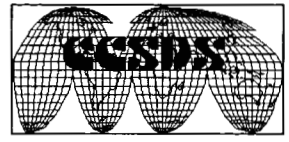
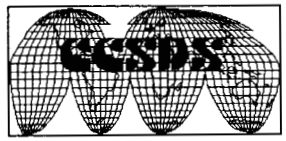


CCSDS
Architecture Working Group

Reference Architecture for Space Data Systems

9 Sept 2003

Peter Shames/Jet Propulsion Laboratory (JPL)
Takahiro Yamada/Institute of Space and Astronautical Science (ISAS)



Overview

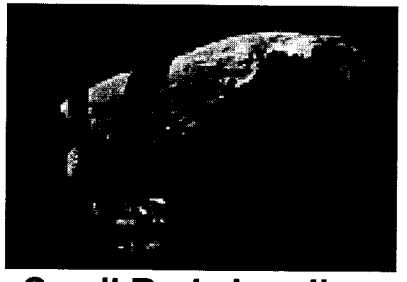
- What's special about systems in space
- Here's the CCSDS
- Introduction to the Reference Architecture for Space Data Systems (RASDS)
- Applying the RASDS to real problems

Challenging New Missions

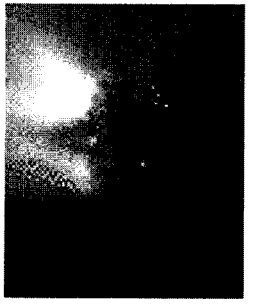
- NASA's future unmanned exploration missions entail challenging new missions that we simply can't fly with today's capabilities

- New Capabilities:
  - Telecom relay at Mars and beyond
  - Autonomous mission operations
  - S/C driven communications

Exploring Unknown Environments

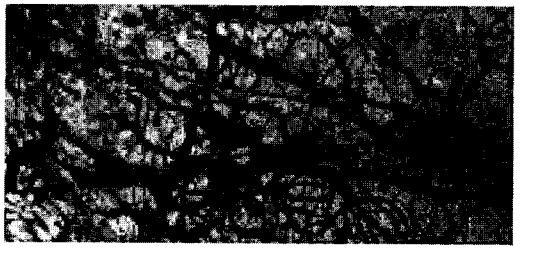


Small Body Landing



Cometary Feature Id Hazard Avoidance

Long Rover Traverse



Planetary Change Detection

Unique Environment of Deep Space Missions

- Extreme Distance
  - Communications performance scales as $1/R^2$
  - Communicating with an Outer Planet mission to Neptune or Pluto requires equipment ~*10 billion* times more sensitive than for a commercial GEO satellite
- Long Round Trip Light Times (tens of minutes to hours)
  - Onboard autonomy required in order to close decision loops faster than a round trip light time
  - Rapid response to in situ environments and conditions
- Wide Range of Environments
  - Challenging thermal, radiation, shock requirements
  - Fault-tolerant hardware and software, some level of autonomous operation
- Unique Navigation Scenarios
  - Small body ops, gravity assist trajectories, aerocapture/aerobraking, SEP, libration point missions, formation flying
- High Launch Cost per Unit Payload Mass
  - Drives need for low mass, low power, small size flight systems
  - Low power S/C put more demand on Deep Space Network (DSN) sensitivity

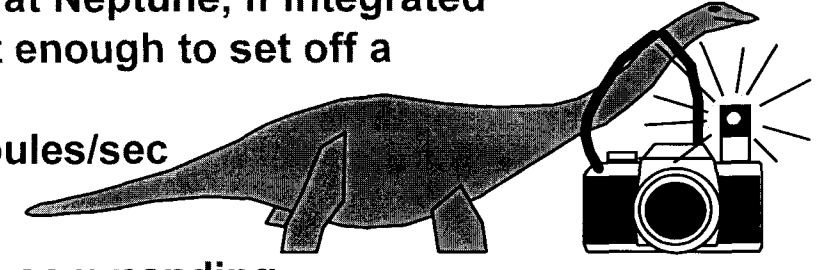
Gee Whiz!

What Makes the DSN Special?

Received Signal Sensitivity:

The received energy from Voyager at Neptune, if integrated for 300 million years, would be just enough to set off a small photographic flashbulb!

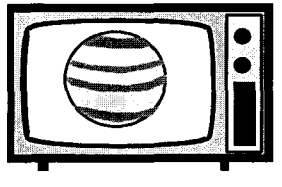
Received power = 10^{-17} Joules/sec



Command Power:

The DSN puts out enough power in commanding Voyager that it could easily provide high quality commercial TV at Jupiter!

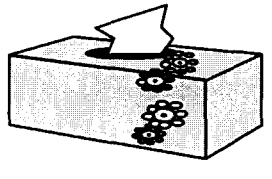
Transmitted power = 400 kW



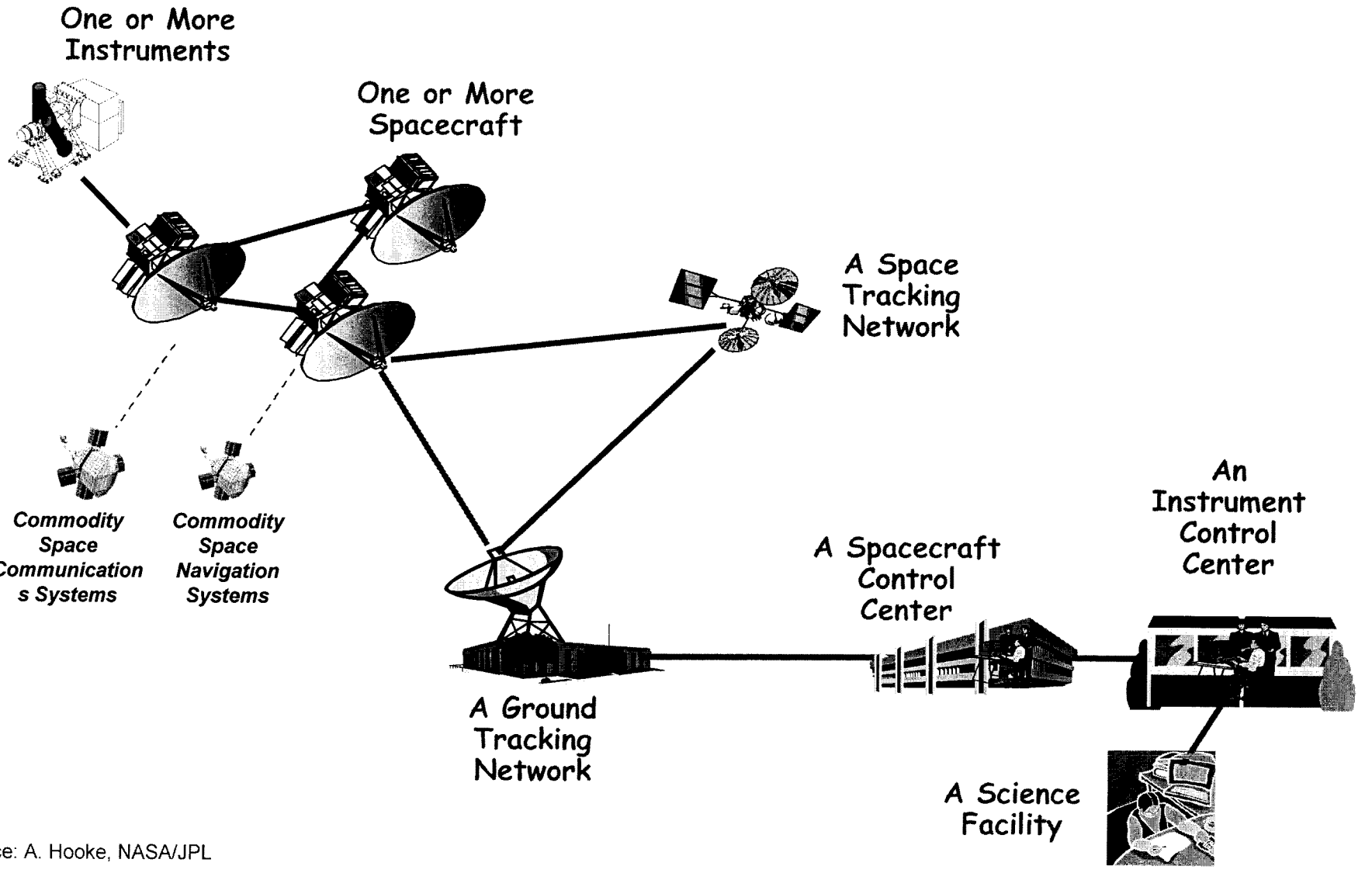
Dynamic Range of the DSN:

The ratio of the received signal power to the DSN transmitting power is like comparing the thickness of a sheet of tissue paper to the entire Earth!

Ratio = 10^{27}



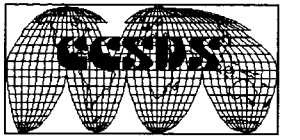
A Physical View of a Space Data System



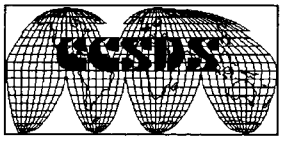
Source: A. Hooke, NASA/JPL


CCSDS:
The Fleet
Space Domain
Spacecraft Platforms
On-Board Systems
Space Qualified ASICs
Consultative Committee for Space Data Systems
268 missions, and counting
Ground Domain
Commercial Ground Networks
Command & Telemetry Data Processing
http://www.ccsds.org
Space Link Extension Forward and Return Services

Rationale
(or, Why do 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



Consultative Committee on Space Data Systems (CCSDS)

- Volunteer member organization composed of Member Agencies, who provide the bulk of the resources, and Observer Agencies who participate at various levels, depending upon their interests and resources.

- One Member Agency per country and one vote for standards approval per Member Agency. Any other agencies may participate in the development work and influence the standards.

- Commercial entities may participate as Associates, usually at the invitation of Member Agencies.

- CCSDS has been in operation for more than 20 years

CCSDS Member Space Agencies

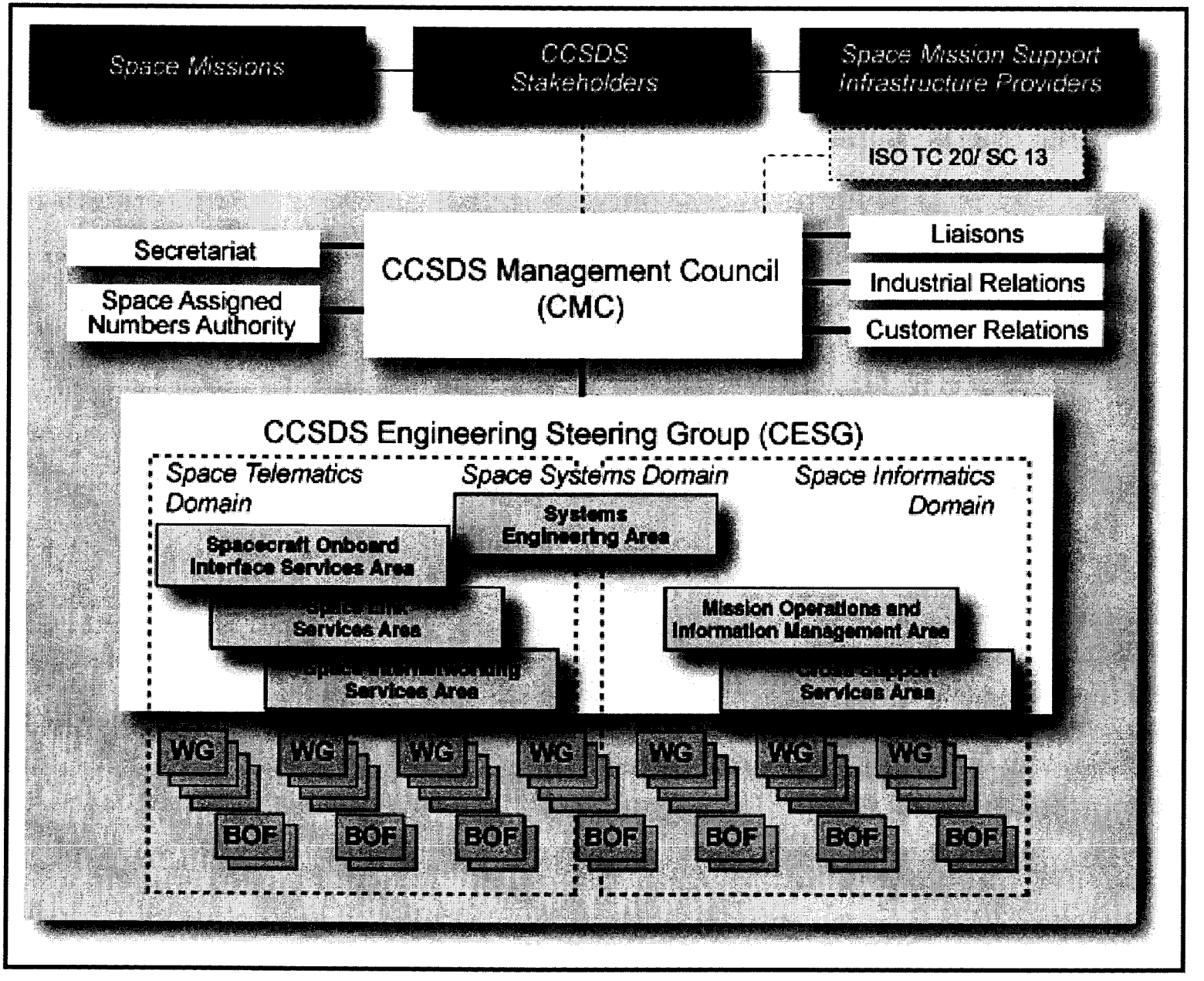
Member Agencies

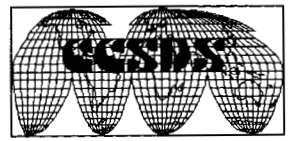
ASI/Italy	*ESA/Europe*
BNSC/UK	*INPE/Brazil*
CNES/France	*NASA/USA*
CSA/Canada	*NASDA/Japan*
DLR/Germany	*RSA/Russia*

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*	

CCSDS Organization

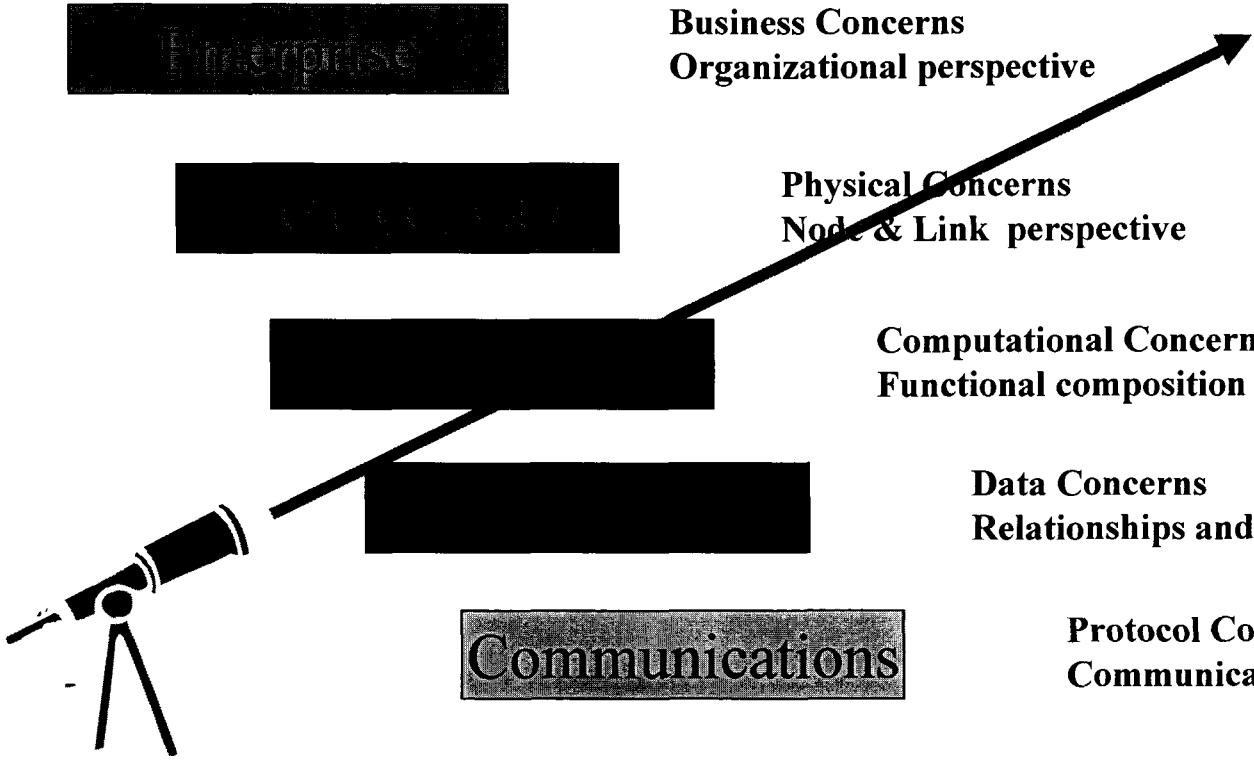




Reference Architecture Purpose

- Establish an overall CCSDS approach to architecting and to developing domain specific architectures
- Define common language and representation so that challenges, requirements, and solutions in the area of space data systems can be readily communicated
- Provide a kit of architect's tools that domain experts will use to construct many different complex space system architectures
- Facilitate development of standards in a consistent way so that any standard can be used with other appropriate standards in a system
- Present the standards developed by CCSDS in a systematic way so that their functionality, applicability, and interoperability may be clearly understood

Space Data System
Several Architectural Viewpoints



Business Concerns
Organizational perspective

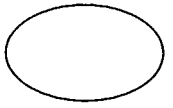
Physical Concerns
Node & Link perspective

Computational Concerns
Functional composition

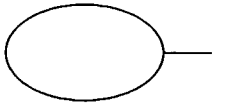
Data Concerns
Relationships and transformations

Protocol Concerns
Communications stack perspective

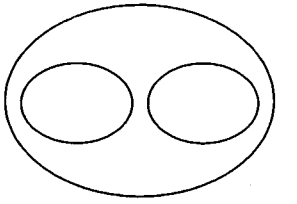
Space Data System Architectural Notation



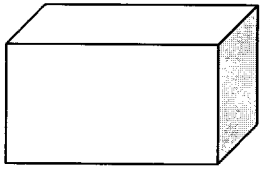
Object



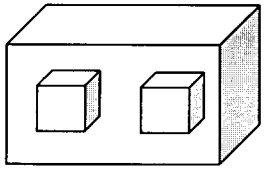
Object with Interface



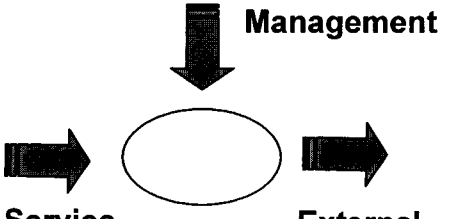
Object Encapsulation



Node (physical location)

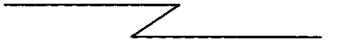


Node Encapsulation (physical aggregation)



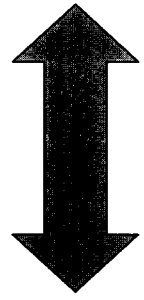
Logical Link

Physical Link

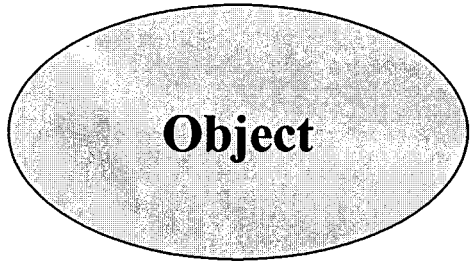


Space Link (rf or optical)

Unified Object Representation



Management Interfaces:
How objects are configured controlled, and reported upon



Service Interfaces:
How services are requested & supplied

Core Functions
What the object does

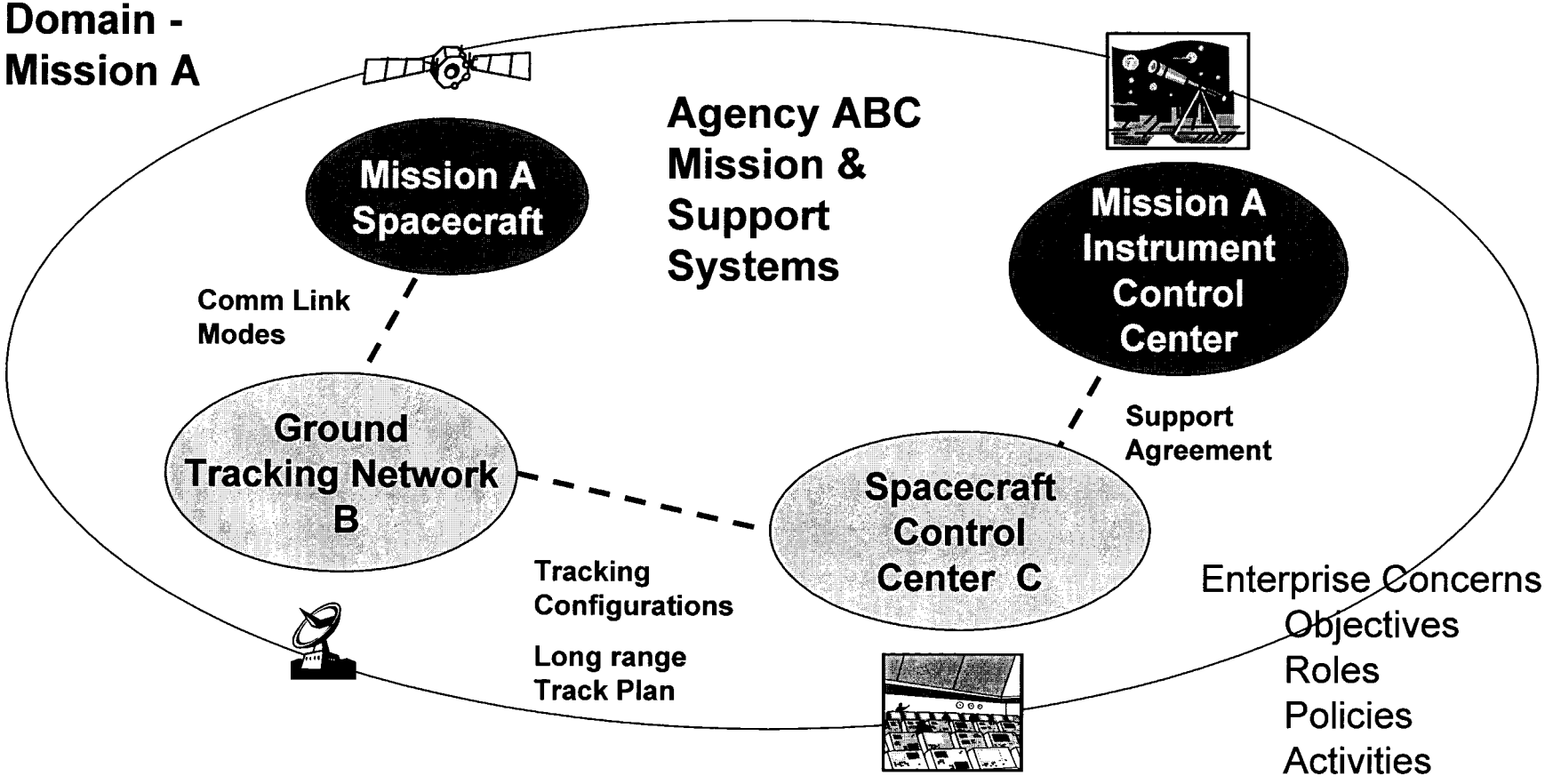
External Interfaces:
How external elements are controlled

Concerns:
Issues
Resources
Policies

Enterprise View

Single Agency Mission Domain & Enterprise Objects

Operations Planning Phase



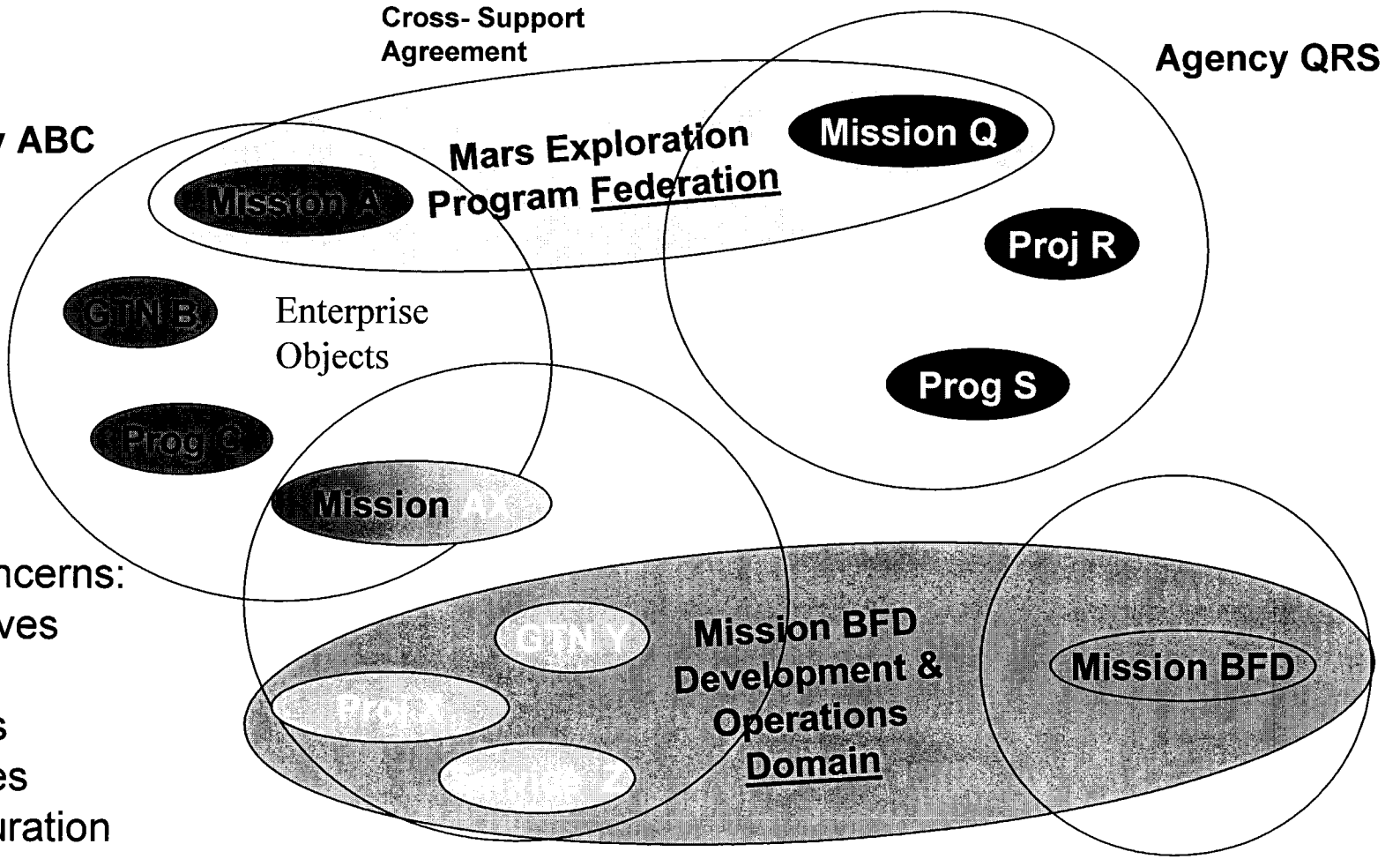
Enterprise Concerns:

- Objectives
- Roles
- Policies
- Activities
- Lifecycle / Phases
- Configuration
- Contracts

Enterprise View

Federated Enterprises with Enterprise Objects

Planning Phase

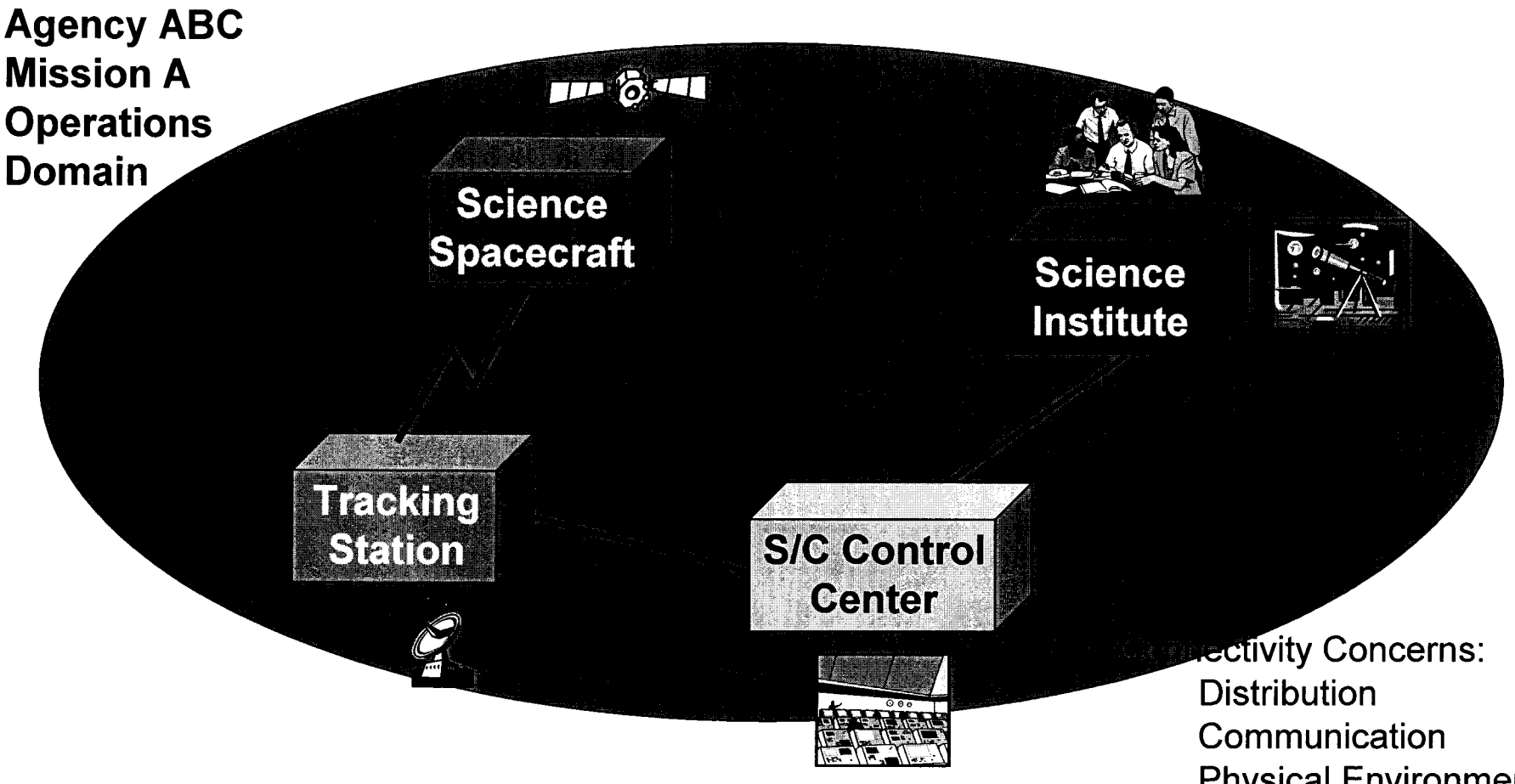


Domain Concerns:

- Objectives
- Roles
- Policies
- Activities
- Configuration
- Contracts
- Lifecycle / Phases

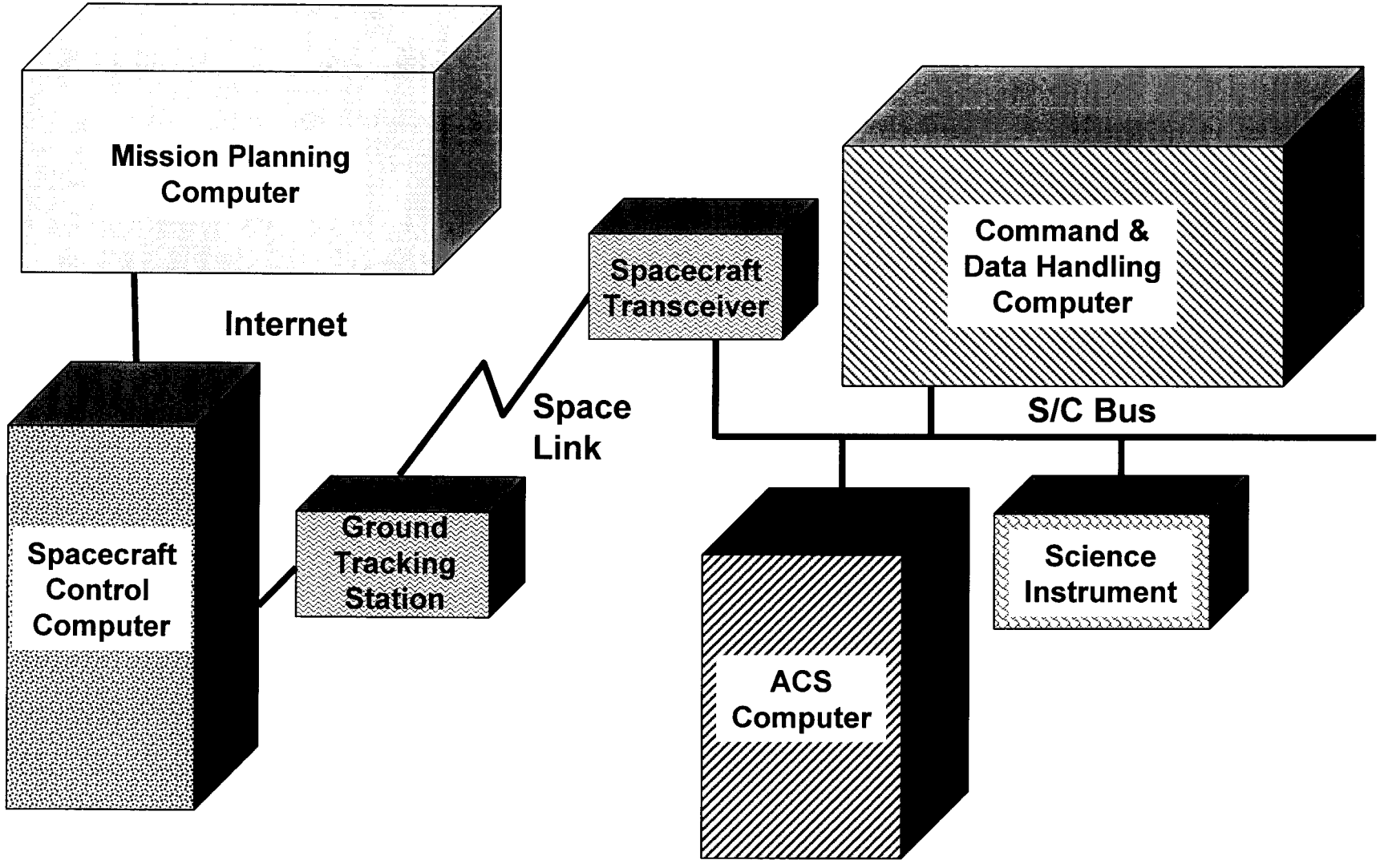
Connectivity View

Single Agency Mission Domain & Nodes

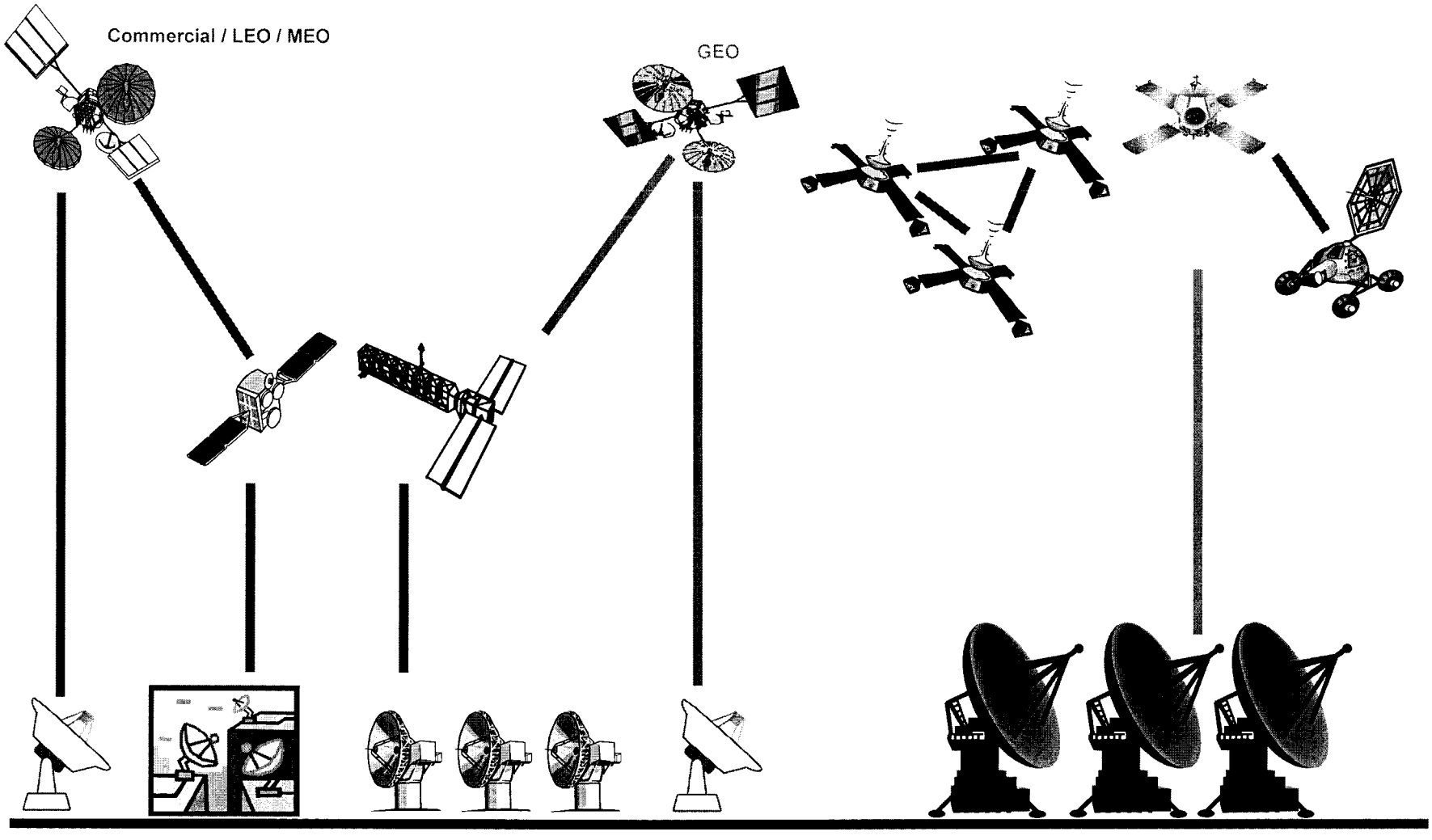


Connectivity Concerns:
- Distribution
- Communication
- Physical Environment
- Behaviors
- Constraints
- Configuration

Connectivity View
Nodes



Connector Properties: Types of Space Links



Near-Earth, LEO Direct

Near-Earth, GEO Relay

Near-Earth, Commercial LEO/MEO Relay

Near-Earth, Direct Broadcast

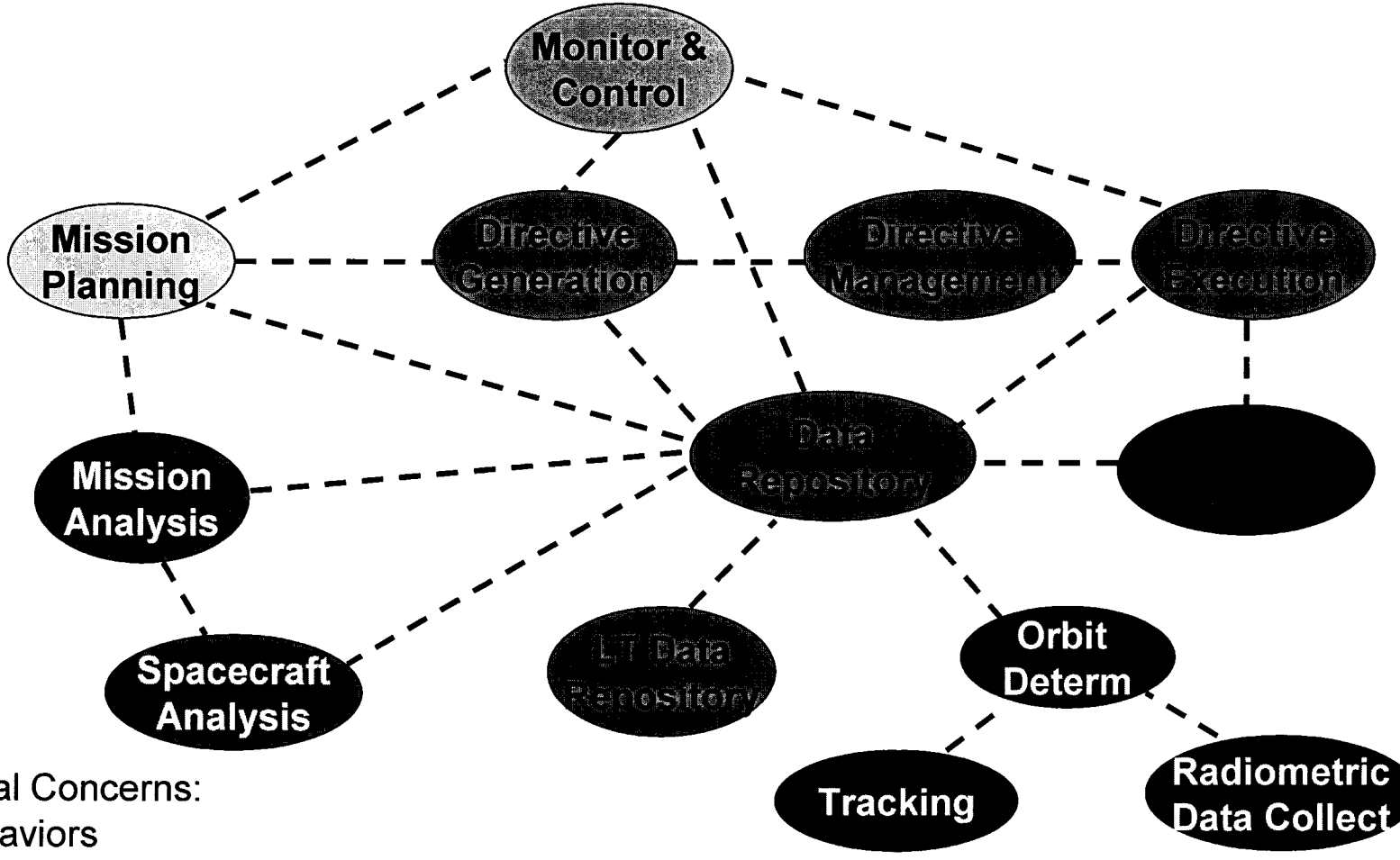
Deep Space Direct (DSN, other)

In-Space Proximity/Relay

Source: A. Hooke, NASA/JPL

Functional View

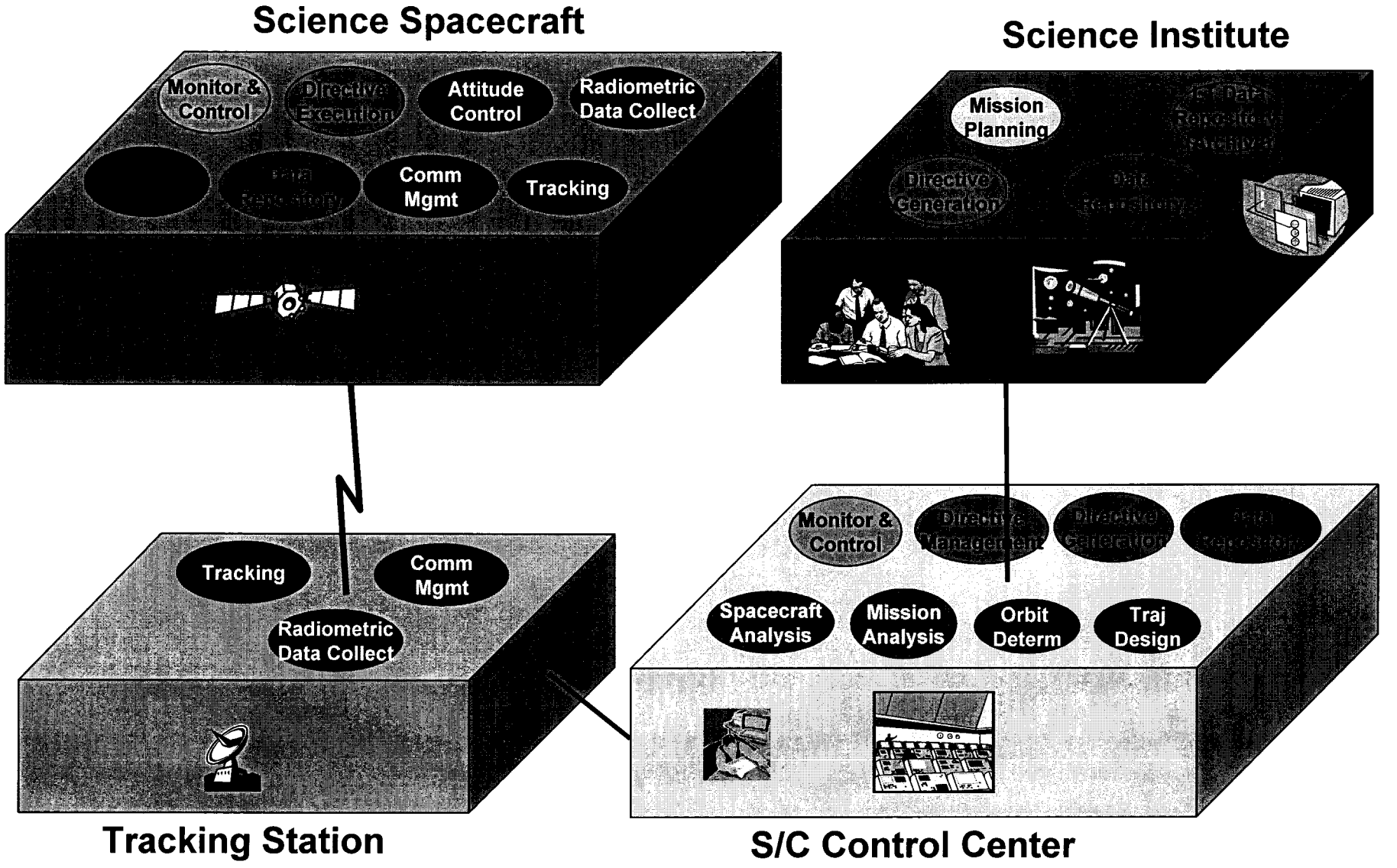
Example Functional Objects & Interactions



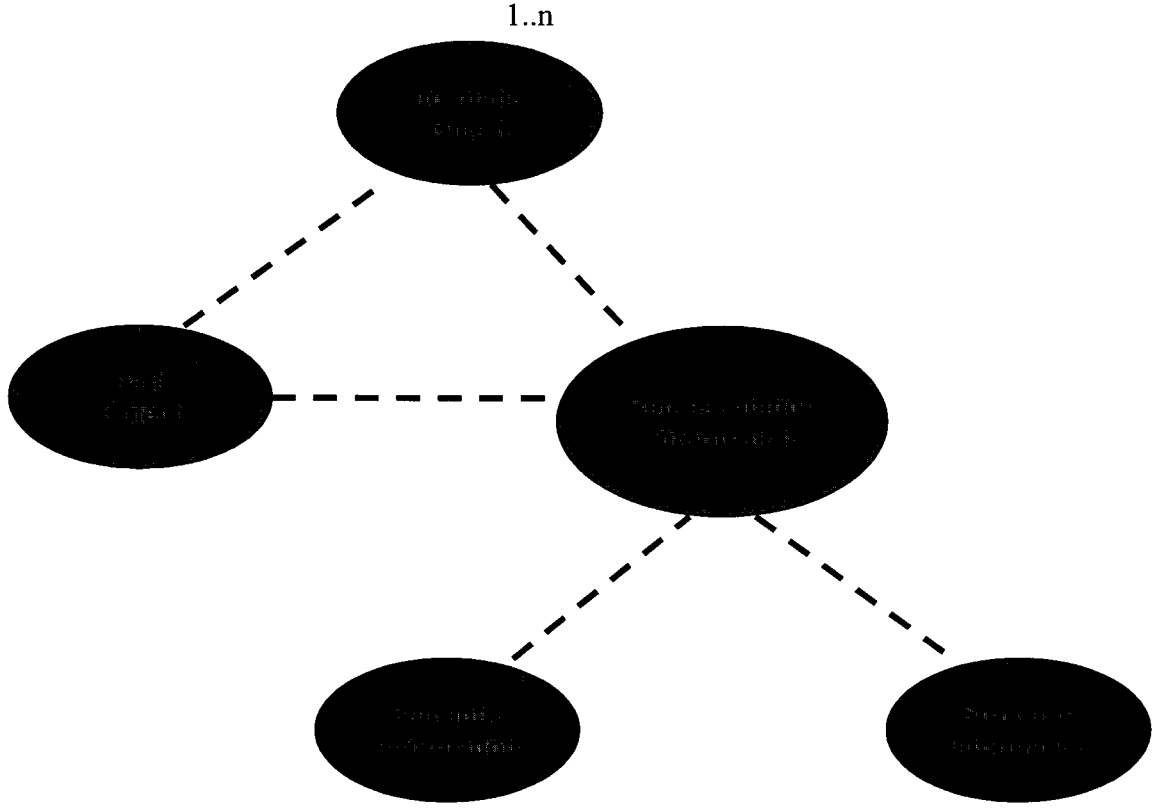
Functional Concerns:

- Behaviors
- Interactions
- Interfaces
- Constraints

Connectivity View - Redux
Mapping Functions to Nodes

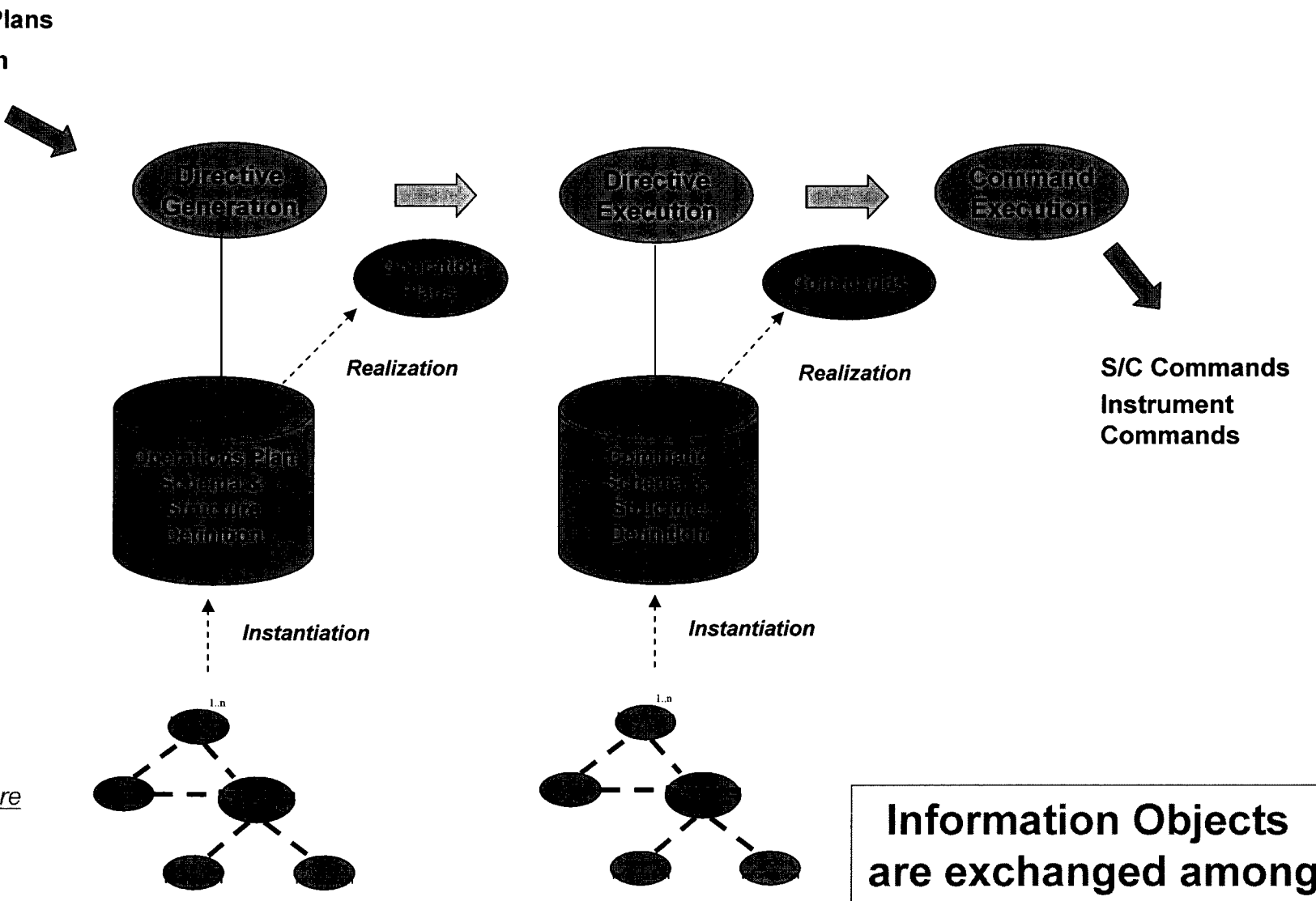


Information Object Basic Relationships



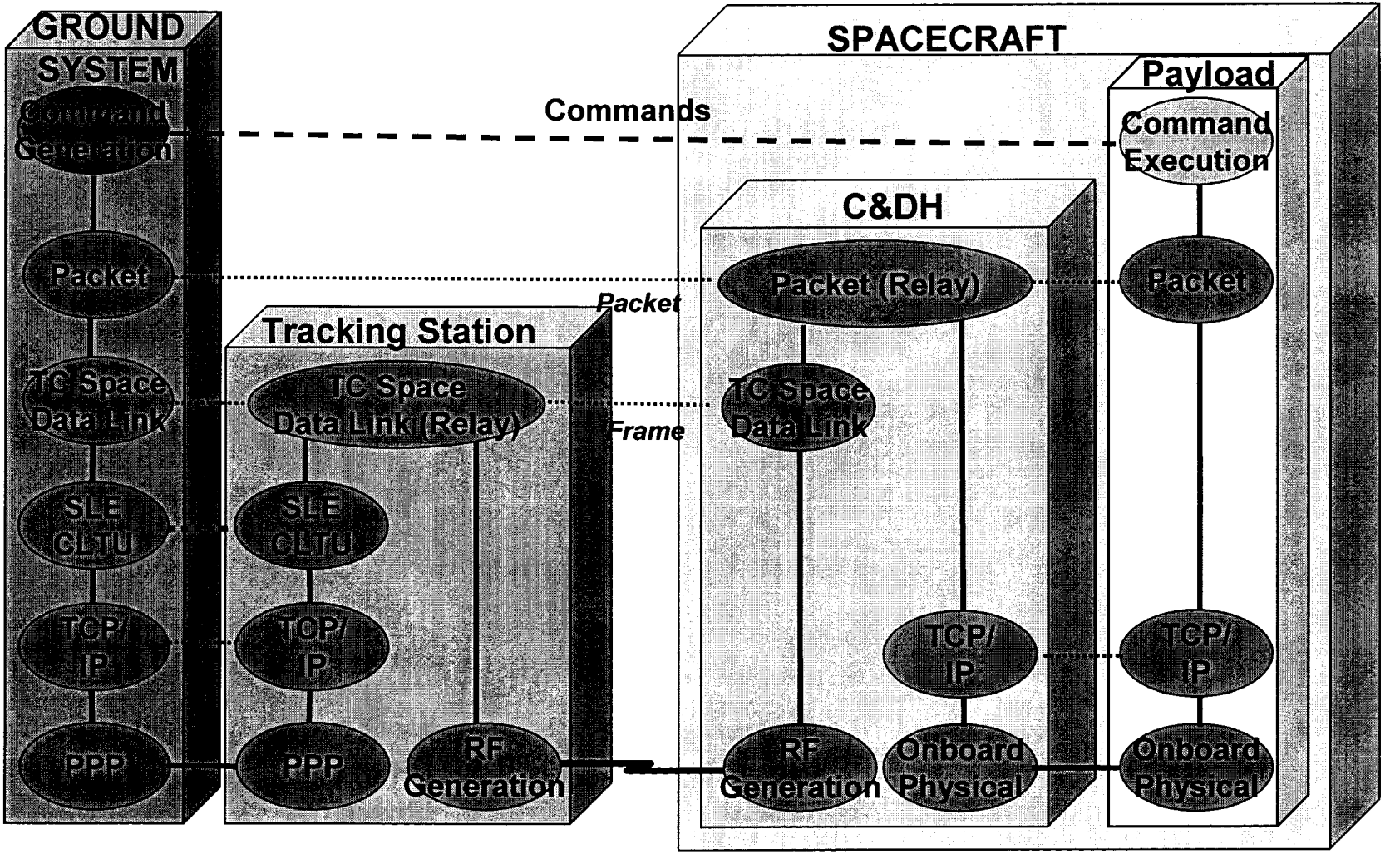
Information Concerns:
- Structure
- Semantics
- Relationships
- Permanence
- Rules

Information Objects Relationship to Functional View

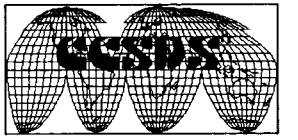


Information Objects are exchanged among Functional Objects

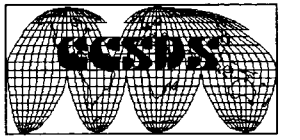
Communications Viewpoint - Protocol Objects
End-To-End Command Processing



Applying the RASDS Reference Architecture



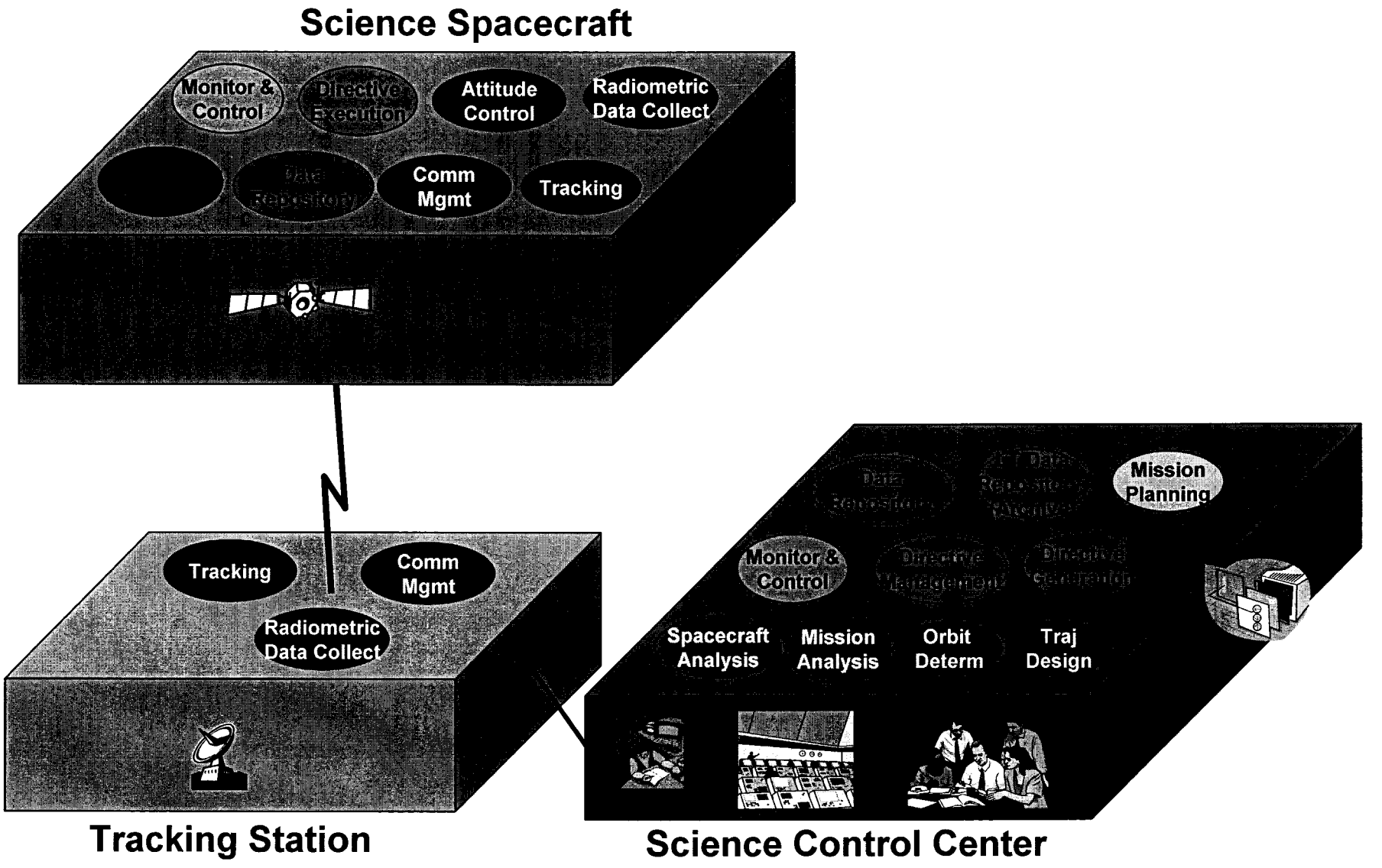
- RASDS is designed to be used as a standard framework by space data system architects and system developers
  - Common methodology for describing space data systems and architectures
- Provides formal methods for describing architectures
  - Each View of a space data system described with Objects and their interactions
  - Characteristics of Objects, their behaviors, and their interactions are described
  - Formal descriptions enable sharing and exchange of information on architectures and systems among different organizations or teams
  - Eliminates re-generating the same information for different purposes, a common occurrence
  - UML profiles and/or XML schemas are being explored as formal representations at NASA (xADL prototype) and ESA (XASTRO project), more work is planned



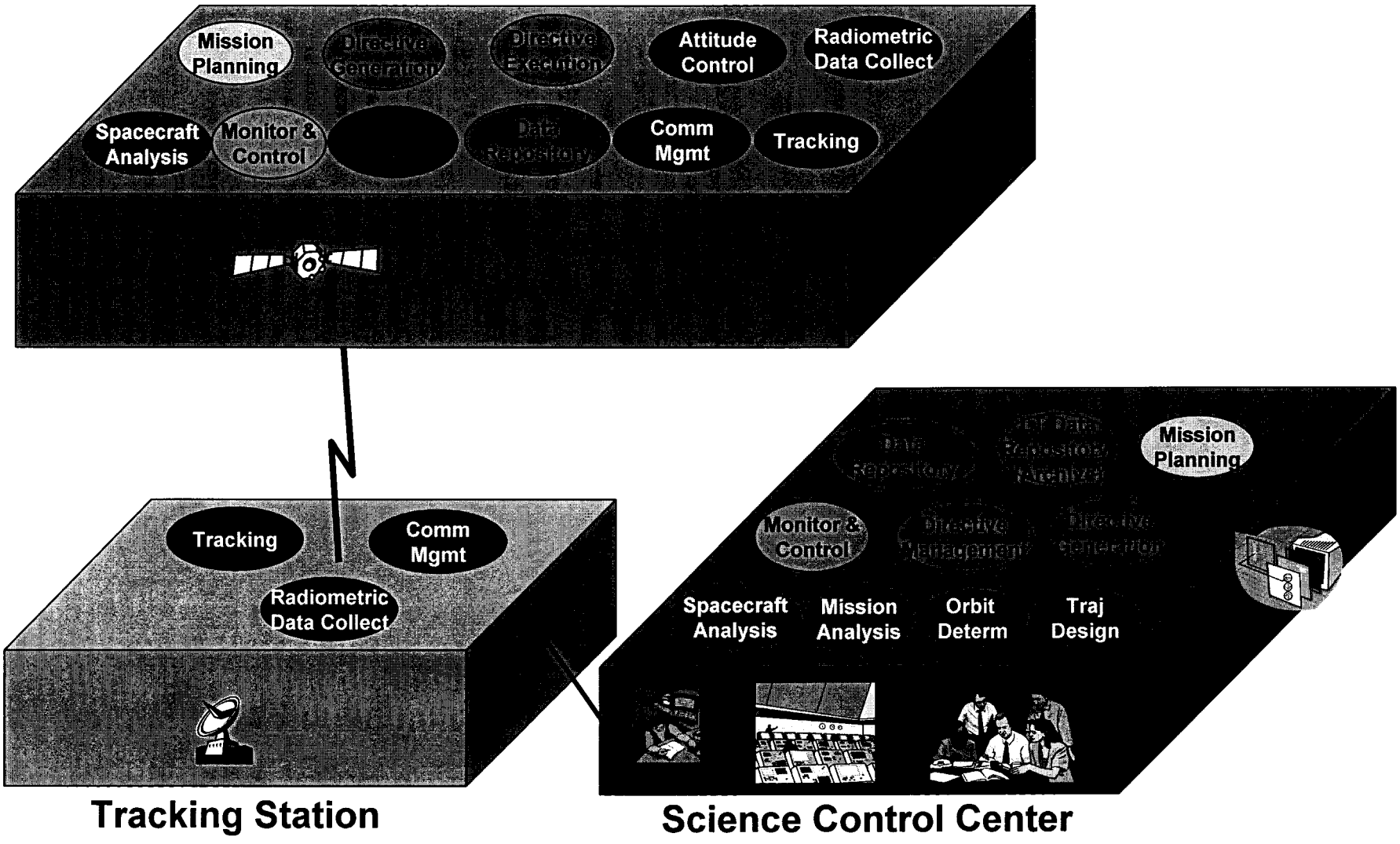
Using RASDS

- RASDS may be used to …
  - Model systems and behaviors (Connectivity & Functionality views)
  - Do design trade analyses, functional allocation (Functionality & Connectivity view)
  - Describe mission configurations & changes during lifecycle (Connectivity view)
  - Do performance studies (Connectivity view)
  - Analyze security domains, risks & approaches (Enterprise and most other views)
  - Evaluate flight / ground trades (Functionality & Connectivity views)
  - Exchange system models & maintain consistency across lifecycle phases (Enterprise, Functional, & Connectivity view)
  - Study effects of different protocol options (Communications and Connectivity views)

Connectivity & Functional Views
PI Mission

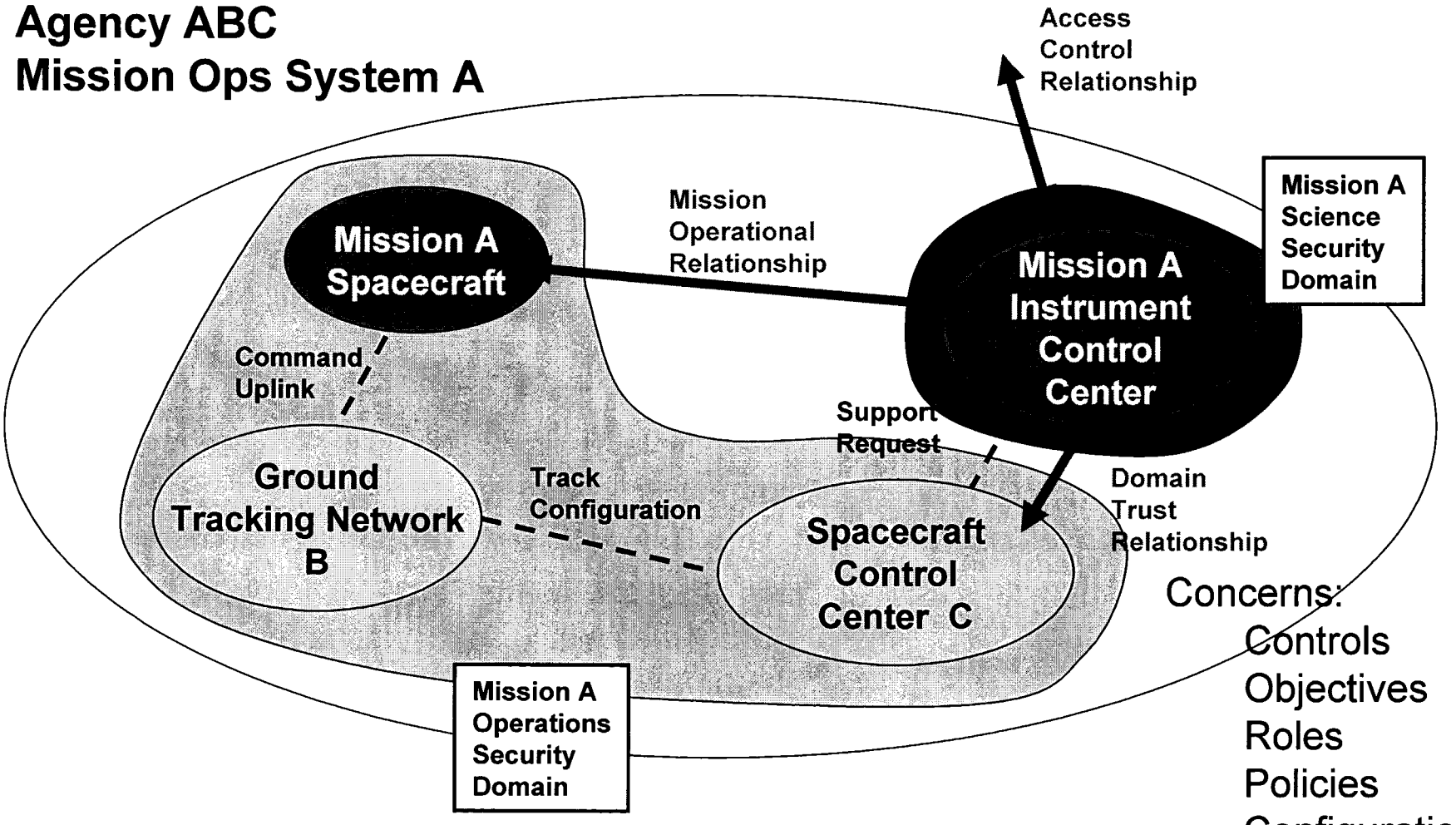


Connectivity & Functional Views
Autonomous Mission

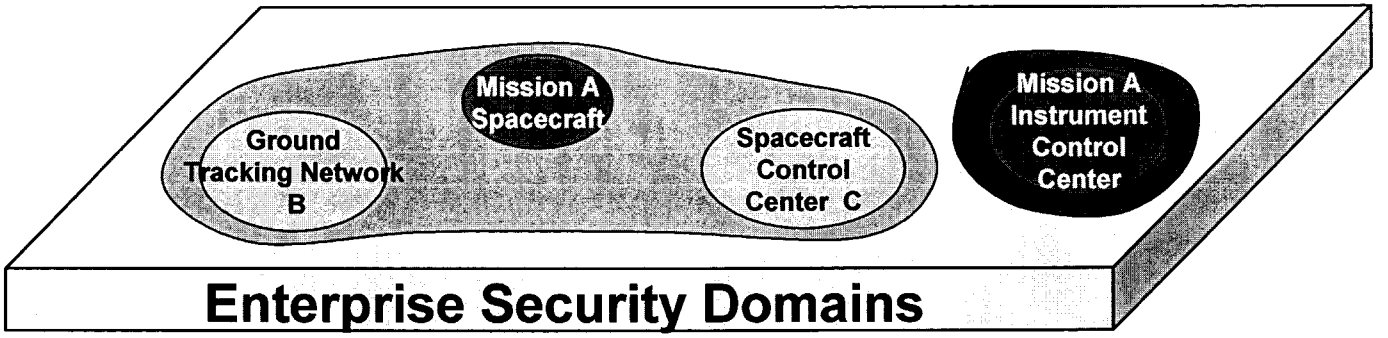


Enterprise View

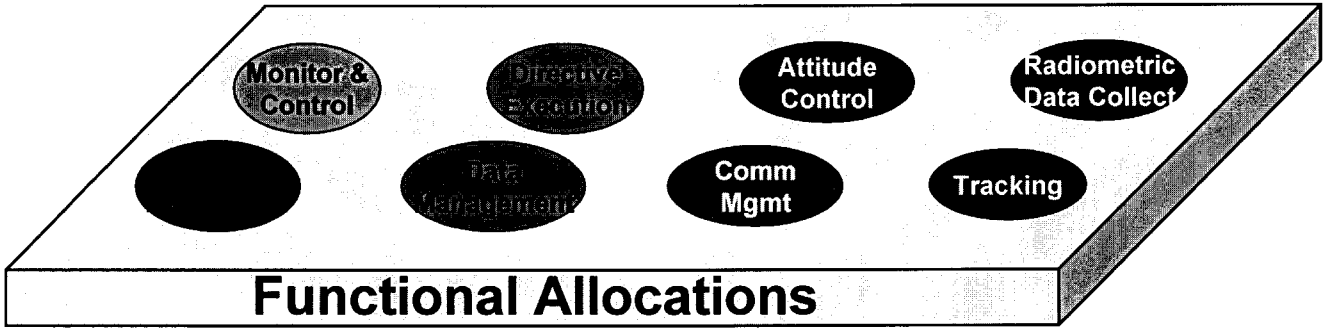
Security Domains for Simple Mission Domain



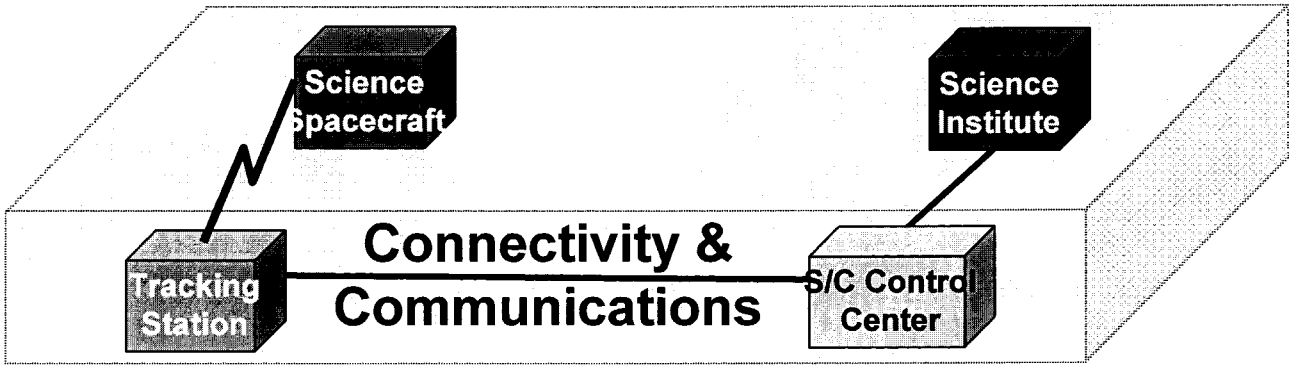
Security Analyses



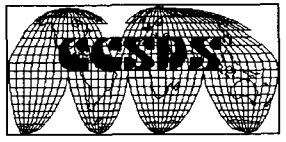
Trust relationships
Policies
Privacy / proprietary issues



Access control
Authentication

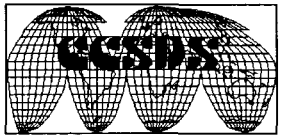


Firewalls
Encryption
Boundary access points



RASDS Summary

- The Reference Architecture for Space Data System (RASDS) provides guidance for describing space data systems using several orthogonal viewpoints
- The viewpoints and their relationships have been introduced
- A few examples of how to apply this demonstrate some of what can be done with this approach
- The next step, providing tools to capture system design and behavior, will permit easy evaluation of high level architecture, design, and performance, and mediate transfer of this knowledge among partners



BACKUP SLIDES

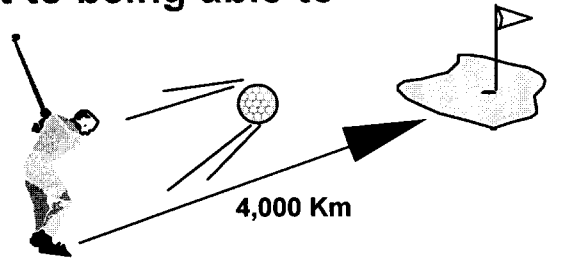
Gee Whiz!

What Makes the DSN Special, contd

Navigational Accuracy:

Voyager navigation at Neptune is equivalent to being able to tee – off from California and place the ball on a green in Washington, D.C.!

Angular accuracy = 50 nrad



Frequency Stability:

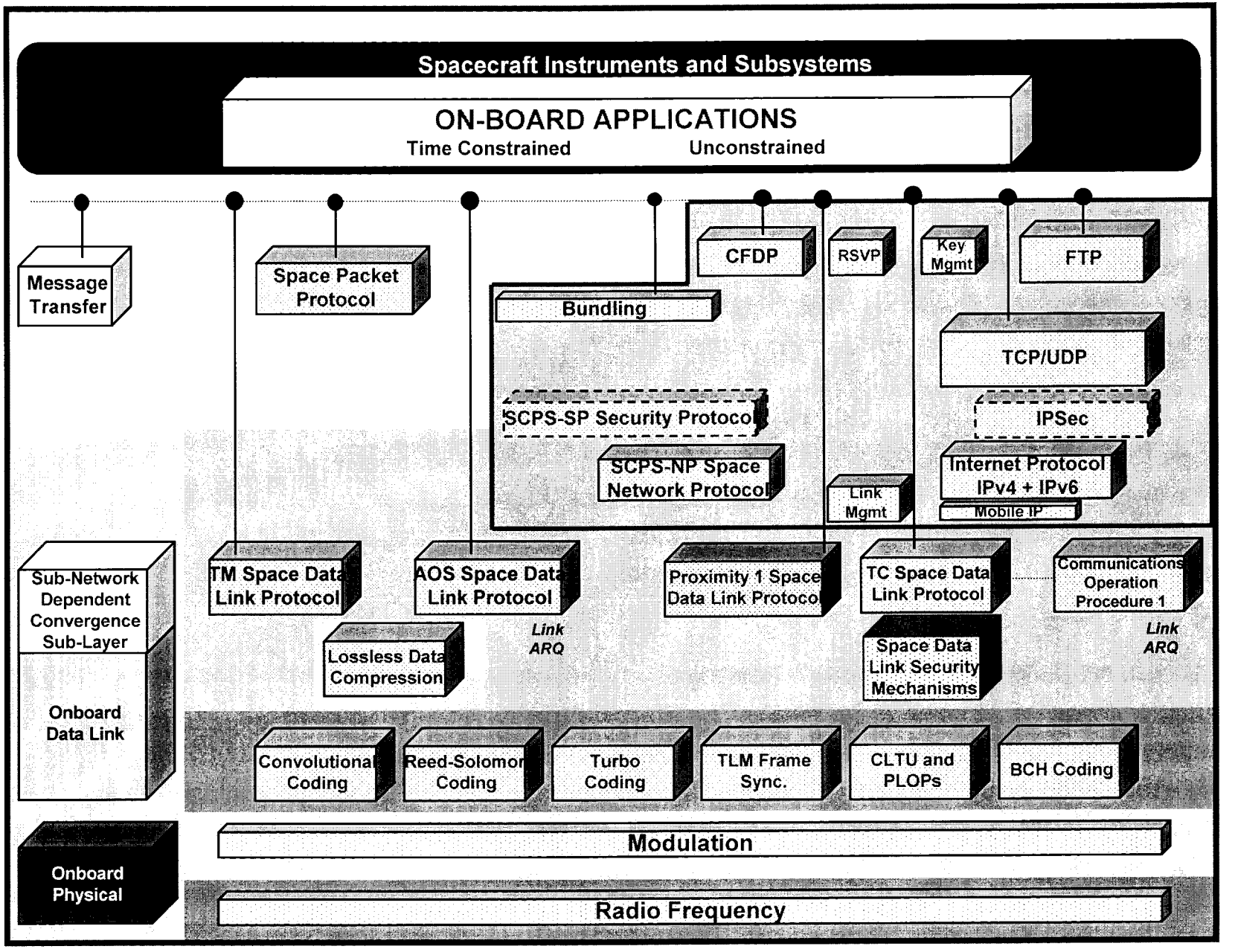
The DSN's ionic clocks used to achieve this navigation accuracy are so stable that only one second of error would accumulate every 30 million years!

Allan variance = 10^{-15} in 1000 seconds

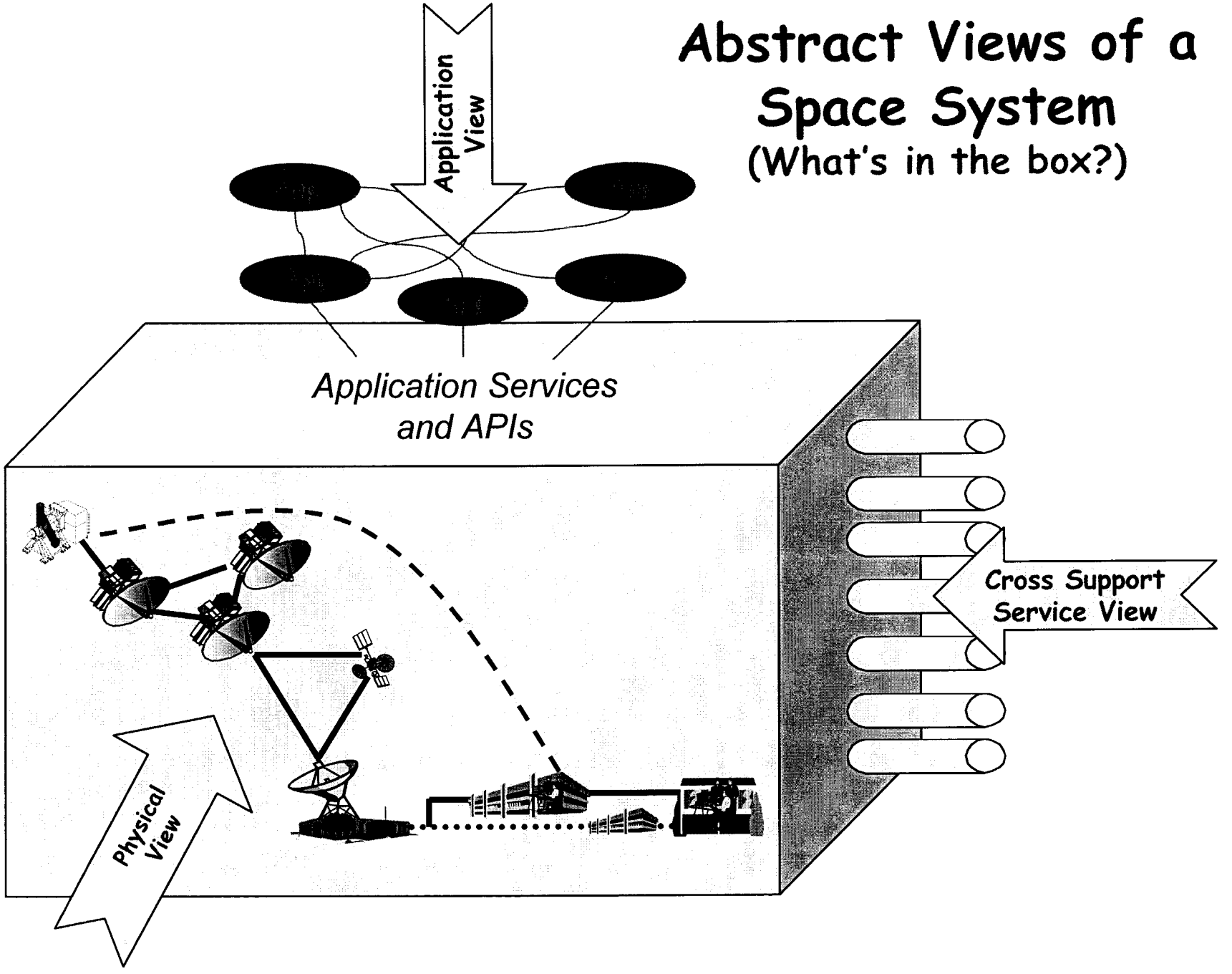
Once-in-a-lifetime Science Opportunities:

The data from a planetary encounter is more valuable than the most rare Earth elements! The reliability of a spacecraft and the DSN together is equivalent to driving an automobile for 3 billion miles without a single failure!

Current & Future CCSDS Standards

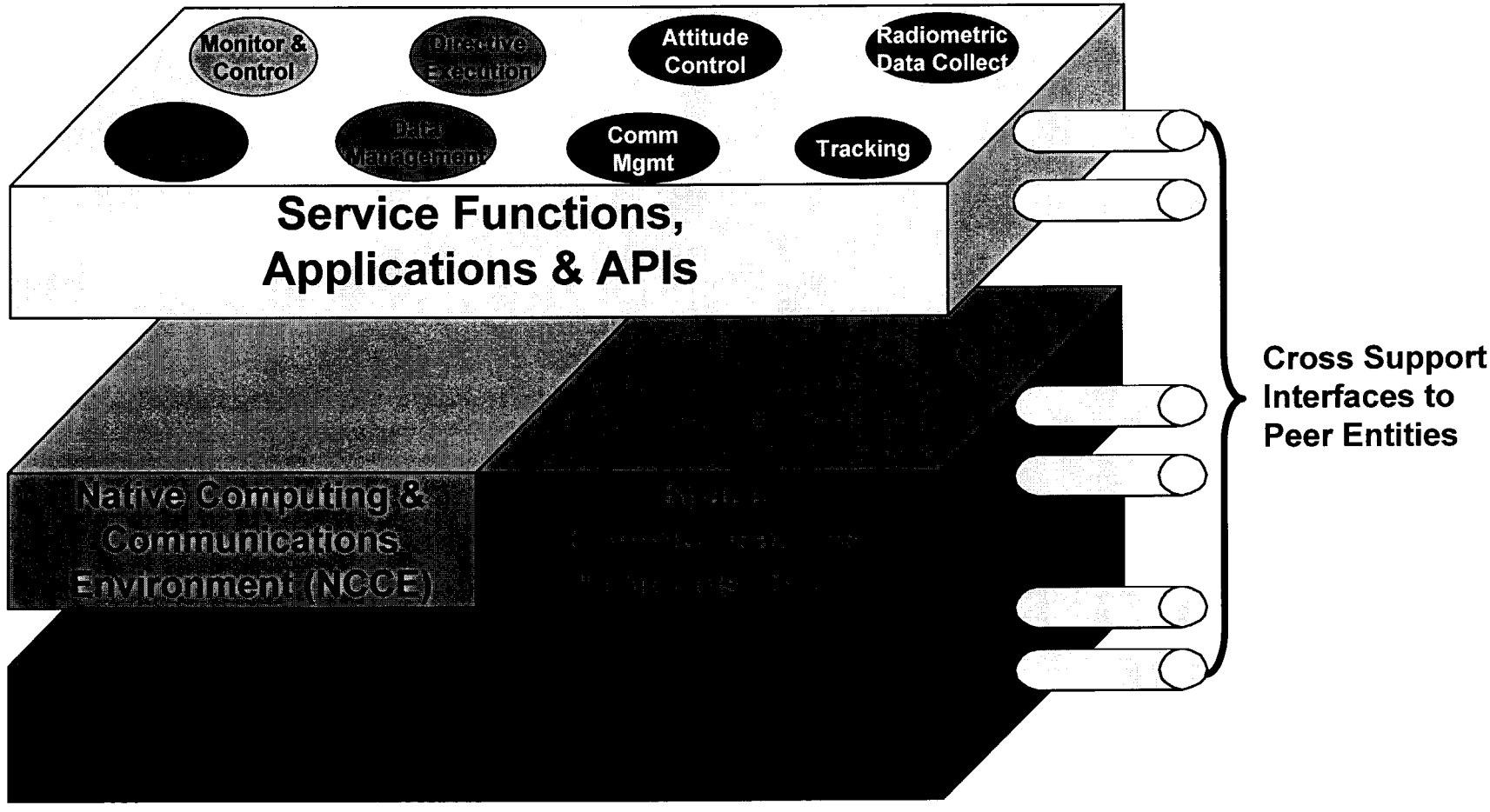


Abstract Views of a Space System
(What's in the box?)



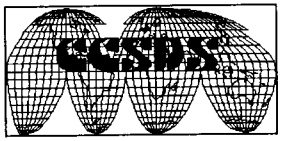
Modified from: A. Hooke, CCSDS

Basic Layered Structure of RASDS Software Systems



Reference Architecture
Cost Saving Elements

- RASDS is to be used as a standard framework by system architects and system developers
  - Reduce cost of system development by not developing individual frameworks
- Provides formal methods for describing architectures
  - E.g. UML profiles and/or XML schemas
  - Each View of a space data system described with Objects and their interactions
  - Characteristics of Objects, their behaviors, and their interactions are described
  - Formal descriptions enable sharing and exchange of information on architectures and systems among different organizations or teams
  - Eliminates re-generating the same information for different purposes, a common occurrence
- Develop software tools, based on existing commercial or academic tools, for generation and manipulation of architectures
- Architectural information can be directly fed to a generic simulator, which simulates the behavior of the system using the received architectural information
- Same information may be fed to software tools for detailed design and documentation of the system
- Approach greatly facilitates automating system design processes which will greatly reduce the cost of system development and verification



Reference Architecture
Cost Saving Summary

- Savings will come from:
  - Using a common, highly capable approach to describing complex systems
  - Using common tools
  - Using model based engineering to design these systems
  - Reuse of models and architectures
  - Sharing architectures and engineering models with partners
  - Development of standards to implement cross support
  - Reuse of compliant components
  - Cross support among agencies & missions