Architecting Families of Complex Space Systems and Networks

NASA Goddard Space Flight Center
Systems Engineering Seminar
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Kul Bhasin
NASA Glenn Research Center
Phone: 216.433.3676
Email: Kul.B.Bhasin@nasa.gov

SCaN "As-Is" Architecture Development Team

Architecture Team Lead

Kul Bhasin

Network Architecture Leads

Abhijit Biswas	DSN
James Bowen	DSN
Wesley Eddy	NISN
Eric Knoblock	GN
Mike Phillips	SN

Network Technical Points of Contact

C. Chang	DSN
Angela Culley	NISN
Larry Kiser	SN
Stephen Levitski	GN
A. Operchuck	NISN

Network Technical Points of Contact Cont.

T. Pham	DSN
Stan Rubin	NISN
Peter Shames	DSN
Chris Spinolo	NISN
Wallace Tai	DSN

DoDAF and RASDS Architecture

Jeffrey Gilbert
Chuck Putt

IT Support

Lee A. Jackson
Sherry L. Peck-Breen
NASA Glenn Logistics and Technical Information Division (LTID) Support

Lunar Communication and Navigation Systems (LCNS) Development Team

Team Lead
Kul Bhasin / Ron Miller

Operational View
Kul Bhasin
Kar-Ming Cheung
David Irimies
Tony Hackenberg
John Hudiburg
David Lassiter
Tom Sartwell
Jonathon Gal-Edd
Jeff Hayden

Systems View
Kul Bhasin
Charles Putt
Chuck Sheehe
Joe Connolly
Jonathon Gal-Edd
Jeff Hayden

Navigation
Mike Mesarch
Mike Moreau
Brian Kennedy
Joe Connolly

Networking Views
Loren Clare
Rich Slywczak
Kul Bhasin
Steve Gnepp
Chuck Putt

Technical View
Loren Clare
Steve Gnepp

Ground Segment
Jonathan Gal-Edd
Tom Sartwell

Space Segment
Mark Flanegan

Lunar Surface Segment
Mike Cauley
Doug Hoder
Chuck Sheehe
Alan Downey
Afroz Zaman
Kue Chun
Joe Warner

Document Development
Ruth Scina
Paulette Ziegfeld

SCWAG Participants
Jim Shier
Erica Lieb

SCaN Cx-Orion Architecture Development Team

Architecture Team Lead
Kul Bhasin

Communications Architecture
David Miller

Network Architecture
Loren Clare
Alan Jeffries
Esther Jennings
Steve Gnepp
Harry Shaw
Chris Spinolo
Shirley Tseng

Navigation Architecture
Brian Kennedy
Mike Maher

Operational Views
Chuck Putt
Mike Phillips
Tom Sartwell
Jeff Hayden

Systems Views
Abi Biswas
Jeff Hayden

Technical Views
David Miller

Traceability
David Miller
Ajithamol Painumkal

Special Contributors
Tony Hackenberg
Karen Richon
William Walsh

IT Support
Paulette Ziegfeld, Editorial
Jeffrey Gilbert, Graphics
Jeff Hayden, Graphics

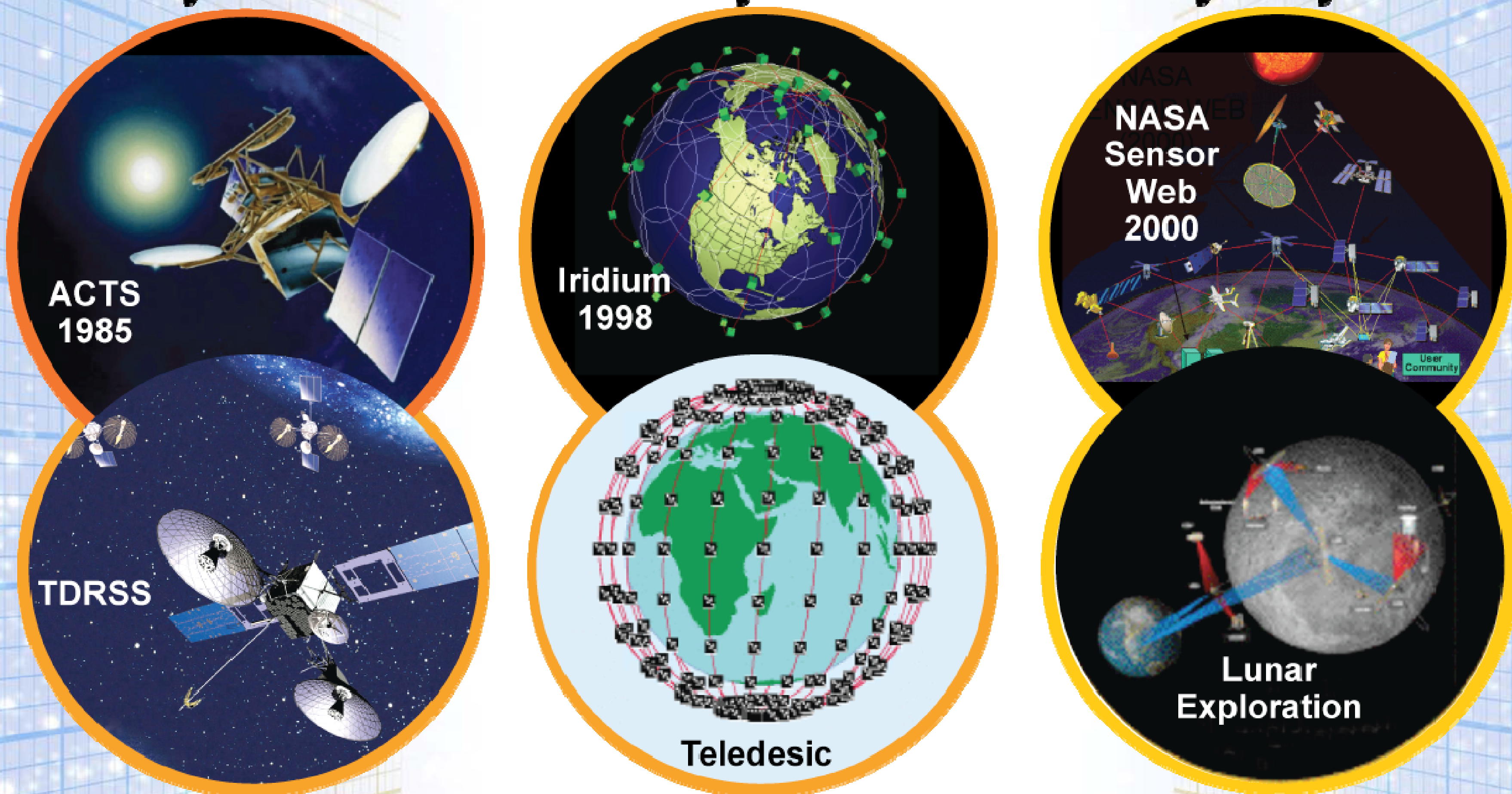
Presentation Overview

- Families of Systems and Networks: Evolutions and Trends
- Systems and Networks Architecting
- Systems Architecture Approach
- Systems Architecture Products

Families of Systems and Networks: Evolutions and Trends

Evolution of Space Communications Systems

Systems | **N x Systems** | **Family of Systems**



Systems (1980's – 1990's)

- Clear objectives,
- Central owner / stakeholder,
- Requirements-driven approach,
- Standard system engineering processes .

N x Systems (late 1990's)

- Increased complexity; Unproven technologies,
- High cost of service,
- Undefined users and customers;
- Inability to integrate multiple space and ground systems.

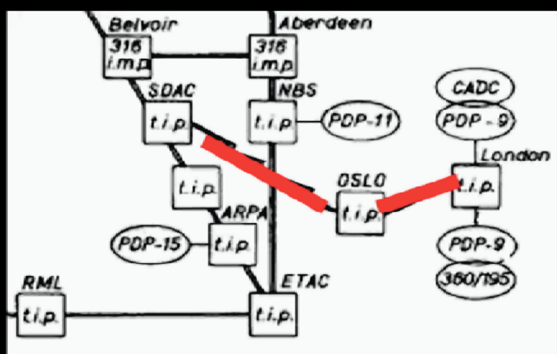
Family of Systems (2000's)

- Increase in inter-dependent interfaces;
- Increase in number and types of systems,
- Protocols,
- Software use and operational and Managerial Independence;
- Increase in system and operational complexity.

1980's – 1990's | late 1990's | 2000's

Space Communications NoN Evolution

Space Links

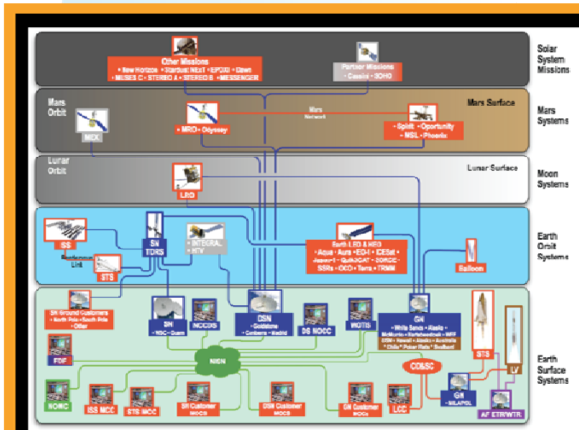


Arpnet Satnet

Single Links Supplementing Terrestrial Networks

1973

Space Networks

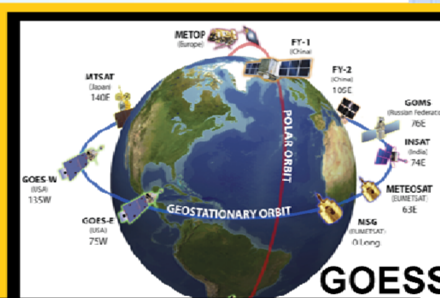


SCaN Networks SN, GN, DSN

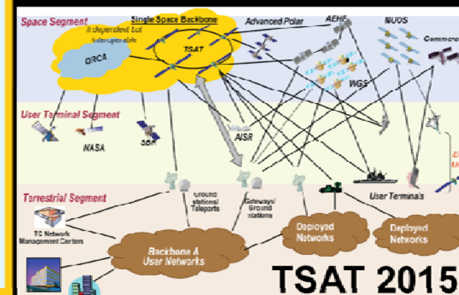
Multiple Distinct Networks with Manual Management and Little Interoperability

1990's – 2000's

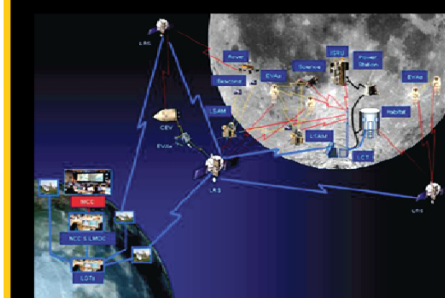
Space NoN



GOESS



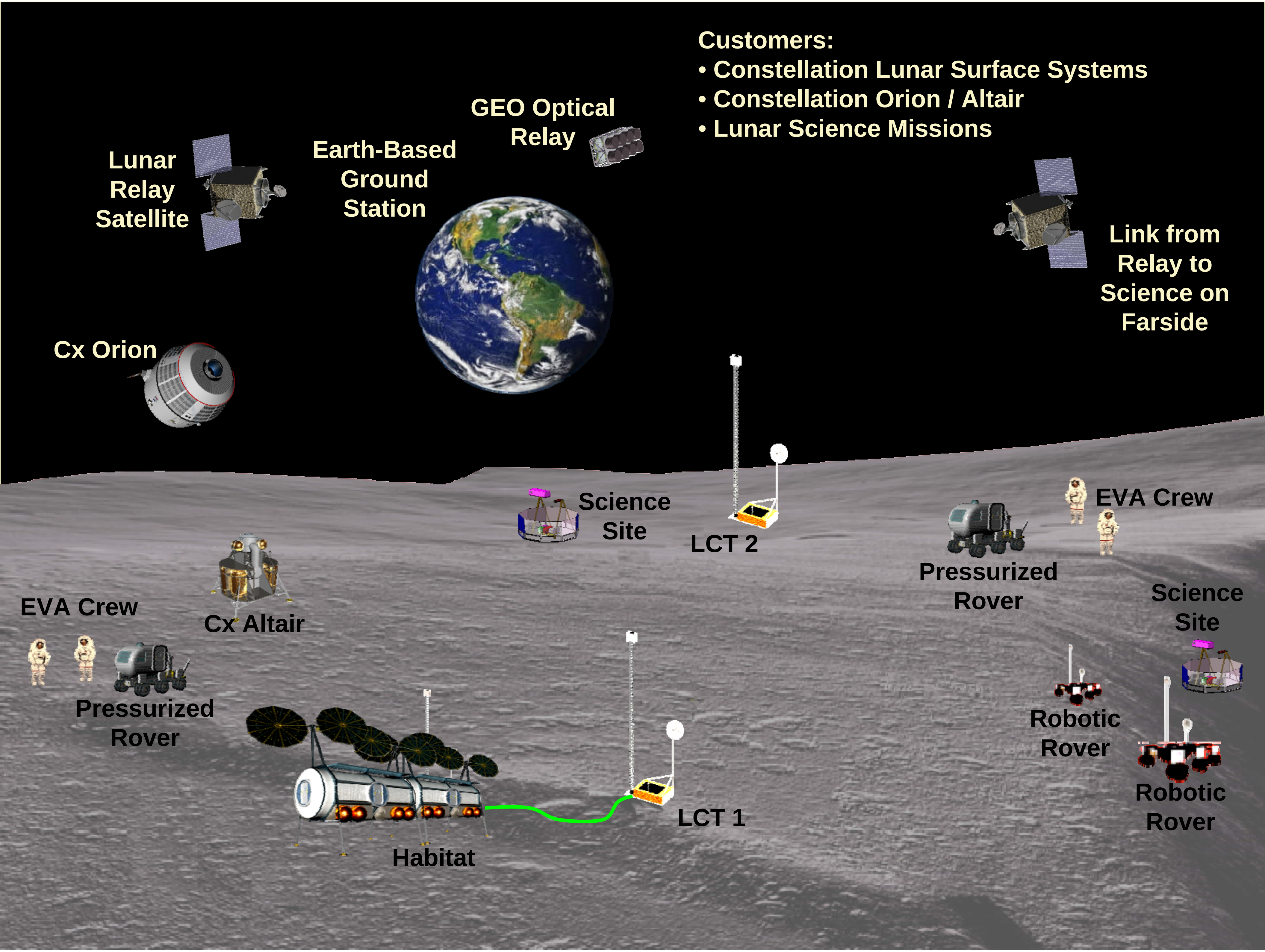
TSAT 2015



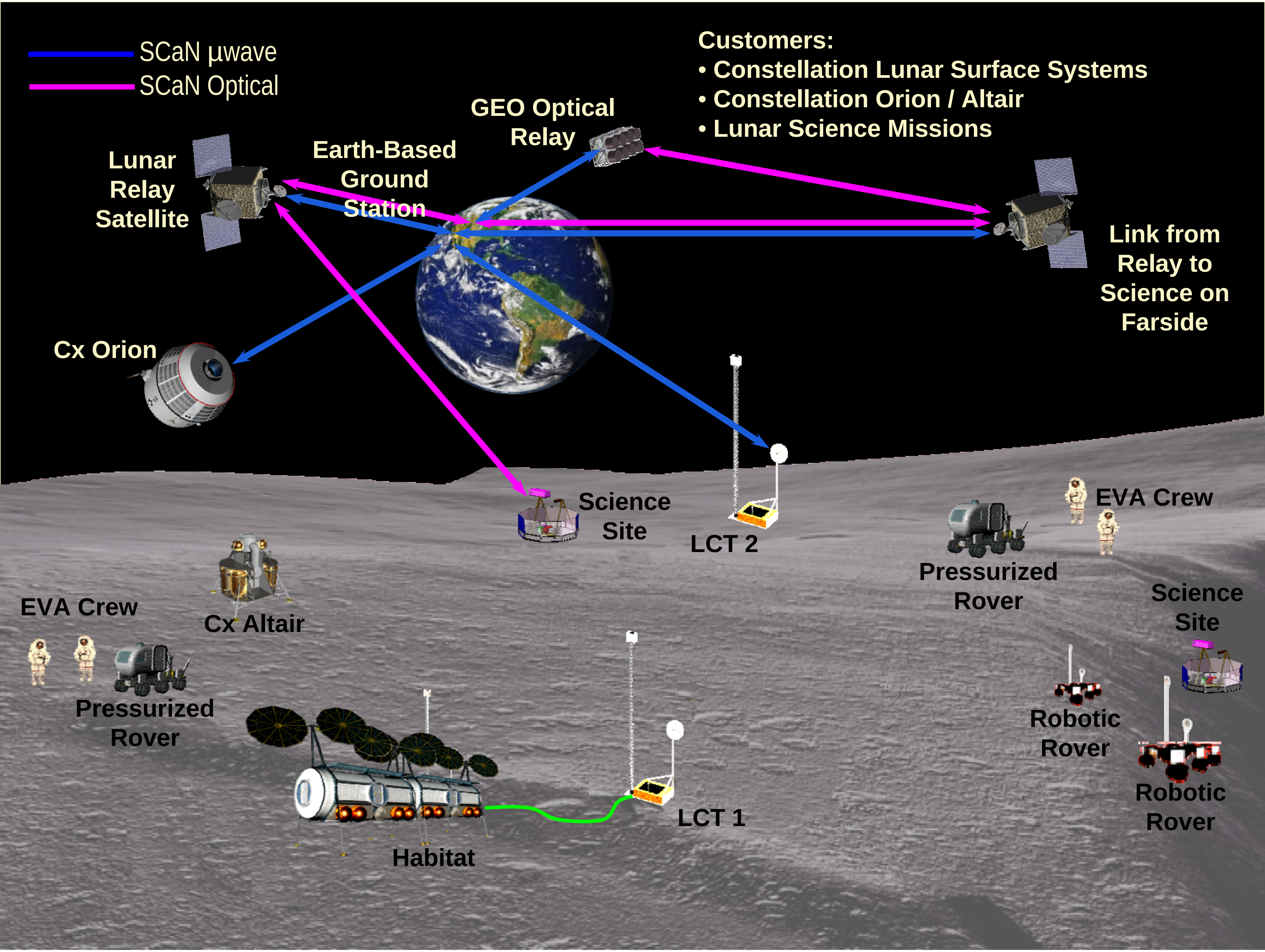
Constellation Lunar Phase 2018

Integrated, Interoperable Networks With Automated Management

2010 – 2030



Customers:
• Constellation Lunar Surface Systems
• Constellation Orion / Altair
• Lunar Science Missions
GEO Optical Relay
Earth-Based Ground Station
Lunar Relay Satellite
Link from Relay to Science on Farside
Cx Orion
Science Site
LCT 2
EVA Crew
Pressurized Rover
Cx Altair
EVA Crew
Science Site
Pressurized Rover
Robotic Rover
Robotic Rover
LCT 1
Habitat



SCaN µwave
SCaN Optical
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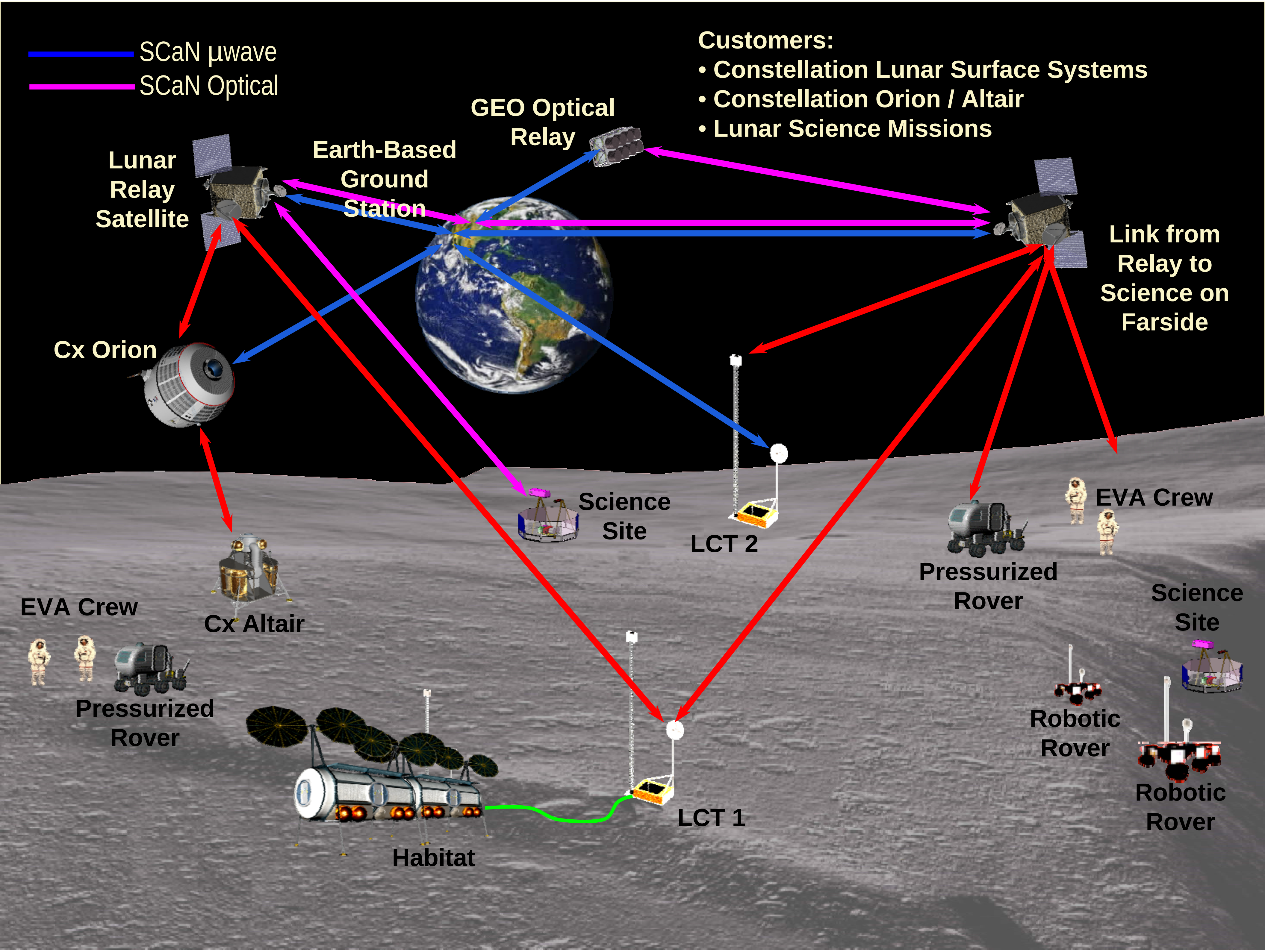

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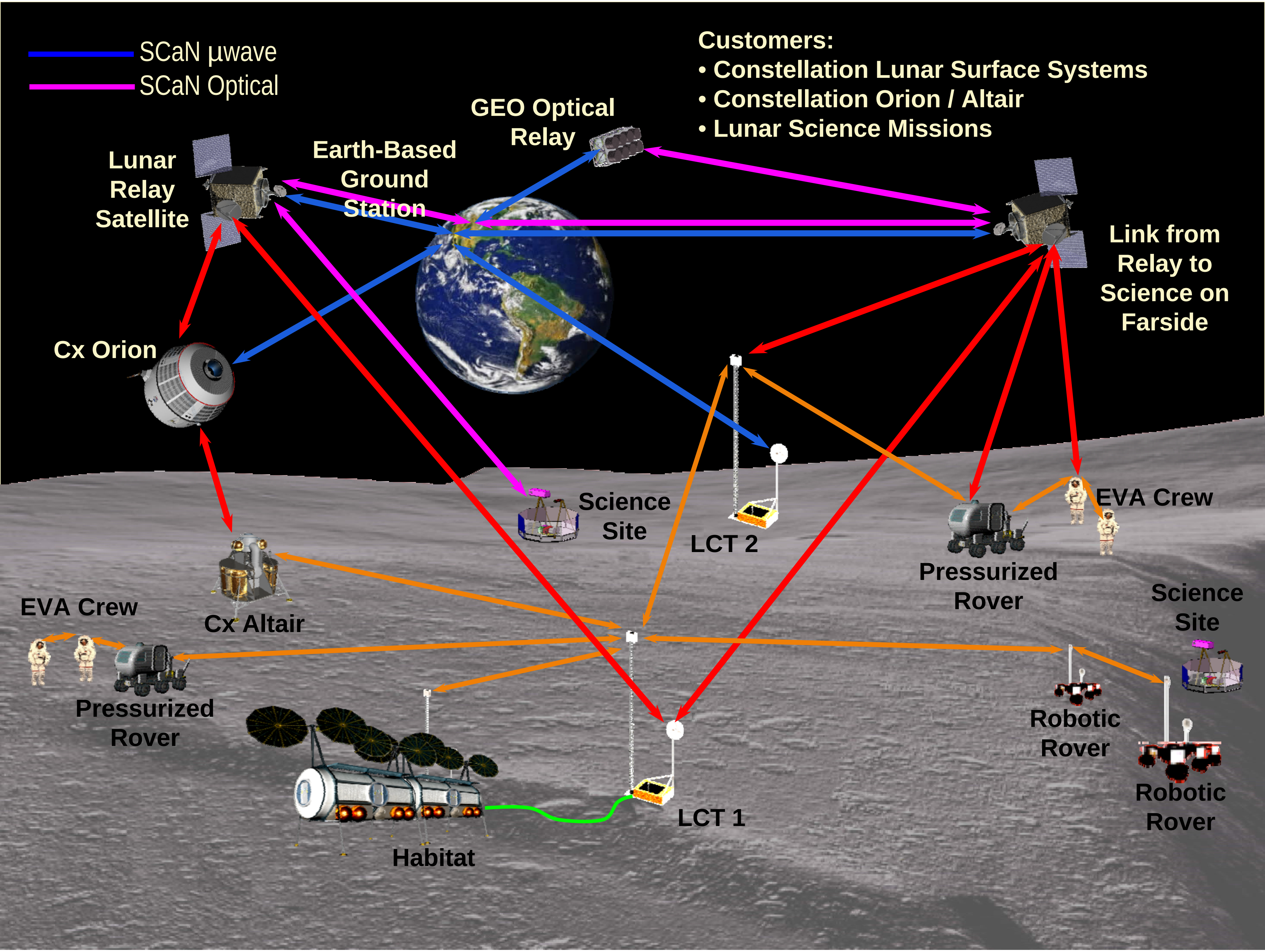
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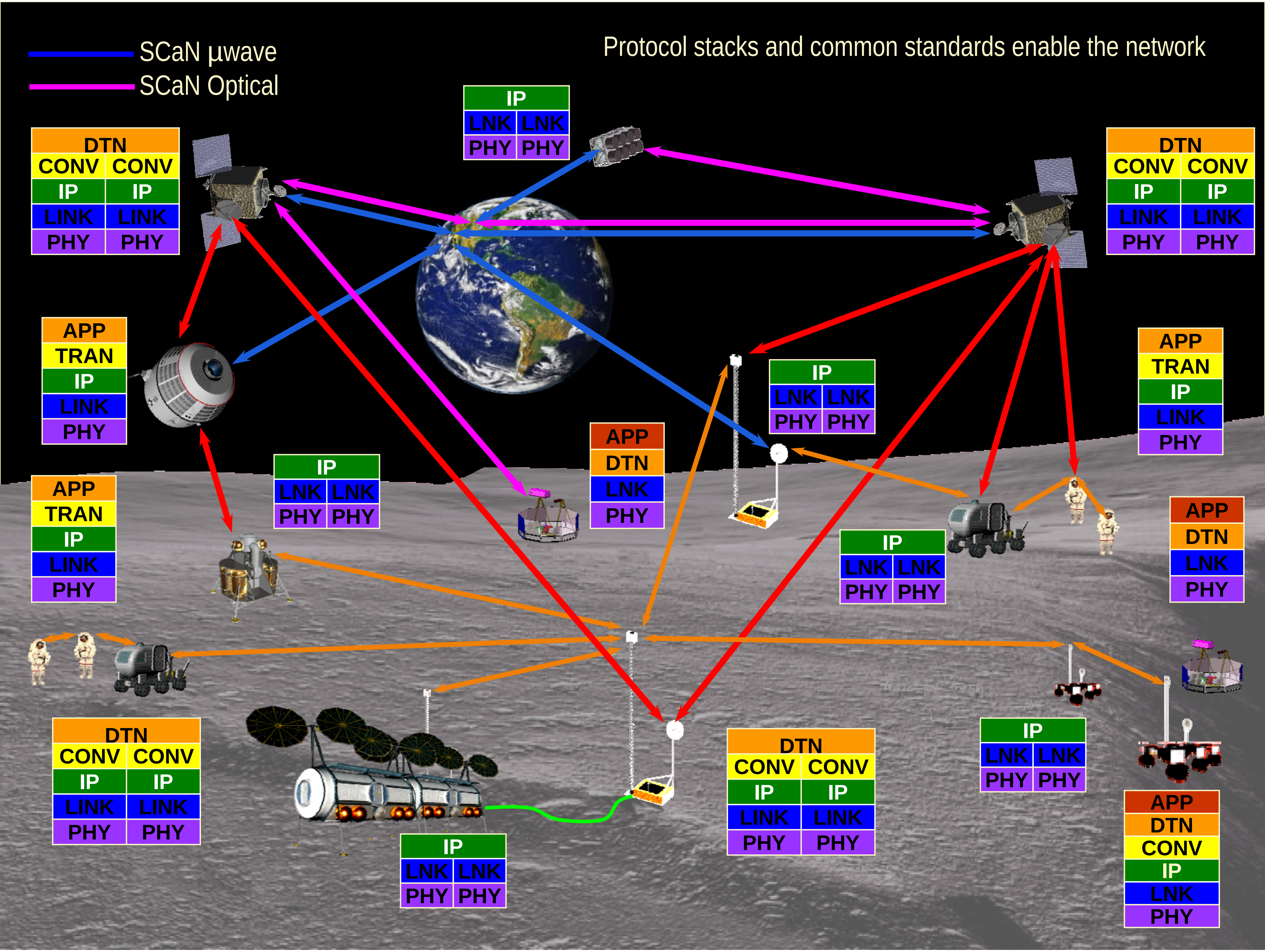
SCaN μwave
SCaN Optical
Protocol stacks and common standards enable the network
IP
LNK LNK
PHY PHY
DTN
CONV CONV
IP IP
LINK LINK
PHY PHY
DTN
CONV CONV
IP IP
LINK LINK
PHY PHY
APP
TRAN
IP
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IP
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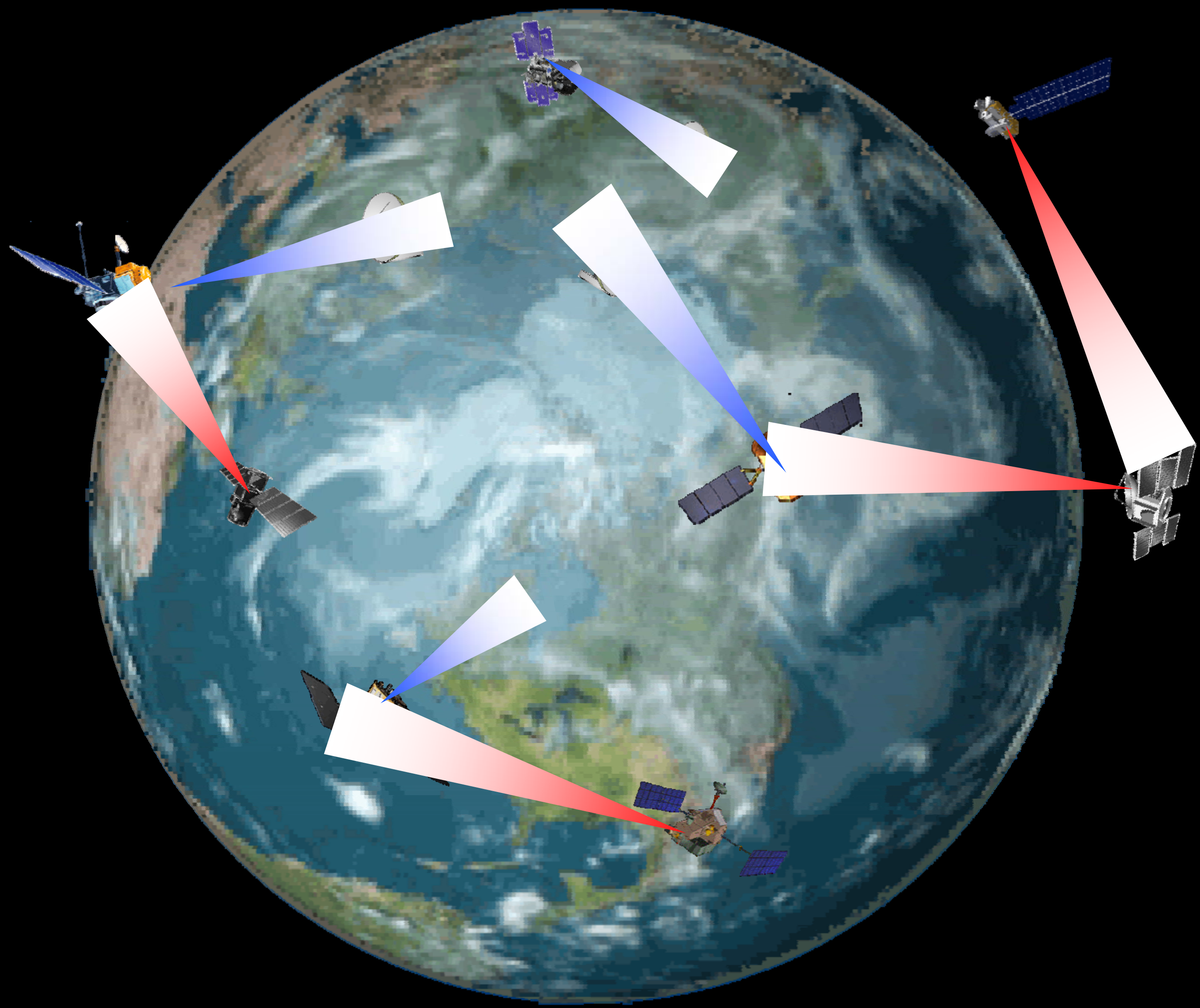
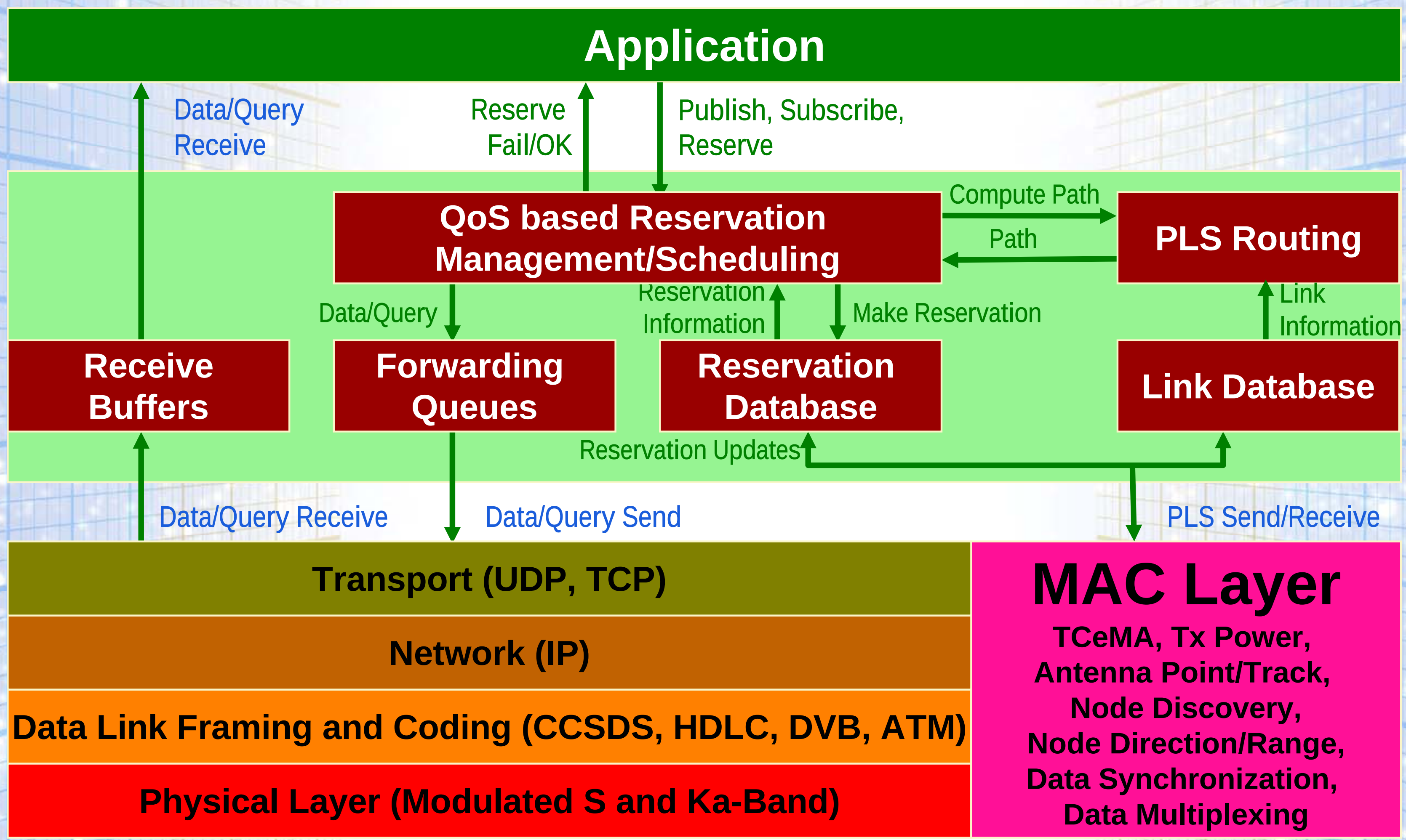
PHY

Autonomous Earth Observing System of Systems and Network of Networks



Autonomous Space Communications Technology (ASCoT) Architecture



Challenges

- System Engineering processes increasingly demand architecture when complex systems are being interfaced in a space environment. However, architecting remains misunderstood.
- Academic/normative approaches are still emerging, as a result, the arch for complex systems is being developed "on the fly" (during program development process)
- Base systems are becoming more complex in terms of their numbers (System of Systems, Network of Networks). 2 levels of complexity.

Introduction to Systems and Networks Architecting

Characteristics of Families of Systems and Networks*

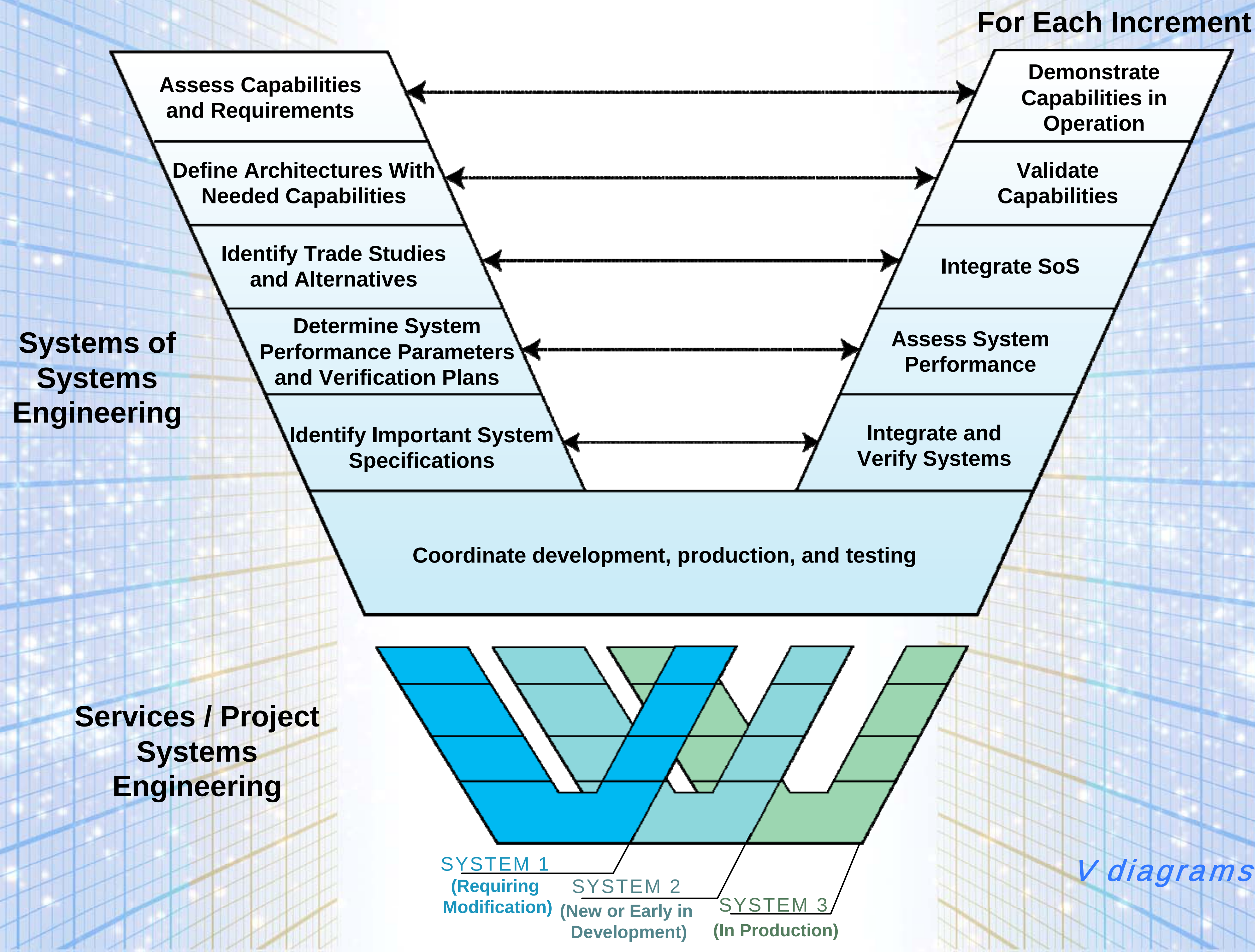
- Large Scale Programs and Systems
  - As a result, many times, single integrated architecture is infeasible
- Diverse Ownership/Management
  - Individual systems might be owned by different agencies/organizations
- Interfaces with Legacy and Future Systems
  - Evolutionary development
  - New systems must work with legacy systems, and be designed to integrate with future systems
- Changing Operations Concepts
  - Families of systems and networks configuration must be flexible to accommodate changes
  - System and network management capabilities must support adaptability
  - Emergent, non-linear properties create changes from original goals
- Criticality of Software
  - Systems are integrated via cooperative and distributed software
  - Software is used to implement much of the system behavior and functionality
- Networks are Enablers and Serve as Infrastructure
  - Development phase
  - Operations phase
  - Support self-organization of systems and reduce operational burden

**Some of this material is adapted from Anna Warner's INCOSE Los Angeles Chapter Meeting Presentation, September 2008*

Why Architecting for Families of Systems and Networks?

- **Who uses it?**
  - Large projects/programs and organizations: military, aerospace, government, enterprises, etc.
- **Who needs it?**
  - Managers – understand overall system, requirements, operations concepts, acquisition needs
  - Engineers – understand how systems interact, provide common language and understanding of architecture across diverse teams tackling different focus areas
- **What is it?**
  - Top-down, comprehensive, collaborative, multidisciplinary, iterative, and concurrent technical processes
- **When is it used in the overall systems engineering process?**
  - Concept Studies / Concept & Technology Development (Pre-Phase A / Phase A) – Develop CONOPS and identify key relationships, capabilities, and needs for acquisition and development; establish baseline for cooperation
  - Preliminary Design & Technology Completion through System Assembly (Phase B through Phase D) – Maintain common baseline for interoperability and provide common concepts across individual system projects
  - Operations & Sustainment (Phase E) – Determine state of SoS and evaluate acquisition plans, capability gaps, etc.; serve as baseline for building future architectures

Systems of Systems Engineering Framework



Systems Architecture Approach

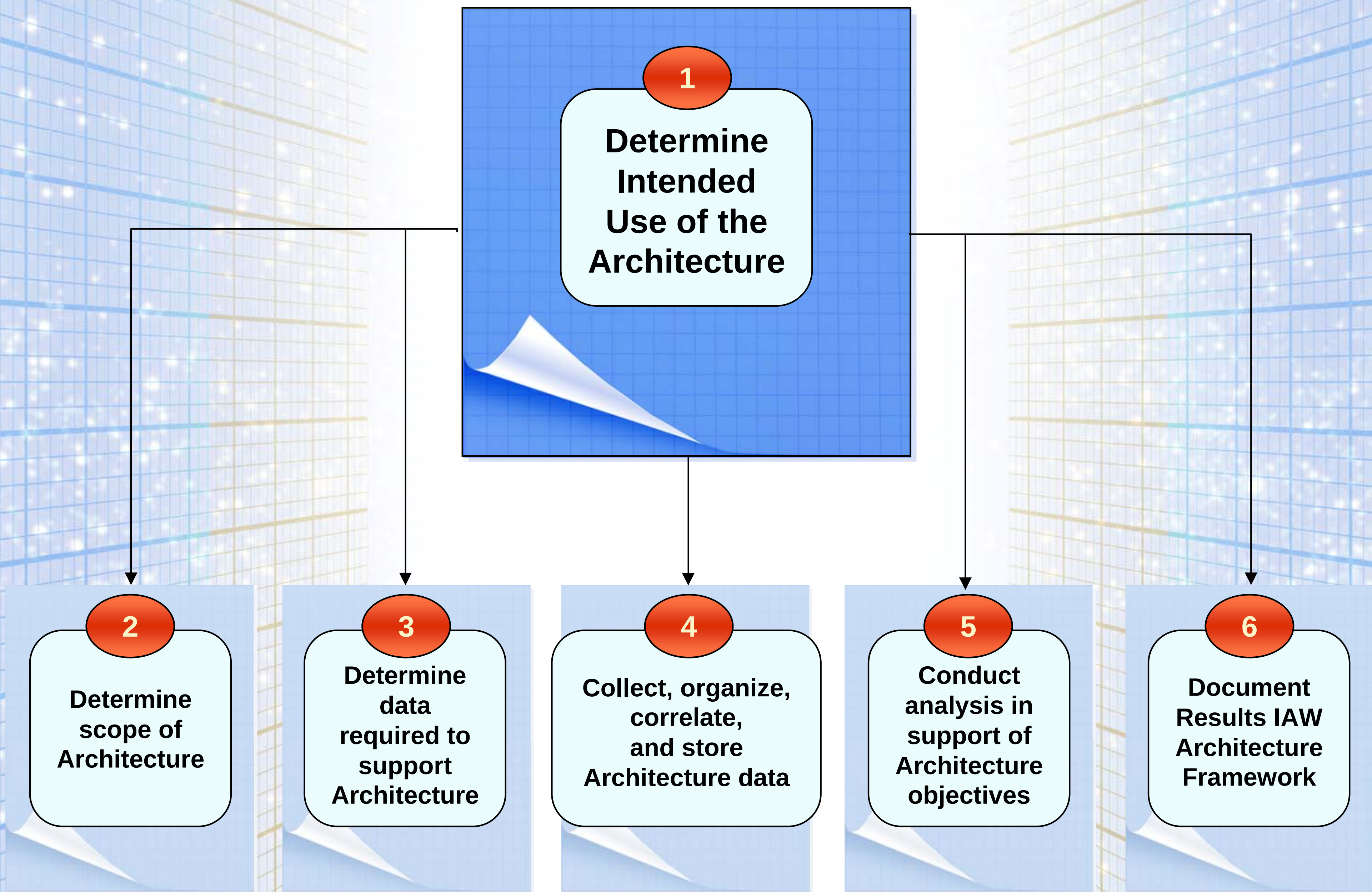
Architecture Development Process

Architecture Framework

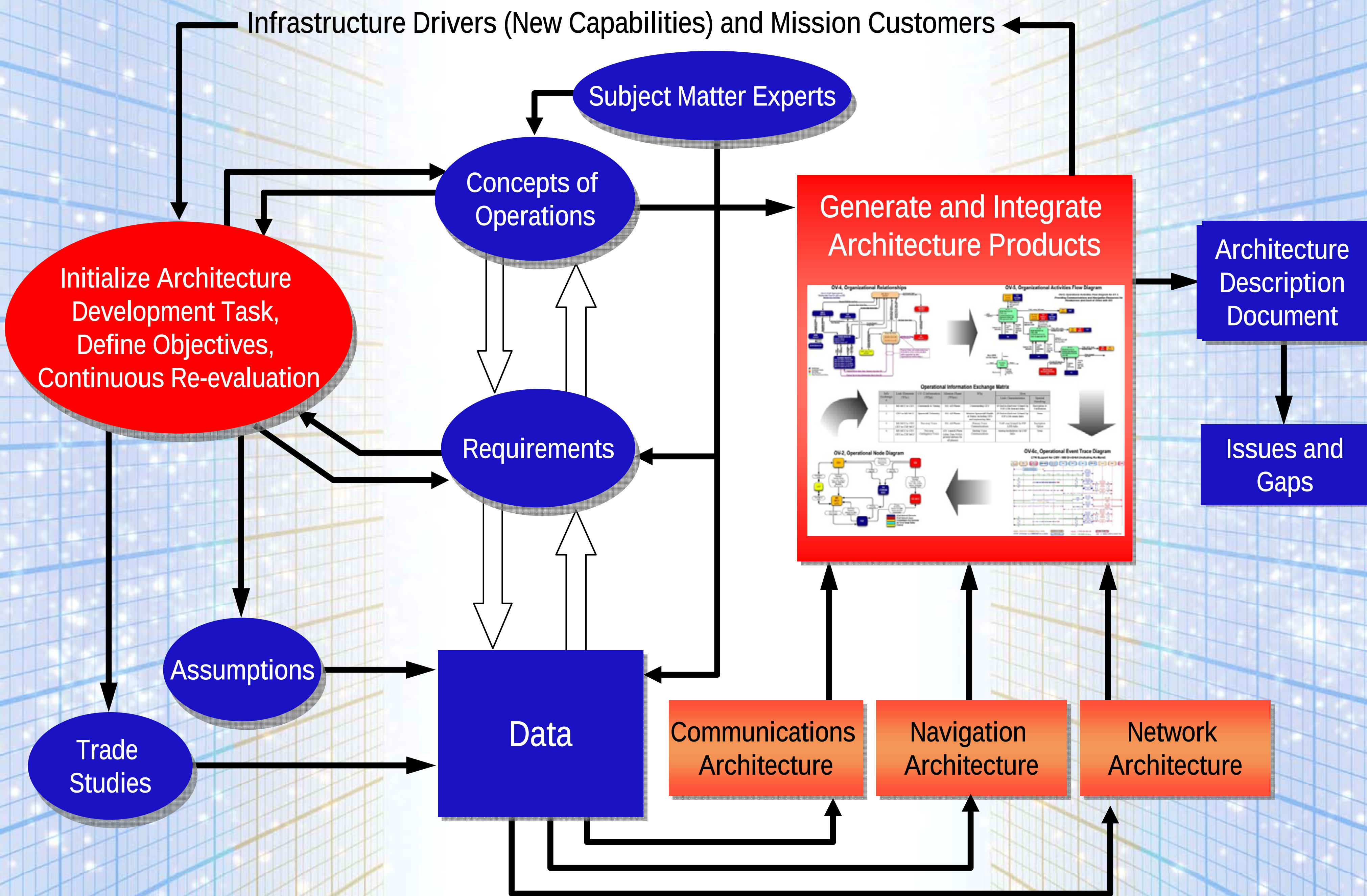
Architecture Development Methods

Six-Step Static Architecture Development Process

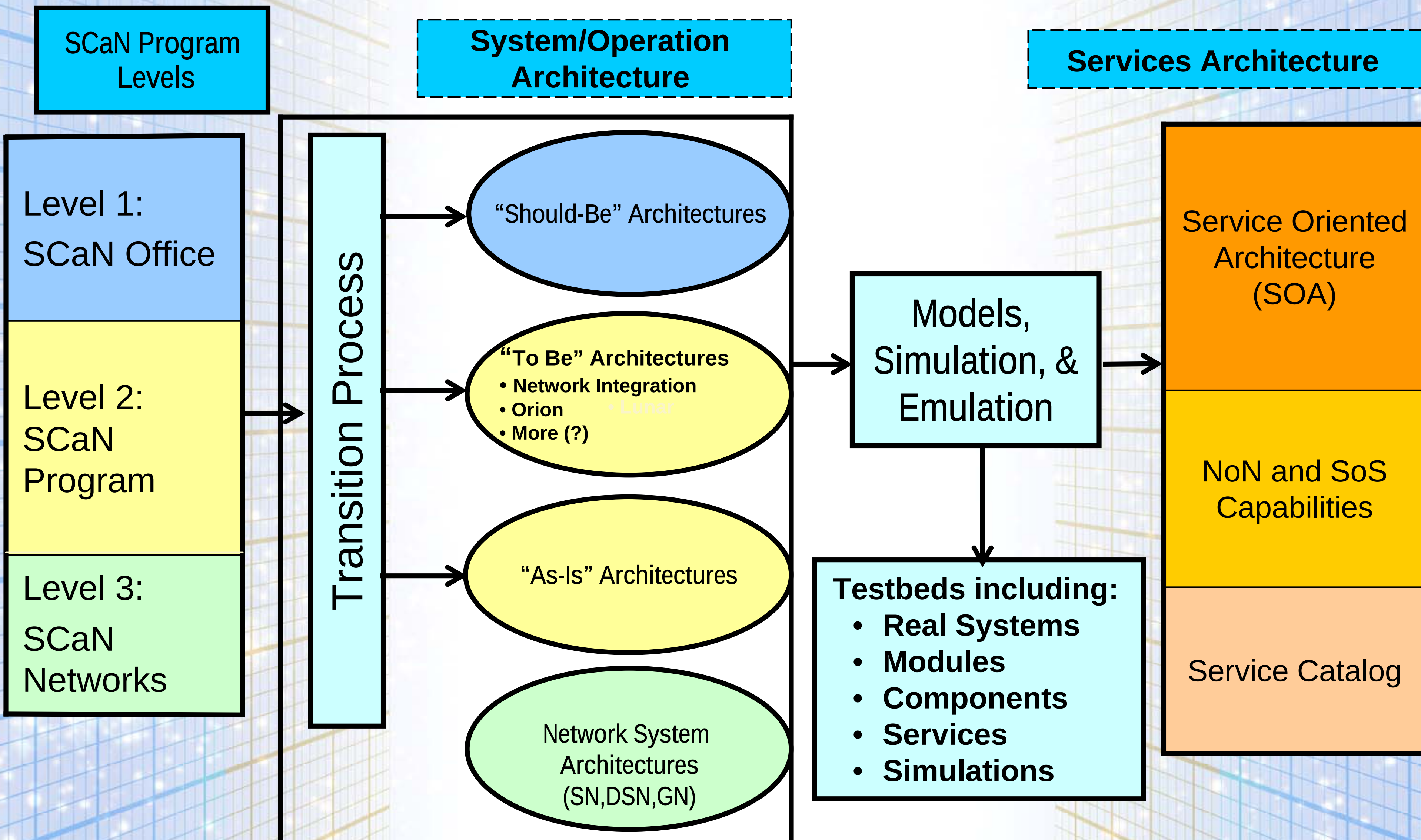
(DoDAF 1.5)



Dynamic Architecture Process Used By the NASA Architecture Team



SCaN System Architecture Engineering



Architecture Roadmapping for the Transition Process

- Process
  - Collects strategic levels of information; examples include Program's Customer Drivers and Plans
  - Concern with longer timeframes than short-term project plans
  - Divide up the timeframe into segments based on budgetary and visionary goals
  - Develop multi-layered approach which shows the inter-dependencies among Drivers, Program/Project Milestones, Operational and Development Capability Plans, and Enablers
  - Clearly show the "Pull" of the program goals and customer requirements to technology developers
  - Clearly show the "Push" of the emerging and relevant technology capabilities

Architecture Frameworks

A Systems Architecture Framework specifies how to organize and present the fundamental organization of a system.

- By analogy, a Framework is the drawings or blueprints you would have to produce for a building.

Some Examples:

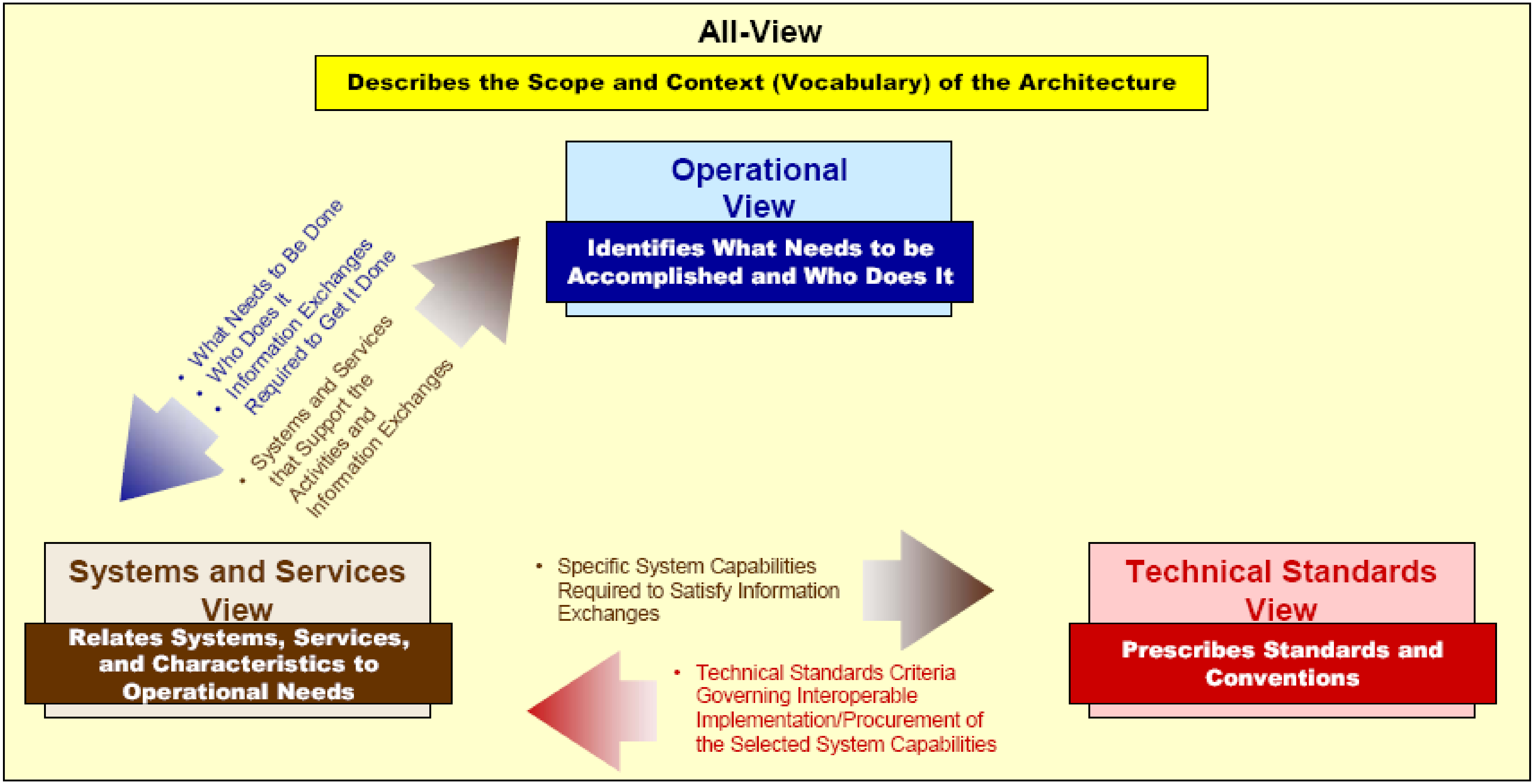
- **The Department of Defense Architecture Framework (DoDAF) Ver 1.5.**
- **The Zachman Framework.**
- **Reference Architecture for Space Data Systems (RASDS) from CCSDS.**

Architecture Views/Viewpoints: Definition

- **Architecture *Views***
  - A *view* is a representation of a whole system from the perspective of a related set of concerns
  - [*alternate definition*… Representations of the overall **architecture** that are meaningful to one or more stakeholders in the system]
  - Each view corresponds to exactly one viewpoint

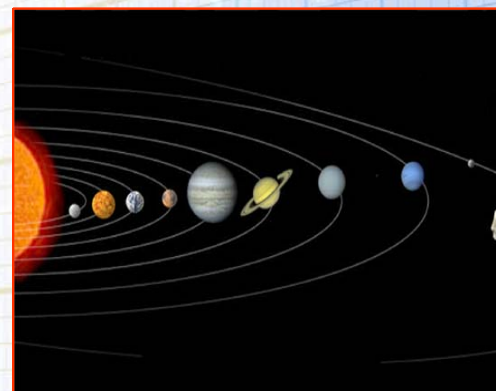
- **Architecture *Viewpoints***
  - A *viewpoint* defines the perspective from which a view is taken
    - A view is what you see. A viewpoint is the vantage point or perspective that determines what you see
  - A viewpoint provides a framework or pattern for constructing views
  - *Each viewpoint is specified by*:
    - Viewpoint name
    - The stakeholders addressed by the viewpoint
    - The stakeholder concerns to be addressed by the viewpoint
    - The viewpoint language, modeling techniques, or analytical methods used
    - The source, if any, of the viewpoint (e.g., author, literature citation)

DoDAF 1.5 Overview – Views



Reference Architecture for Space Data Systems*

- **RASDS (Reference Architecture for Space Data Systems) is described by the CCSDS Systems Architecture Working Group *specifically for space systems.***



Viewpoints

Enterprise	**Business Concerns** **Organizational perspective**
Functional	**Computational Concerns** **Functional composition**
Information	**Data Concerns** **Relationships and transformations**
Connectivity	**Physical Concerns** **Node & Link perspective**
Communications	**Protocol Concerns** **Communications stack perspective**

*Peter Shames, Jet Propulsion Laboratory

Zachman Framework Views and Viewpoints

THE ZACHMAN ENTERPRISE FRAMEWORK² ™

	WHAT	HOW	WHERE	WHO	WHEN	WHY	
SCOPE	Inventory Identification e.g. Inventory Types	Process Identification e.g. Process Types	Network Identification e.g. Network Types	Organization Identification e.g. Organization Types	Timing Identification e.g. Timing Types	Motivation Identification e.g. Motivation Types	STRATEGISTS
BUSINESS	Inventory Definition e.g. Business Entity Business Relationship	Process Definition e.g. Business Transform Business Input	Network Definition e.g. Business Location Business Connection	Organization Definition e.g. Business Role Business Work	Timing Definition e.g. Business Cycle Business Moment	Motivation Definition e.g. Business End Business Means	EXECUTIVE LEADERS
SYSTEM	Inventory Representation e.g. System Entity System Relationship	Process Representation e.g. System Transform System Input	Network Representation e.g. System Location System Connection	Organization Representation e.g. System Role System Work	Timing Representation e.g. System Cycle System Moment	Motivation Representation e.g. System End System Means	ARCHITECTS
TECHNOLOGY	Inventory Specification e.g. Technology Entity Technology Relationship	Process Specification e.g. Technology Transform Technology Input	Network Specification e.g. Technology Location Technology Connection	Organization Specification e.g. Technology Role Technology Work	Timing Specification e.g. Technology Cycle Technology Moment	Motivation Specification e.g. Technology End Technology Means	ENGINEERS
COMPONENT	Inventory Configuration e.g. Component Entity Component Relationship	Process Configuration e.g. Component Transform Component Input	Network Configuration e.g. Component Location Component Connection	Organization Configuration e.g. Component Role Component Work	Timing Configuration e.g. Component Cycle Component Moment	Motivation Configuration e.g. Component End Component Means	TECHNICIANS
OPERATIONS	Inventory Instantiation e.g. Operations Entity Operations Relationship	Process Instantiation e.g. Operations Transform Operations Input	Network Instantiation e.g. Operations Location Operations Connection	Organization Instantiation e.g. Operations Role Operations Work	Timing Instantiation e.g. Operations Cycle Operations Moment	Motivation Instantiation e.g. Operations End Operations Means	WORKERS
Released October 2007	INVENTORY	PROCESS	NETWORK	ORGANIZATION	TIMING	MOTIVATION	Version 2.01

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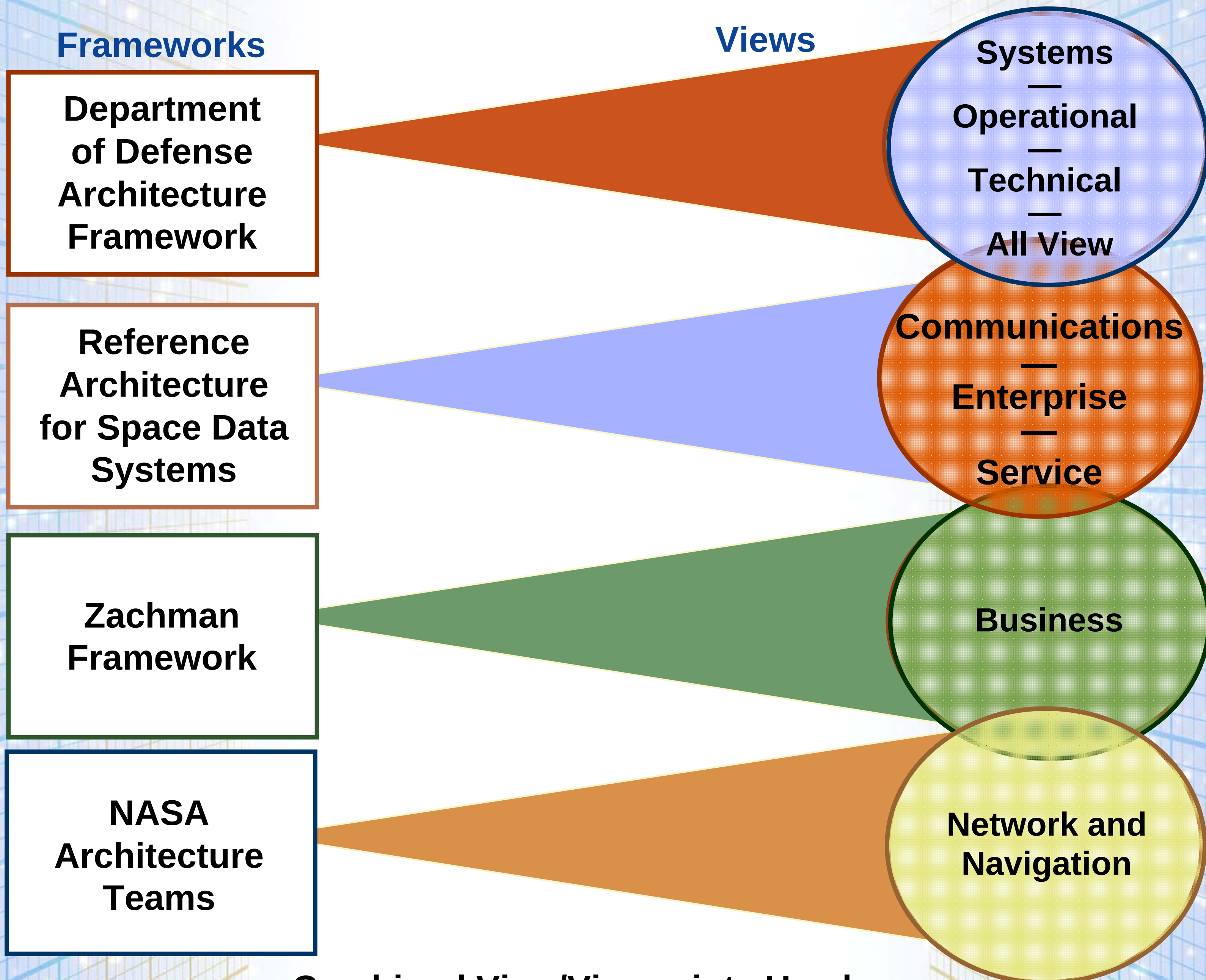
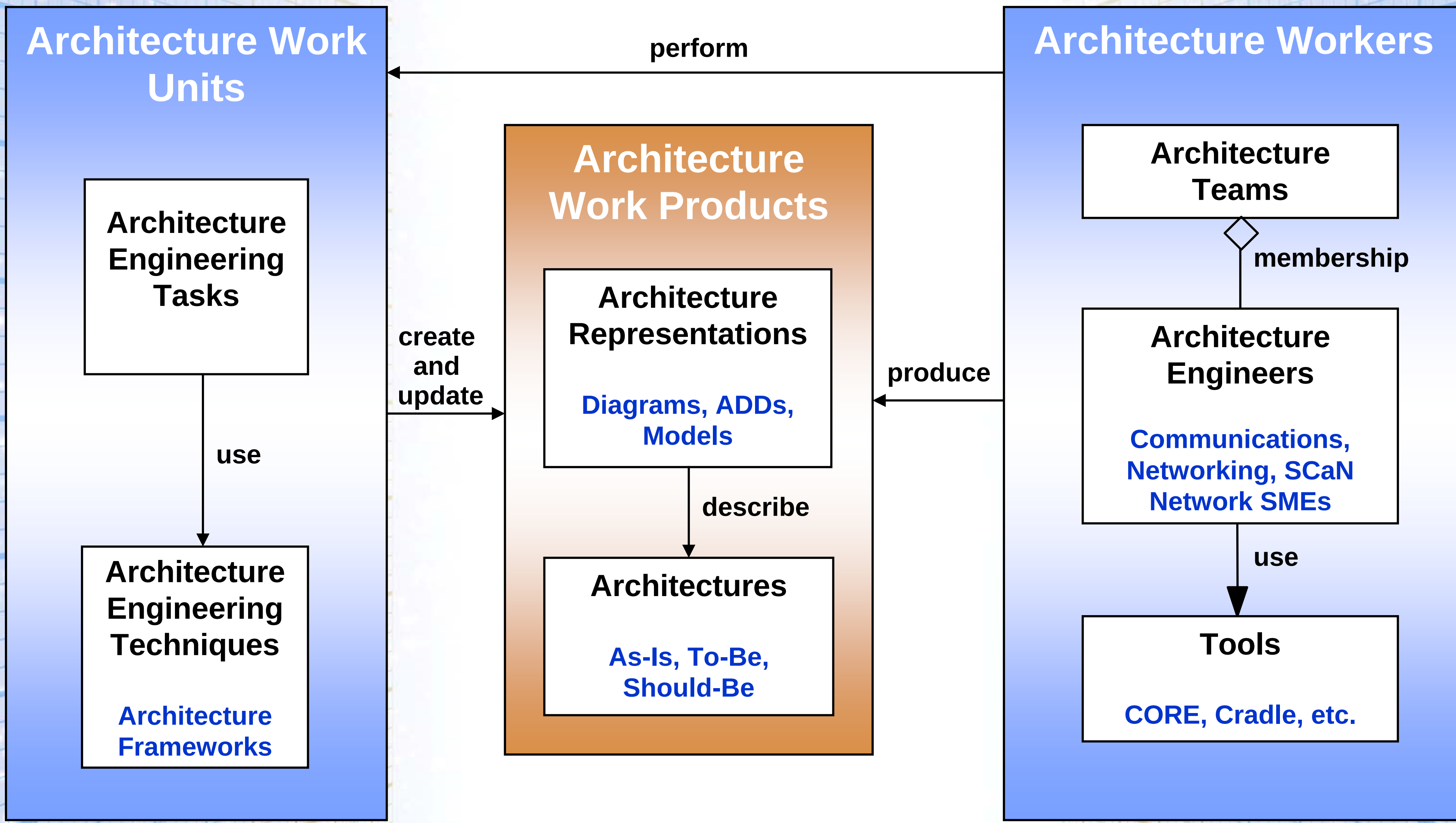
Architecture Frameworks Used by NASA Architecture Teams



Combined View/Viewpoints Used

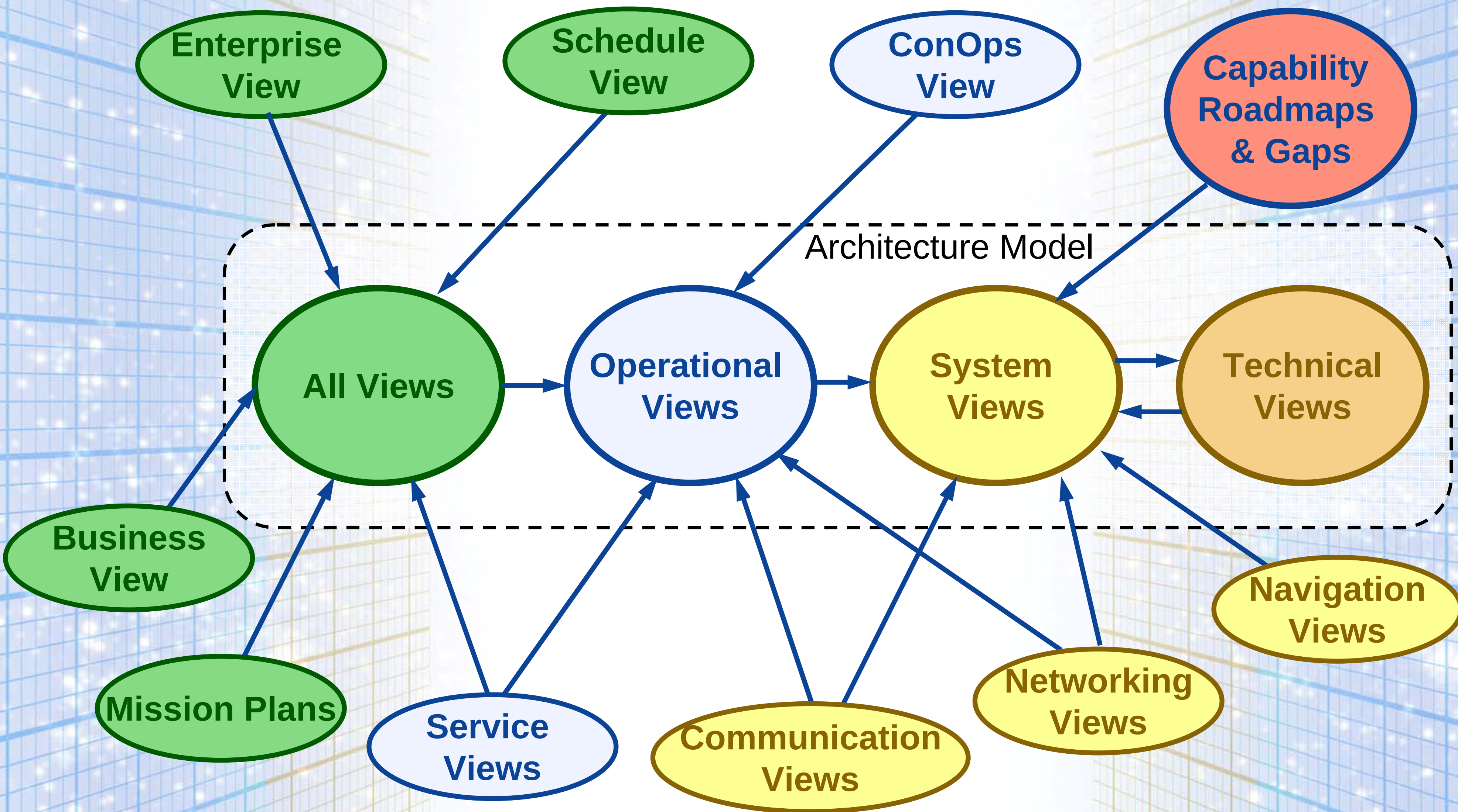
Architecture Development Method

Systems Architecture Engineering Components*



*adapted from: Donald Firesmith (CMU Software Engineering Institute) Method Framework for Engineering System Architectures (MFESA)

Relationships Among Perspectives With the Model Architecture *



* Varies from program to program

SCaN Architecture Representation Method