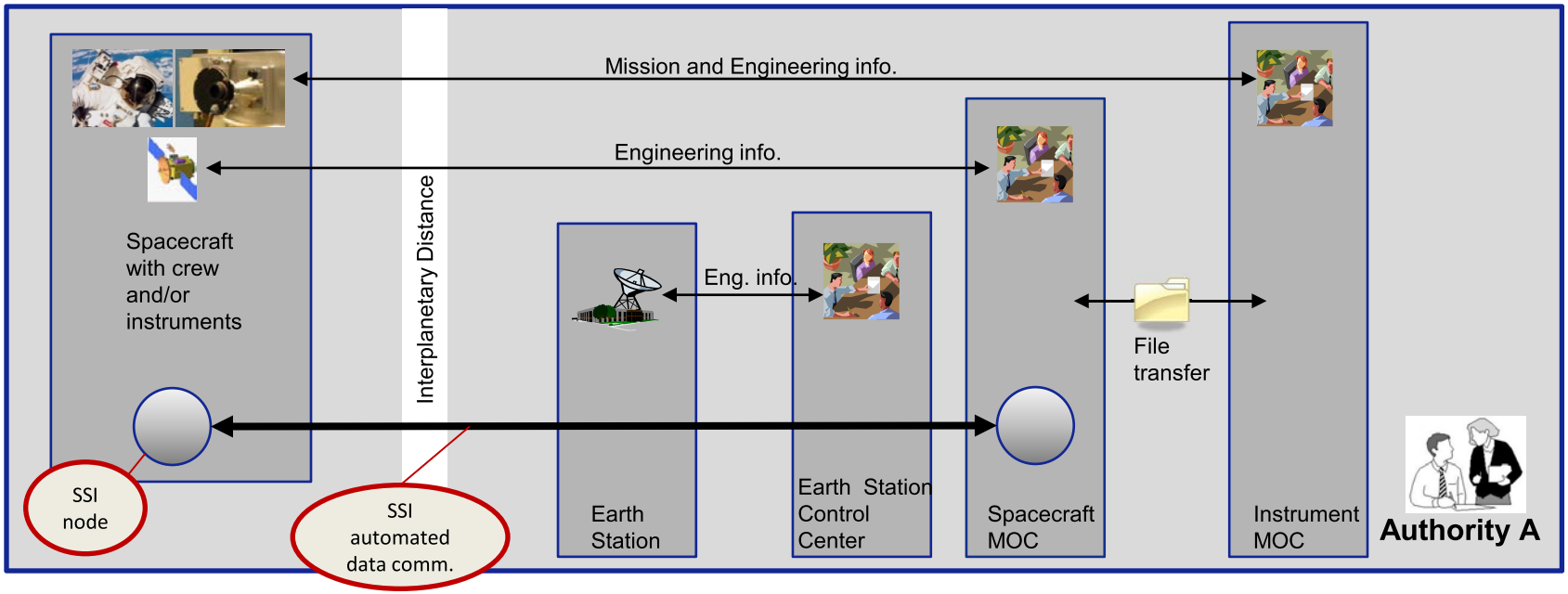
Objectives of the SSI

- SSI is **an automated communication system for space ventures**.
  - The Internet simplifies communication among people and businesses on Earth.
  - Analogously, SSI will simplify communication among engineers, scientists, and robots in space flight missions.
- By automating flight mission communications, SSI should:
  - Improve efficiency in communication over space links, **increasing science data return**.
  - Simplify cross support among missions, **reducing risk** and further **increasing science data return**.
  - Eliminate some chores performed by human operators, **reducing cost**.

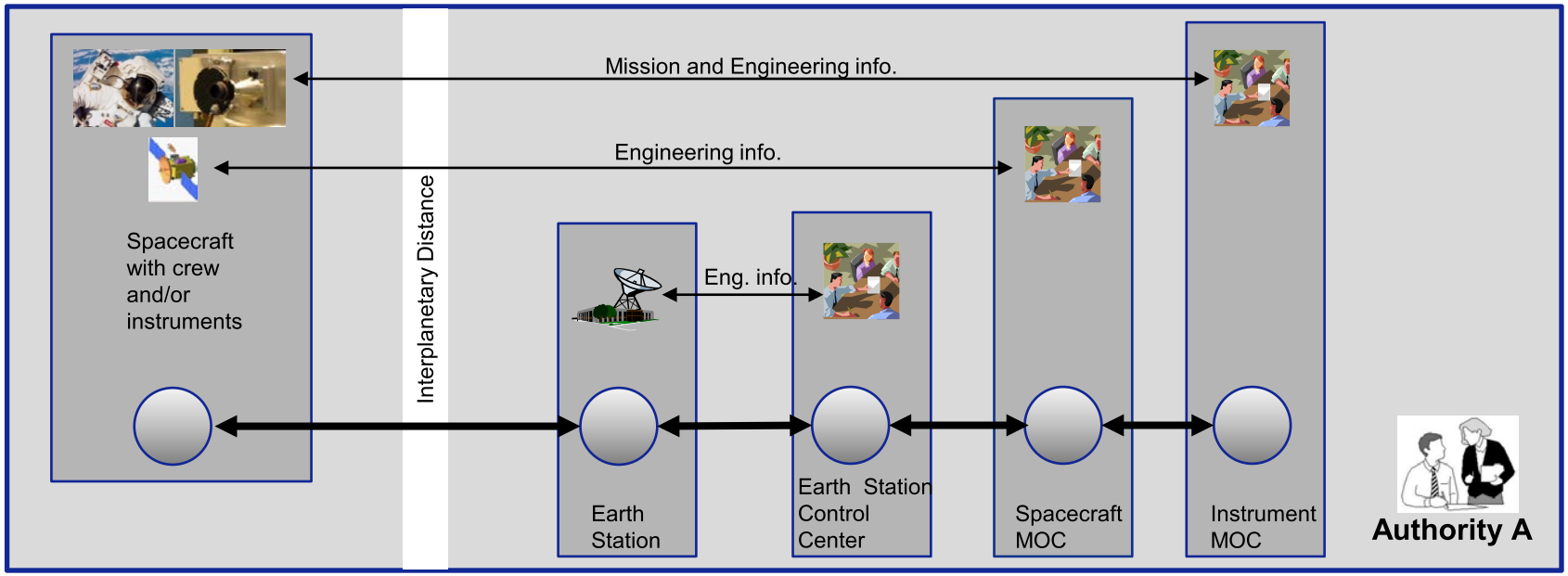
Architecture of the SSI

- Instruments, spacecraft, habitats, ground stations, mission operations centers, investigators' workstations (and more) all may be "nodes" of a single unified, end-to-end network.
- All nodes are peers – may function as end systems, forwarders, or both. No notion of "hosts" versus "routers."
- Network traffic is forwarded via internationally standardized protocols, including security protocols.
- The network inherently tolerates long signal propagation delays and recurring extended lapses in connectivity.
  - All forwarding is performed on a store-and-forward basis: when outbound links are unavailable, data are retained in local storage pending establishment of a link that can carry the data.

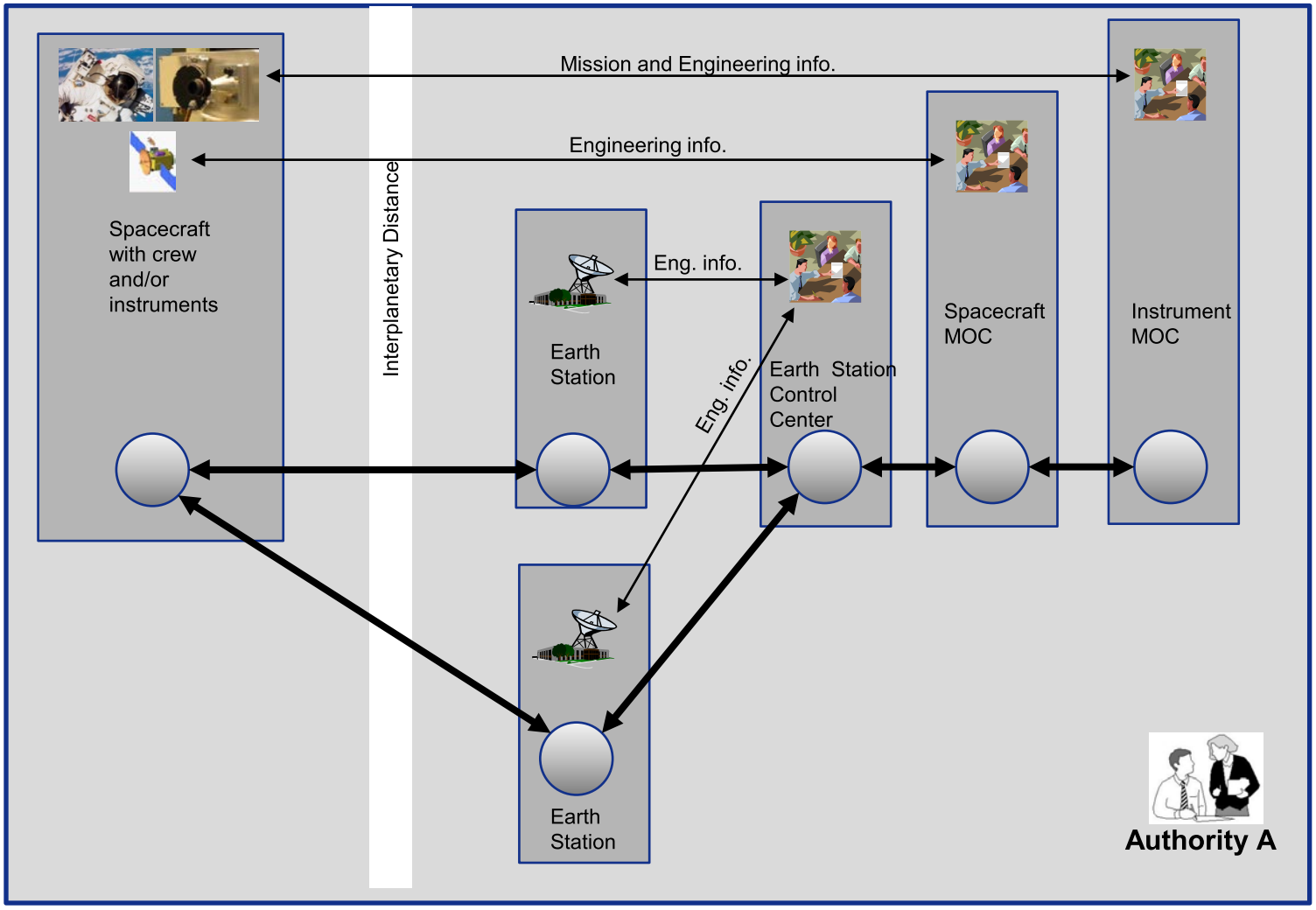
Minimal SSI


Mission and Engineering info.
Engineering info.
Eng. info.
Interplanetary Distance
Spacecraft with crew and/or instruments
File transfer
SSI node
SSI automated data comm.
Earth Station
Earth Station Control Center
Spacecraft MOC
Instrument MOC
Authority A

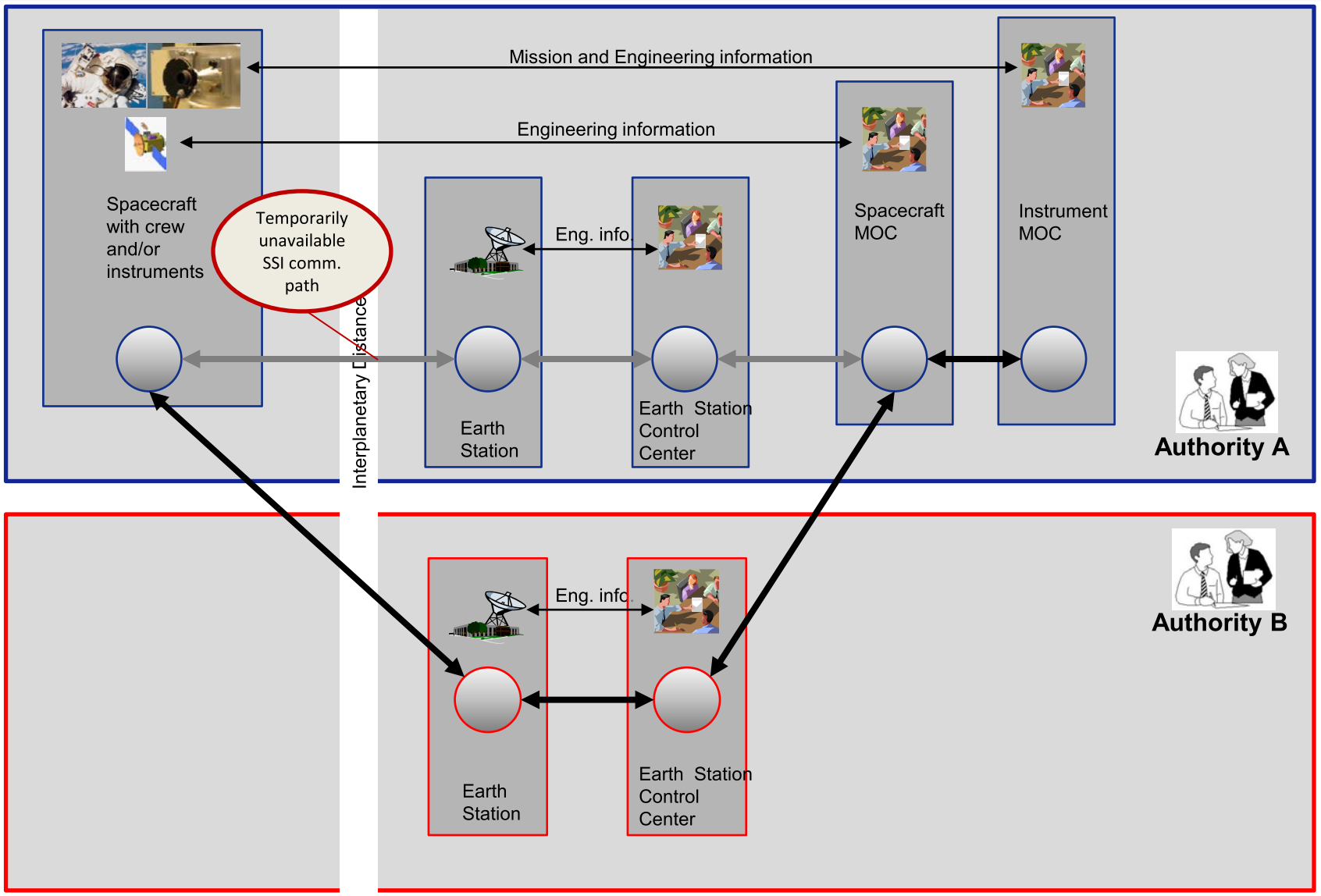
End-to-end SSI for an Isolated Mission



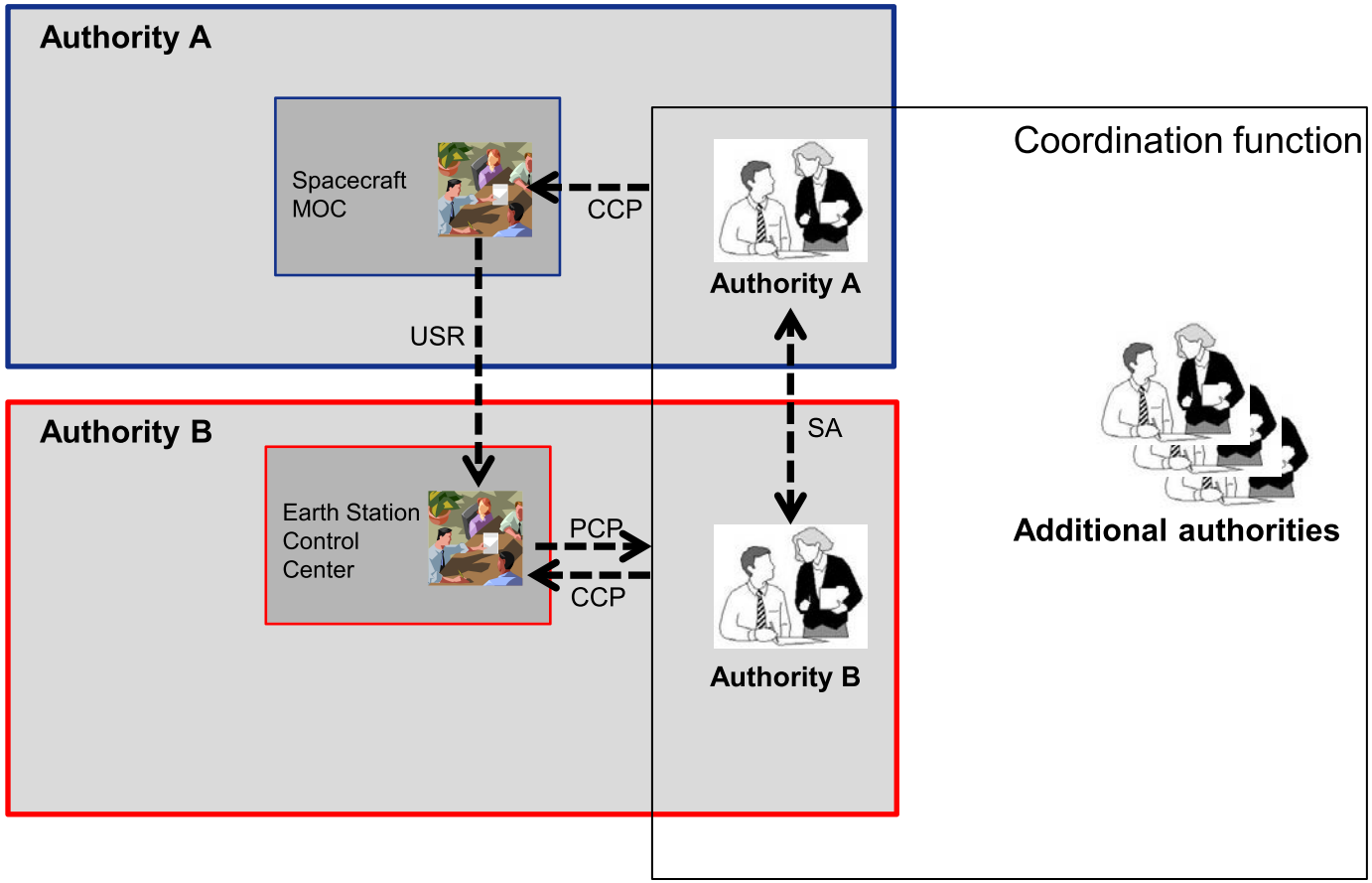
Parallel Paths in SSI



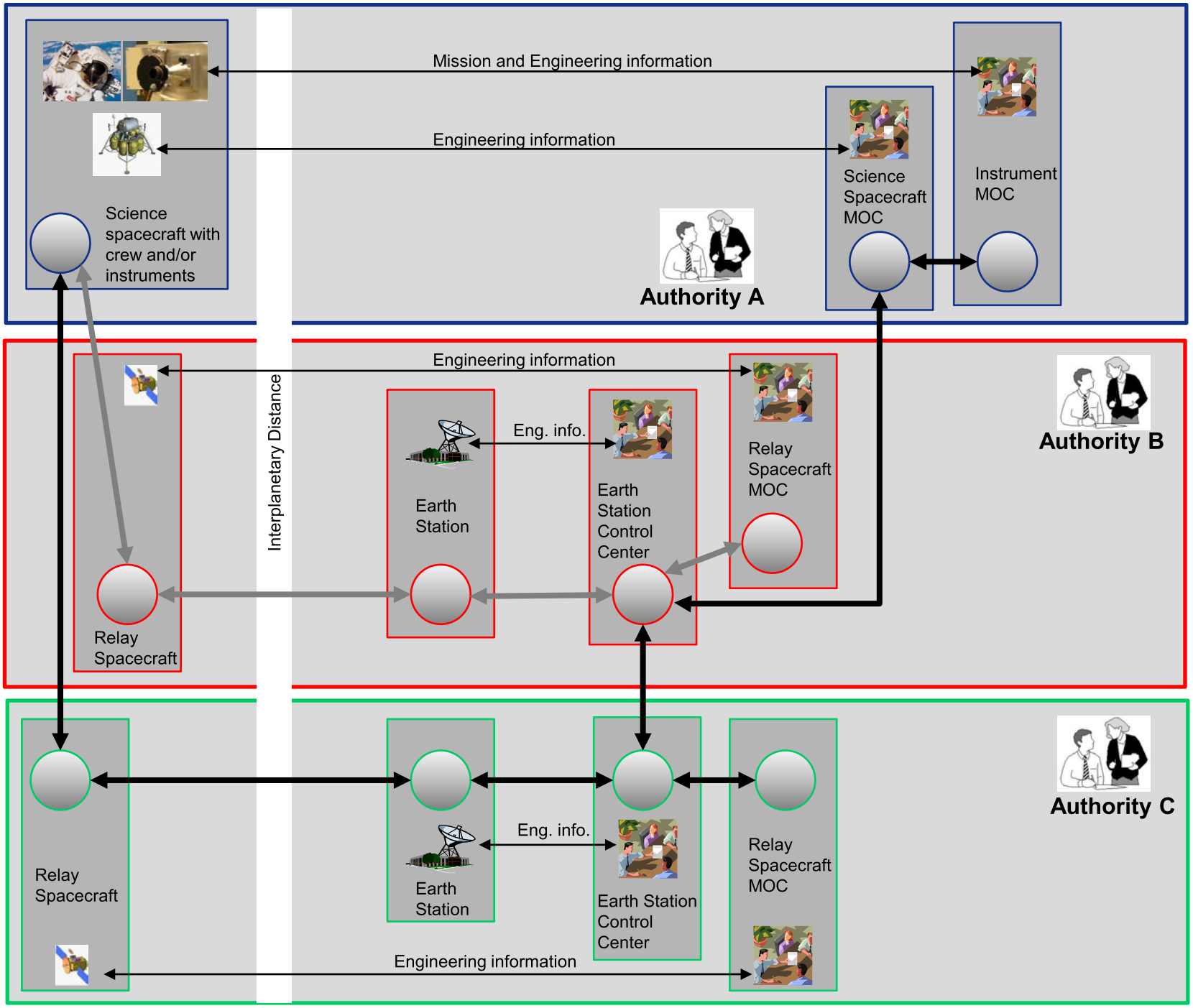
SSI Cross-Support



Coordination Procedures in SSI



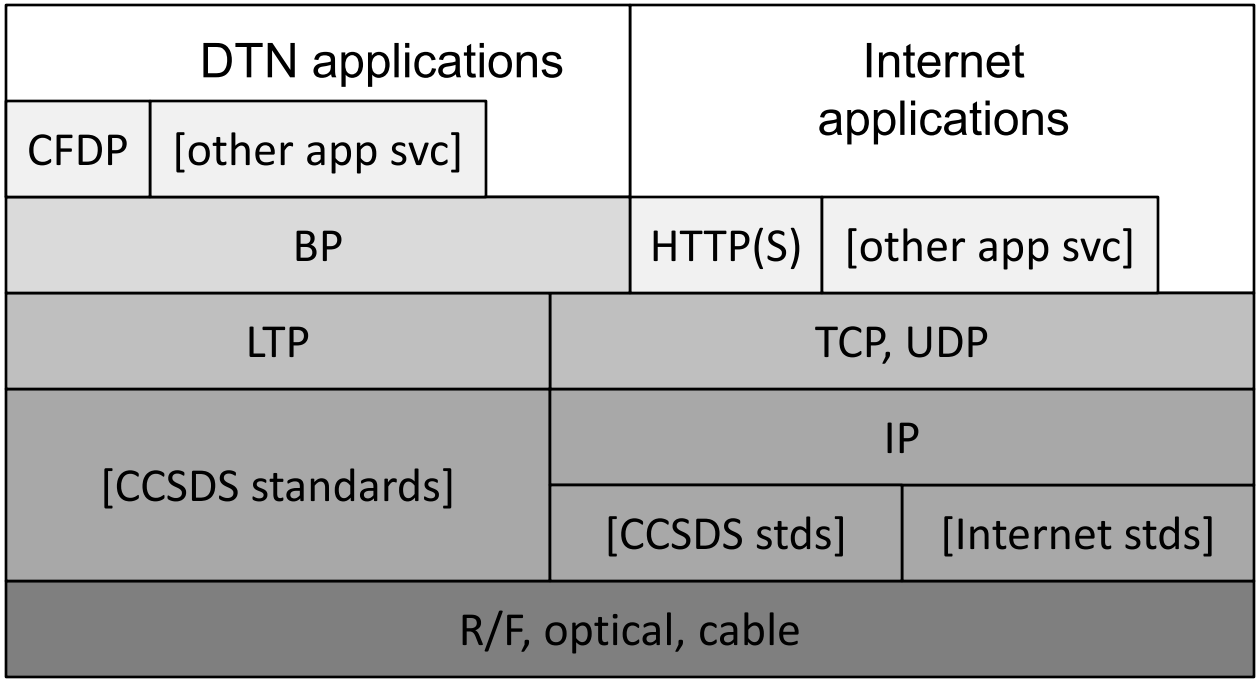
CCP Composite contact plan
PCP Provider contact plan
PA Peering agreement
SA Service agreement
USR User schedule request


Mission and Engineering information
Engineering information
Science spacecraft with crew and/or instruments
Science Spacecraft MOC
Instrument MOC
Authority A
Engineering information
Interplanetary Distance
Eng. info.
Earth Station
Earth Station Control Center
Relay Spacecraft MOC
Relay Spacecraft
Authority B
Relay Spacecraft
Eng. info.
Earth Station
Earth Station Control Center
Relay Spacecraft MOC
Engineering information
Authority C

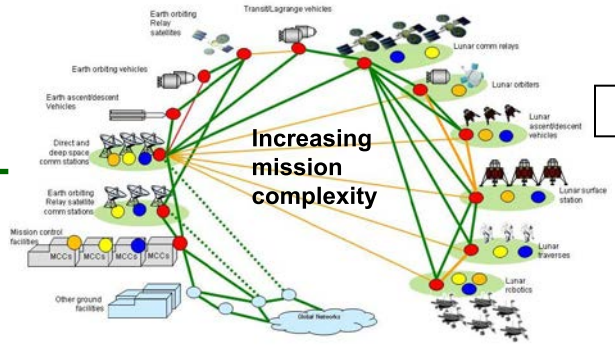
SSI Technology

- Two different network protocols may both be employed in engineering the SSI's network infrastructure: the **Internet Protocol (IP)**, used in the familiar terrestrial Internet, and the **Bundle Protocol (BP)** upon which **Delay-Tolerant Networking (DTN)** technology is based.
- Any SSI node may be equipped with an IP stack, a DTN stack, or both.
- IP communications may be conducted in parallel with DTN communications. In addition, DTN communications may overlay IP communications in segments of DTN end-to-end paths where the Internet protocols work well.

SSI Protocol Stack



Delay-Tolerant Networking



problem

International Space Flight Community

Interagency Operations Advisory Group

Chartered SISG to recommend an approach for space Internetworking

Space Internetworking Strategy Group

NASA, ESA, CNES, DLR, JAXA….

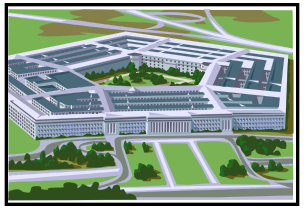
Recommends DTN

problem

DTN Research Group (formed within the Internet Research Task Force)

Designed protocols that let networks tolerate link disruptions and long delays

DTN Protocol Specifications

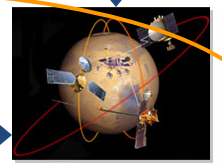


DARPA

problem

Implementation

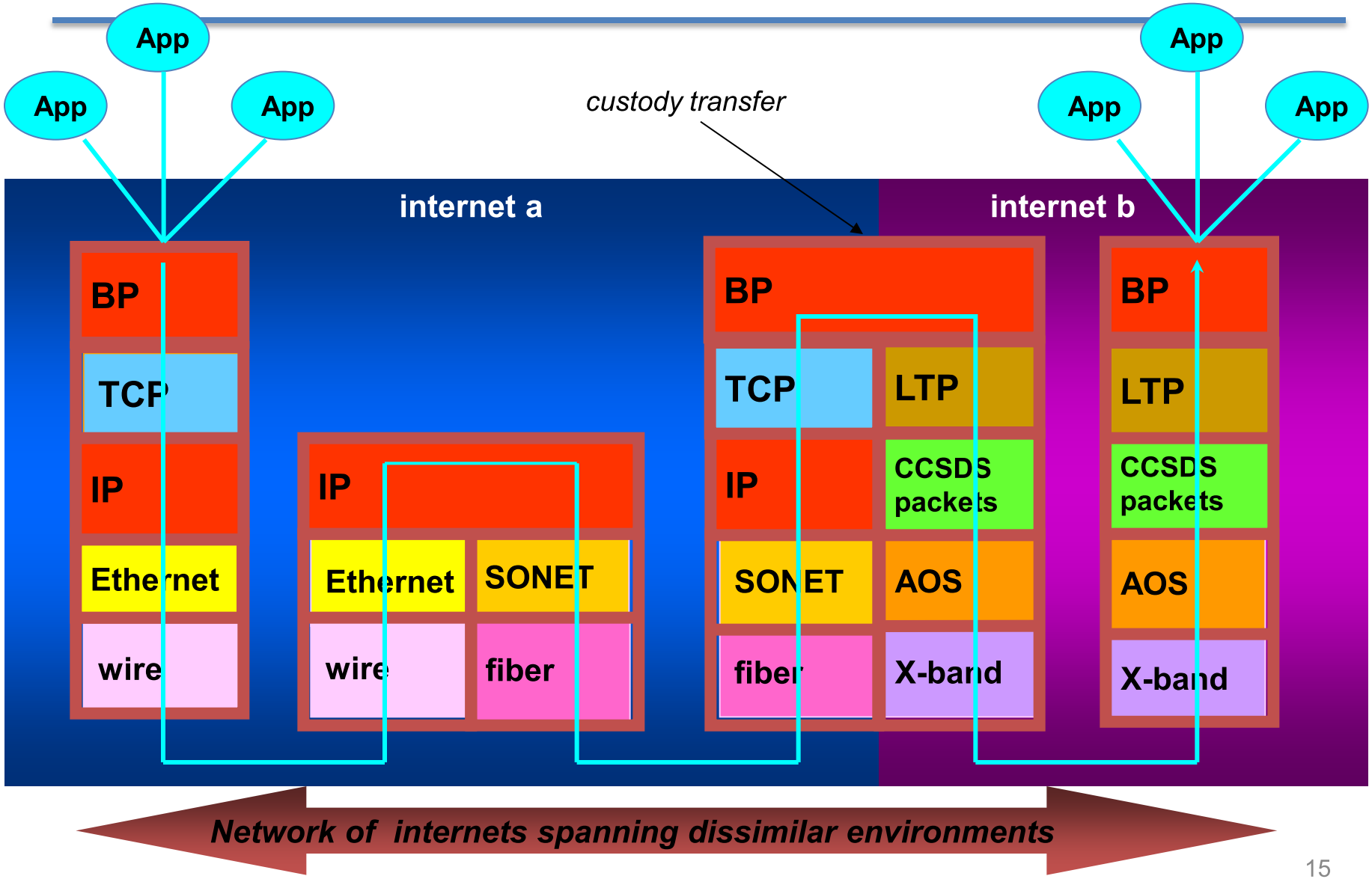
ION



Solar System Internet

DTN for resource-limited systems

DTN as an Overlay



DTN for Mission Communications

- Automatic **relay** operations.
  - Retain data until outbound link is available.
  - Then transmit until link is no longer available.
- Fine-grained **routing**: automatic selection of (possibly parallel) links to transmit over, based on the final destination of the data.
- Automatic selection of data to transmit, based on mission-specified **priority**.
- Automatic **retransmission** of lost or corrupted data.
- Automatic **aggregation** of data into blocks, to limit return traffic (acknowledgments).
- **Custodial forwarding**, for early release of retransmission buffer space.
- Automatic **congestion control**, based on rate management.
- Automatic **data aging and purging** based on bundle's "time to live".
- Optional status reports for detailed **tracing and data accounting**.
- Support for **file transfer**, **message exchange**, **multi-point delivery**.
- Support for **security**: authentication, encryption.

Functional Timeline

- SSI participation will be voluntary and incremental:
  - Stage 1 is technology. An isolated flight mission will reduce cost and risk if it merely adopts the automated SSI communication protocols.
  - Stage 2 is procedural integration of multiple isolated networks. Collaborating missions can further reduce cost and risk by basing coordinated interoperation on the SSI protocol standards.
  - Stage 3 is automated integration: eventually mission coordination can itself be automated.
- Different missions in the same agency or multiple agencies may be at different stages of SSI adoption concurrently.
- Stage 3 is a unified space communications fabric that new flight missions can utilize at very low cost.

Features of SSI

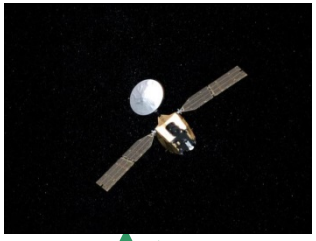
- Global support
  - International standards
  - Voluntary agreements among national space agencies and – potentially – commercial space flight operators.
- Local control
  - All participants retain complete control of their flight and ground communication resources.
  - Only explicitly offered resources are made available through the SSI.
- Resource protection
  - Congestion forecasting and rate control to prevent over-utilization.
  - Authentication, integrity protection, and confidentiality mechanisms to defend against attack.

Use Cases and Benefits of Using SSI

- Earth orbiters
  - **Automatic handover** of satellite data flow from one Earth station to the next. Continuous flow between spacecraft and operations centers.
  - High-speed download spikes **automatically buffered** for transmission over lower-speed (and less expensive) terrestrial network links.
- Deep space
  - Data lost in transit (e.g., due to weather) are **automatically retransmitted**, over interplanetary distances and intermittent links.
- Relay missions
  - Multiple orbiters forward data to and from multiple landed vehicles, honoring **prioritization** decisions made at the data sources.
  - **Alternative data paths** readily available in case a relay fails.

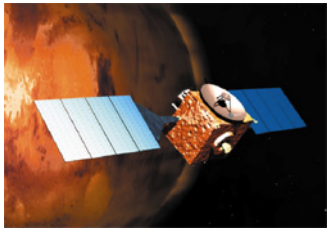
Conceivable Scenario: Mars Network

MRO



Odyssey

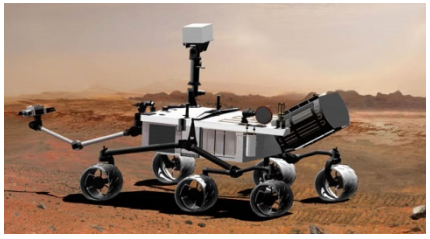
Mars Express



X-band Direct-to-Earth

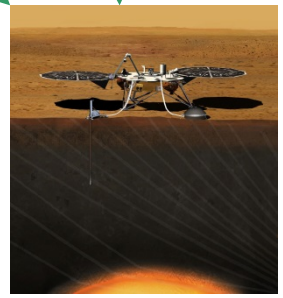
UHF Relay Link

Backup/Demo UHF Link



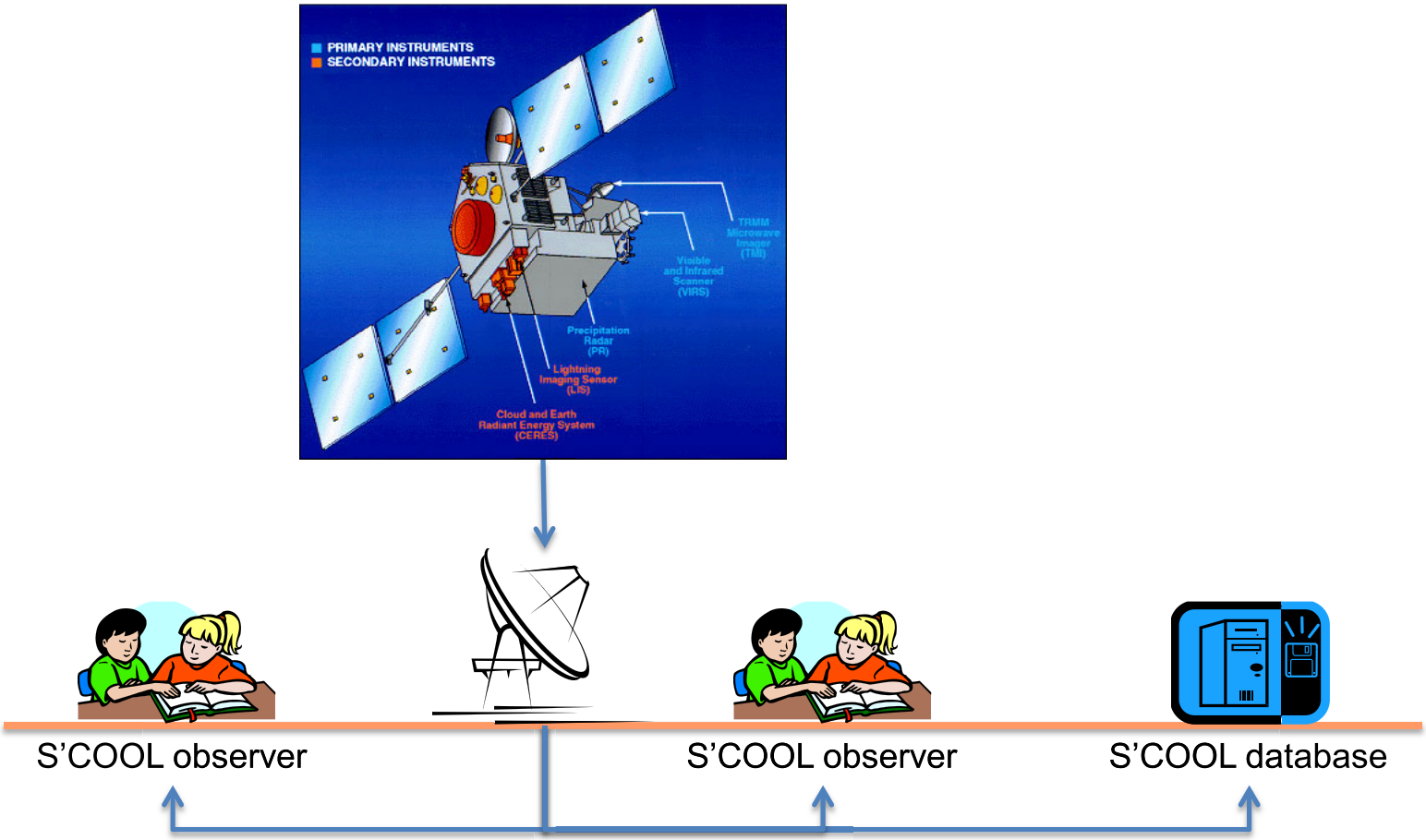
Curiosity

Opportunity



InSight

Conceivable Scenario: Remote Sensing



Outlook and Conclusions

- SSI technology was first demonstrated on the EPOXI spacecraft, 15 million miles from Earth, in 2008.
- The first fully operational subnet of the SSI is under development now, connecting the International Space Station (ISS) with NASA's Huntsville Operations Support Center:
  - Initial science network operations on-board ISS began in 2009, connecting instruments to a control center in Boulder, Colorado.
  - On 10 September 2013, ISS Change Request 013799 was approved. It authorizes permanent deployment of two DTN nodes on the Joint Station LAN, for use by machines throughout the space station.
- As agencies gain experience with SSI technology, the network can grow to meet demand.

Thanks!

Questions?