The Interplanetary Internet:

The Next Frontier in Mobility

Internet Global Summit

INET 2001

Stockholm

6 June, 2001

Interplanetary Internet Special Interest Group:

http://www.ipnsig.org

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Next Generation Internet (NGI) Initiative

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Introduction and overview

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In-situ internetworking

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Interplanetary backbone communications

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Interplanetary dialog and terrestrial relevance

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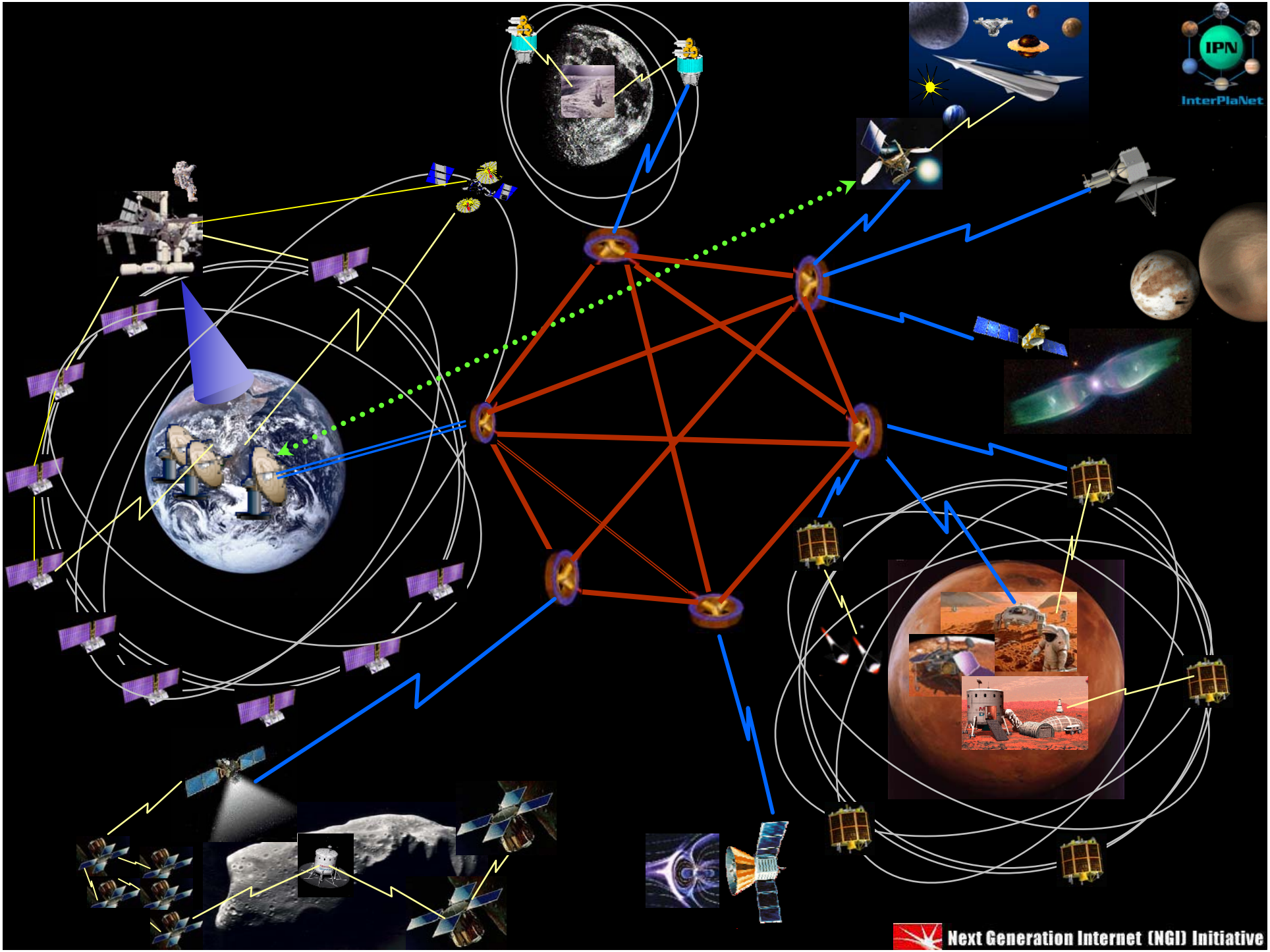
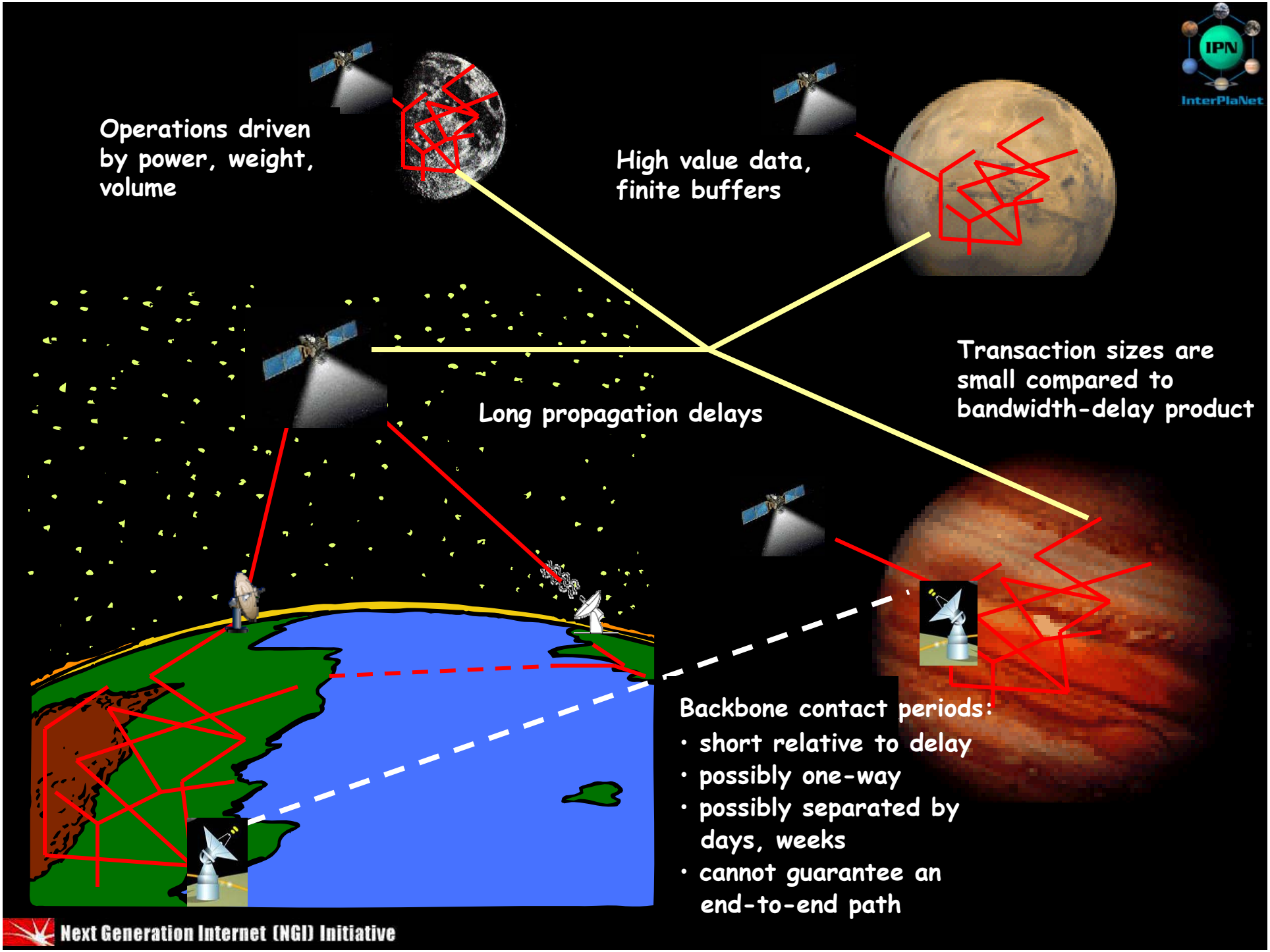
Summary


IPN
InterPlaNet
Next Generation Internet (NGI) Initiative


Operations driven by power, weight, volume
High value data, finite buffers
Transaction sizes are small compared to bandwidth-delay product
Long propagation delays
Backbone contact periods:
• short relative to delay
• possibly one-way
• possibly separated by days, weeks
• cannot guarantee an end-to-end path
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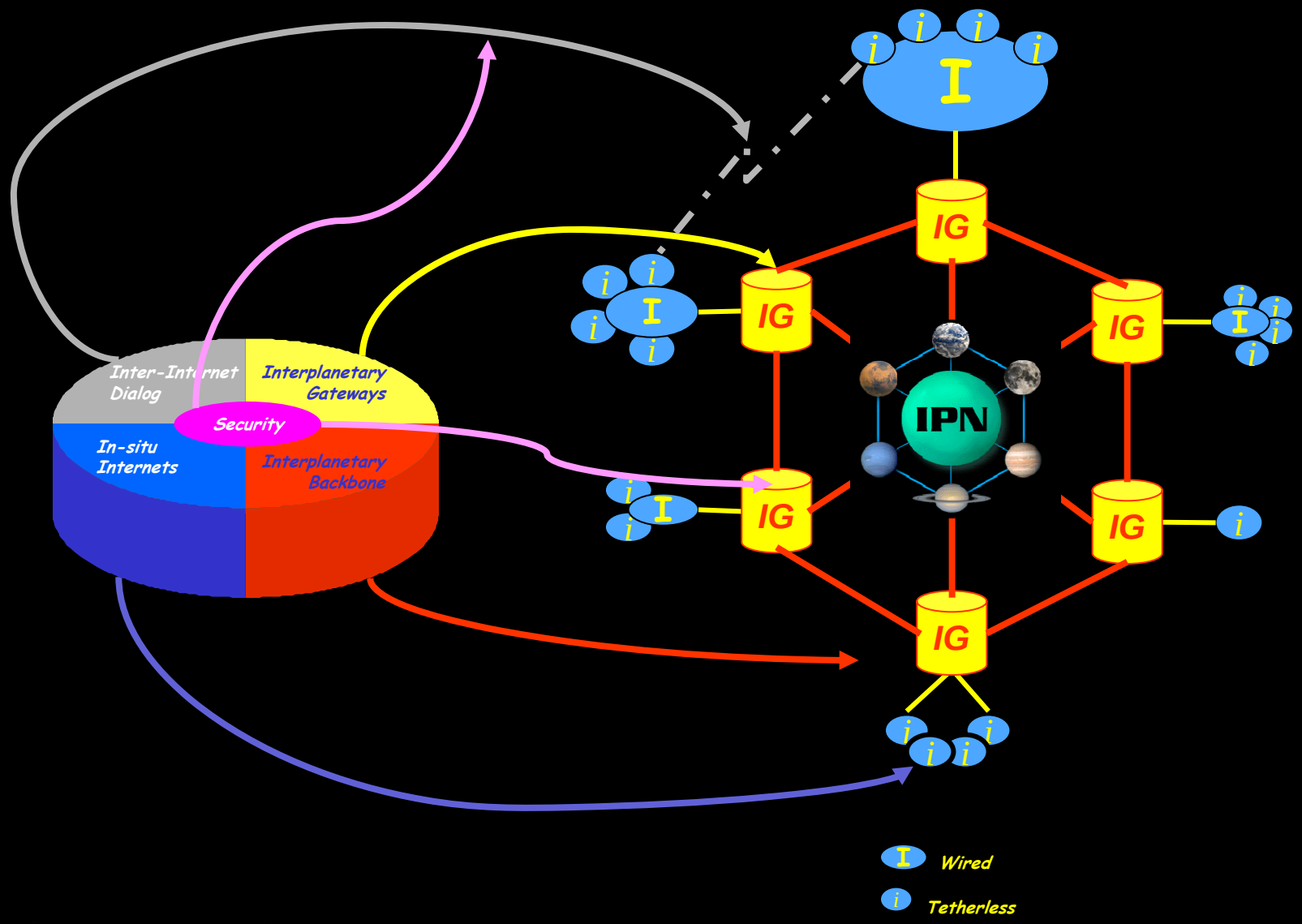
IPN Technology Thrust Areas



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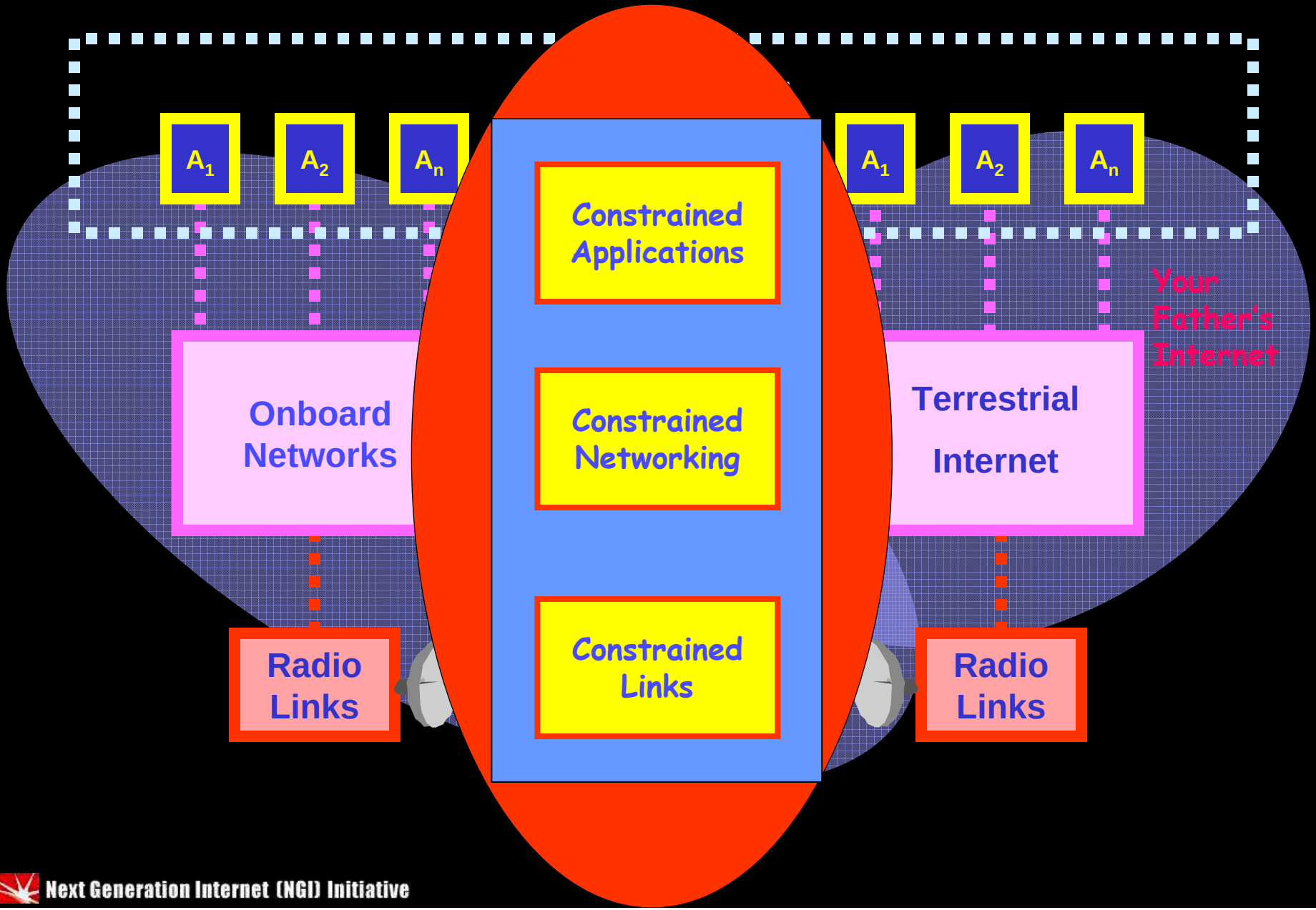
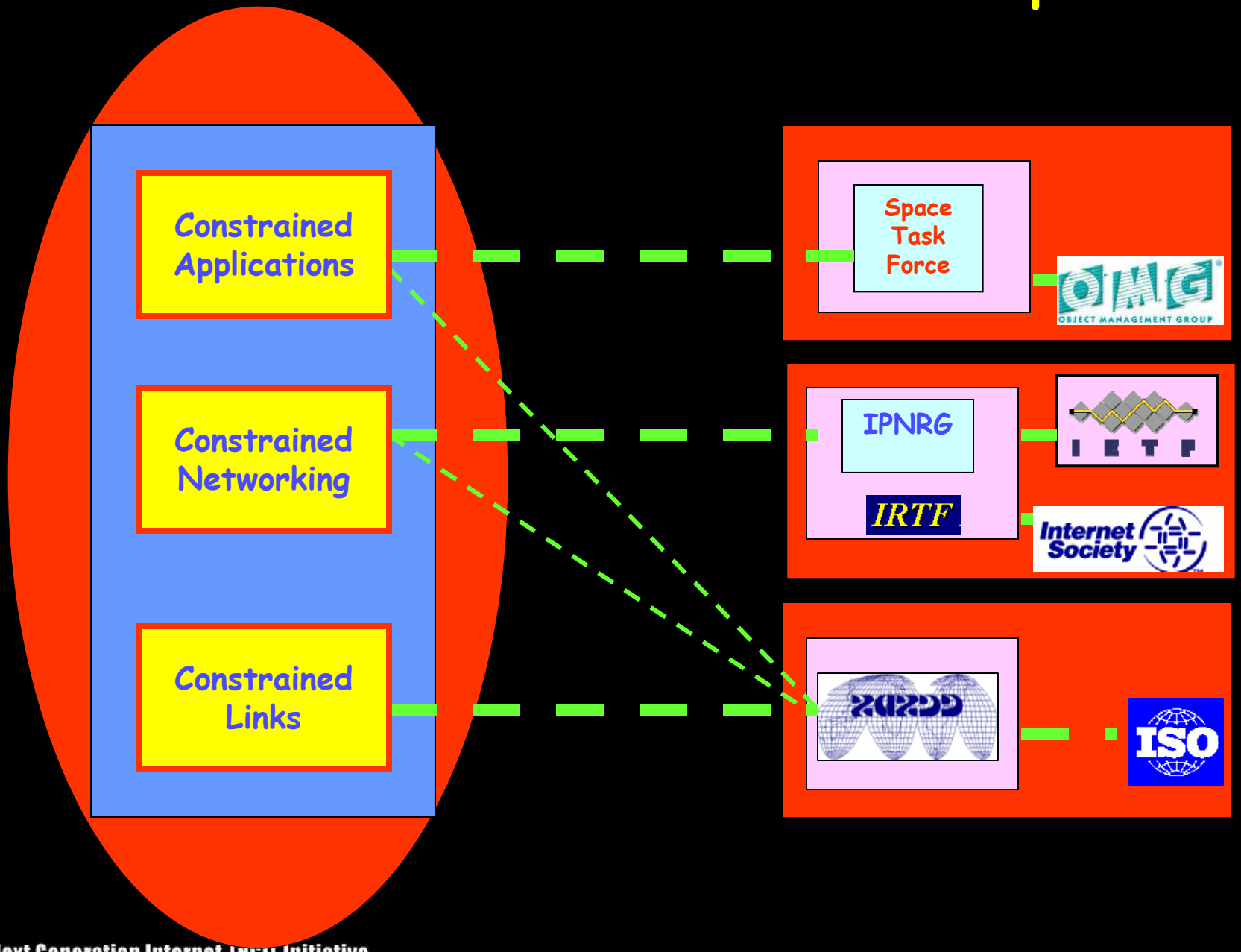
Model of Space/Ground Communications



Current Standardization Options



Consultative Committee for Space Data Systems

Member Agencies

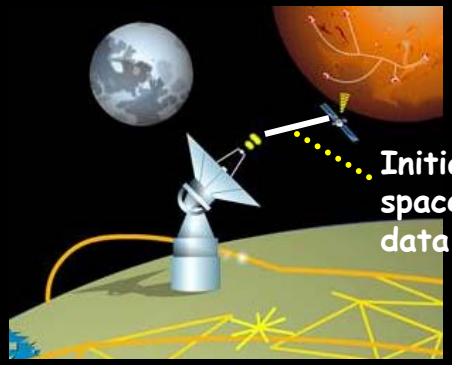
Agenzia Spaziale Italiana (ASI)/Italy.
British National Space Centre (BNSC)/United Kingdom.
Canadian Space Agency (CSA)/Canada.
Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
Centre National d'Etudes Spatiales (CNES)/France.
Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V. (DLR)/Germany.
European Space Agency (ESA)/Europe.
Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
National Aeronautics and Space Administration (NASA HQ)/USA.
National Space Development Agency of Japan (NASDA)/Japan.

Observer Agencies

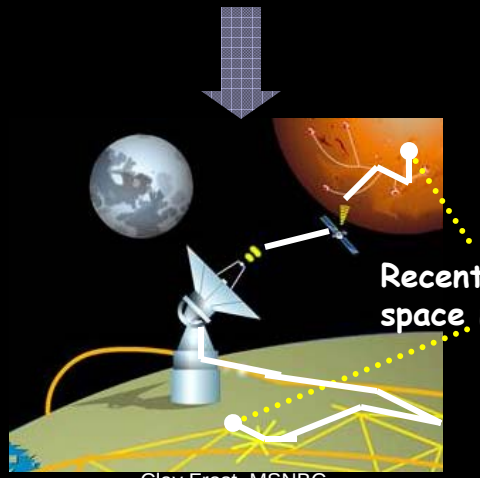
Australian Space Office (ASO)/Australia.
Austrian Space Agency (ASA)/Austria.
Belgian Science Policy Office (SPO)/Belgium.
Centro Tecnico Aeroespacial (CTA)/Brazil.
Chinese Academy of Space Technology (CAST)/China.
Communications Research Laboratory (CRL)/Japan.
Danish Space Research Institute (DSRI)/Denmark.
European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
European Telecommunications Satellite Organization (EUTELSAT)/Europe.
Hellenic National Space Committee (HNSC)/Greece.
Indian Space Research Organization (ISRO)/India.
Industry Canada/Communications Research Centre (CRC)/Canada.
Institute of Space and Astronautical Science (ISAS)/Japan.
Institute of Space Research (IKI)/Russian Federation.
KFKI Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
MIKOMTEK: CSIR (CSIR)/Republic of South Africa.
Ministry of Communications (MOC)/Israel.
National Oceanic & Atmospheric Administration (NOAA)/USA.
National Space Program Office (NSPO)/Taiwan.
Swedish Space Corporation (SSC)/Sweden.
United States Geological Survey (USGS)/USA.

The Consultative Committee for Space Data Systems (CCSDS) is an international voluntary consensus organization of space agencies and industrial associates interested in mutually developing standard data handling techniques to support space research, including space science and applications

http://www.ccsds.org



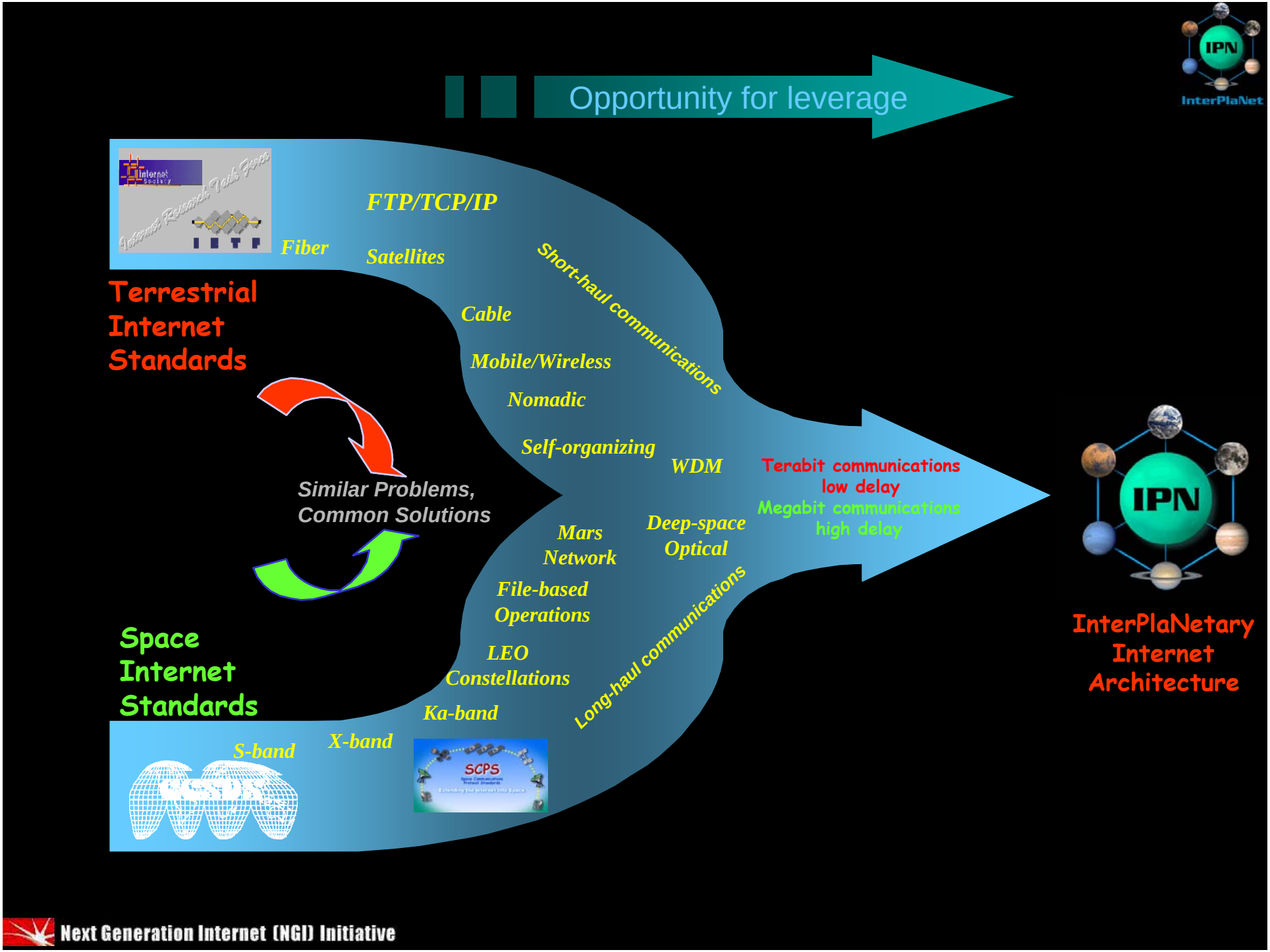
Initial focus:
space/ground
data link protocols

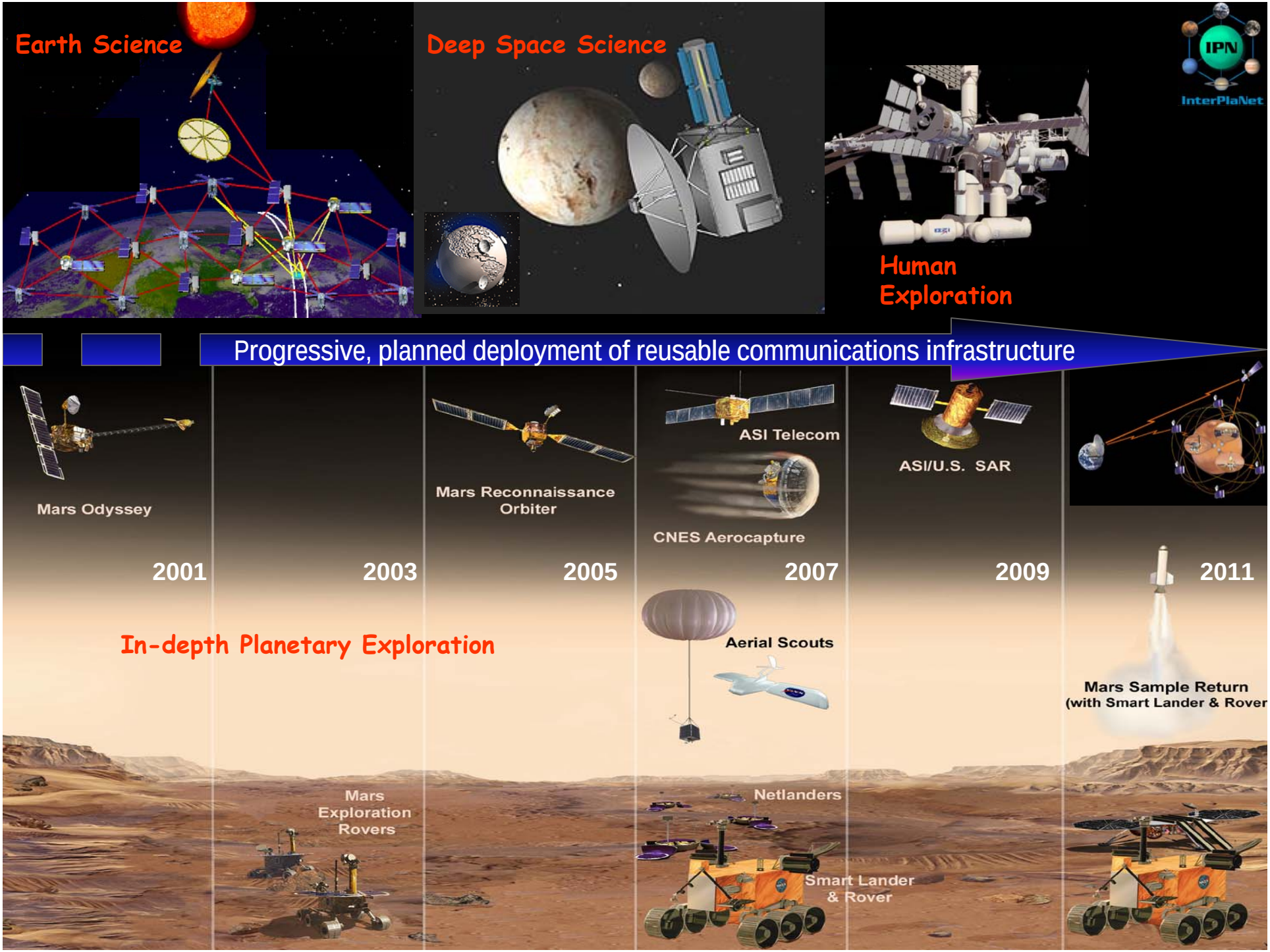


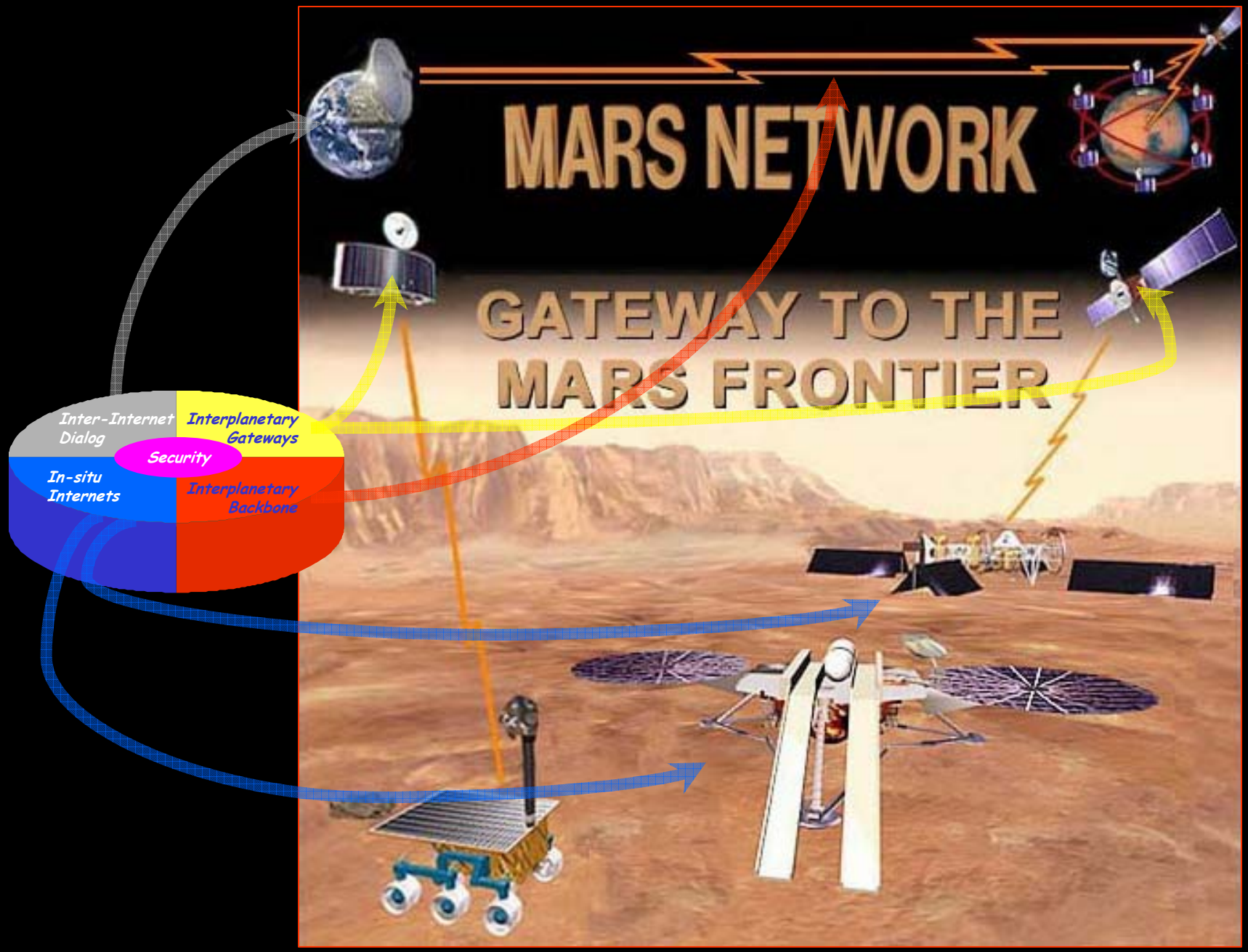
Recent focus:
space networking

Clay Frost, MSNBC

CCSDS:
The Fleet
Space Domain
Spacecraft Platforms
On-Board Systems
Space Qualified ASICs
CCSDS
Consultative Committee for Space Data Systems
155 missions, and counting
Ground Domain
Commercial Ground Networks
Command & Telemetry Data Processing
Space Link Extension Forward and Return Services
Astro-E
INTEGRAL
Gravity Probe B
Lunar-A
EOS LAM-2
EOS AM-2
Selene
JASON
SIRTF
MAP (MIDEX-02)
CHAMP
ERS-1
EOS PM-2
Solar-B
ETS-VIII
QuikSCAT
EOS PM-1
SAMPEX (SMEX-1)
Radarsat
EOS LAM-1
Astro-F
Muses-C
ROSETTA
EOS CHEM-1
GALEX (SMEX 7)
Spacelab-Deutsche 2
ERS-2
FAST (SMEX-2)
METOP 1
International Space Station (ISS)
Mars 98 Orbiter
Mars 98 Lander
Planet-B
ROCSAT-1
EURECA
ISO
Hotbird-3
HESSI (SMEX 6)
VCL (ESSP-01)
IMAGE (MIDEX-01)
Genesis (Discovery 5)
Cluster II
STRV-1 A/B
Cassini
TEAMSAT
YES
ARTEMIS
STENTOR
Rossi XTE
XMM
ALOS
CATSAT (STEDI 3)
ENVISAT-1
ABRIXAS
Landsat-7
BeppoSAX
ADEOS-2
MIR 18 and follow-on missions
MGS
EOS AM-1
OERSTED
WIRE (SMEX-6)
TIMED
NEAR
AXAF-I
TOMS EP-1
MPF
TRMM
DS-1
SNOE
Hotbird 4
EO-1 (NMP-2)
HTV
STRV-1 C/D
TRACE (SMEX-4)
FUSE
ACE
Lunar Prospector
ARIANE 5
Meteor-3M/ SAGE III
SWAS (SMEX-3)


Opportunity for leverage
IPN
InterPlaNet
FTP/TCP/IP
Fiber
Satellites
Short-haul communications
Terrestrial Internet Standards
Cable
Mobile/Wireless
Nomadic
Self-organizing
WDM
Similar Problems, Common Solutions
Terabit communications low delay
Megabit communications high delay
Mars Network
Deep-space Optical
File-based Operations
Space Internet Standards
LEO Constellations
Long-haul communications
Ka-band
S-band
X-band
SCPS
IPN
InterPlaNetary Internet Architecture


Earth Science
Deep Space Science
Human Exploration
IPN
InterPlaNet
Progressive, planned deployment of reusable communications infrastructure
Mars Odyssey
Mars Reconnaissance Orbiter
ASI Telecom
CNES Aerocapture
ASI/U.S. SAR
2001
2003
2005
2007
2009
2011
In-depth Planetary Exploration
Aerial Scouts
Mars Sample Return (with Smart Lander & Rover
Mars Exploration Rovers
Netlanders
Smart Lander & Rover


MARS NETWORK
GATEWAY TO THE
MARS FRONTIER
Inter-Internet Dialog
Interplanetary Gateways
Security
In-situ Internets
Interplanetary Backbone

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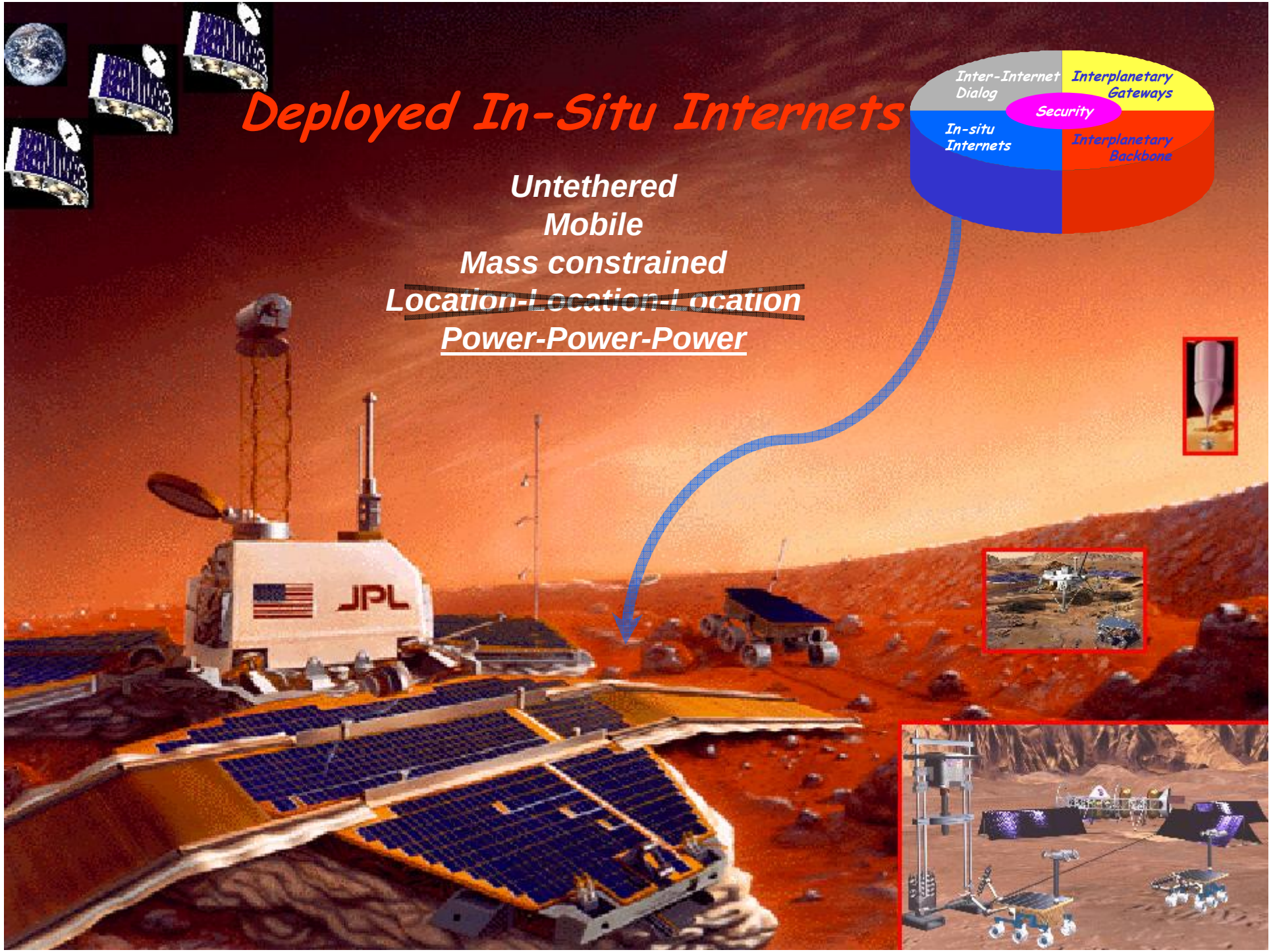
Deployed In-Situ Internets

Untethered
Mobile
Mass constrained
~~Location-Location-Location~~
Power-Power-Power



Deployed Internets: A Broad Range of Possible Configurations

- A single lander with an IPN gateway to a (real or virtual) internal network
- Small number of cooperating robots on planetary surface (e.g. Single lander, single rover)
- Orbiter-to-surface communication and coordination (e.g. sample return recovery)
- Multiple beyond-line-of-sight missions connected by low-orbit communication satellites
- Planet-stationary satellites for relay and gateway functions
- Spacecraft on-board LANs
- The Earth's Internet

Some Functions of Deployed Internets

- Science Data and Telemetry Return
- Command and Control of In-Situ Elements
- Telescience/Virtual Presence
  - Initially back-hauled to earth
  - Secondarily, in support of robotic control of robotic exploration
  - Eventually, in support of human in situ control of robotic exploration

Differences between IPN remotely-deployed internets and the terrestrial Internet

	Terrestrial "Wired"	Terrestrial "MANET"	IPN in-situ "Wireless"
Power availability	Not critical	Important	Of overriding importance
Signal-to-Noise Ratios	Fiber clean	Low SNR f(power, node density)	Very low SNR f(power)
Infrastructure	Fixed	Deployable, mobile	Deployable, mobile
Transmission medium	Fiber, copper	Free space RF, IR	Primarily free space RF
Deployment $	Relatively low	Moderate	High, f(mass)
Operations $	Relatively low	TBD	High, f(reliability)
Repair, upgrade $	Relatively low	TBD	Very high

Power Management is of Preeminent Importance

- *Power availability* affects all aspects of deployed internet operation
  - Solar conversion is the primary power source for foreseeable future
  - Example: The average solar intensity in Mars orbit is 590 W/m2, compared with 1370 W/m2 in Earth orbit
  - Surface-based solar panels are subject to
    - Atmospheric dust limiting available solar energy
    - Dust build-up on/erosion of solar panels, reducing effectiveness over time
    - Location-based reductions in solar intensity
    - Seasonal variations in solar intensity
- Efficiency of communication *at all layers* is required to offset the limitations of power availability

Terrestrial "Edge" Technologies with Potential In-situ Use

Technology	Applications
Directional Links	All power-constrained point-to-point communications (orbiter to surface, lander to rover, etc.)
Directional MANETs, Power Aware Routing	Multi-rover missions, beyond-line-of-sight excursions, "outpost" operations
Sensor Networks	Ultra-low-power, focused experimentation
Schedule-driven routing	Landers supported by low-orbiting satellites
Quality of Service in mobile networks	Resource use optimization; Human presence

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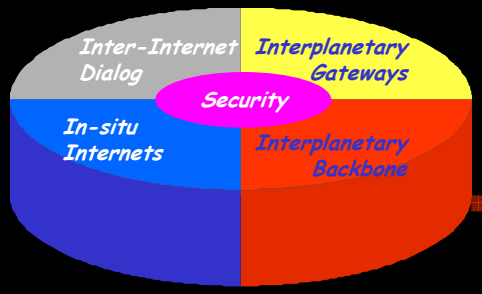

What's a Backbone?

- *A set of high-capacity, high-availability links between network traffic hubs*
  - **Terrestrial backbone links are between hubs like Houston and Chicago.**
  - **Interplanetary backbone links are between hubs like Earth and Mars.**

Differences Between Terrestrial and Interplanetary Backbones

	Terrestrial	Interplanetary
Delay (sec)	< .1	10 to 10,000
Connectivity	Wired; structural, continuous	Radiant; operational, intermittent
Medium	Copper, glass	Space; high BER
Deployment $	“low”	Very high
Operations $	“low”	High (power is costly)
Repair, upgrade $	“low”	Very high

What These Differences Imply

- Cost per second of transmission is very high, so…
  - ***Don't waste transmission opportunities.***
- Intra-backbone connectivity might never be end-to-end, so…
  - ***Don't rely on end-to-end connectivity*** for protocol operations. Use store-and-forward techniques.
- End-to-end round trip time may vary from minutes to *weeks, so…*
  - ***Don't rely on negotiation*** or other conversational protocol mechanisms; by the time a conversation converges, the reason for it may have passed. Make protocol decisions autonomously, locally.

Resulting Backbone Differences

	Terrestrial	Interplanetary
Transport	TCP	bundling
Network	IP	bundle routing
Link	SONET	“LTP” / CCSDS
Physical	Optical fiber	R/F or laser

How Far Have We Gotten?

- There is a working prototype: the **CCSDS File Delivery Protocol (CFDP).**
  - Architecturally very similar to IPN.
  - International standard, four experimental implementations.
  - Baselined for Deep Impact mission, potentially others.
- But CFDP was designed to support individual space flight missions, not to serve as the infrastructure for a permanent, general-purpose network.
  - Addressing scheme is simple but limited.
  - Application, transport, network, and reliable link layers are combined into a single protocol, which only does file transfer.
- Specification of proposed IPN protocols is under way.

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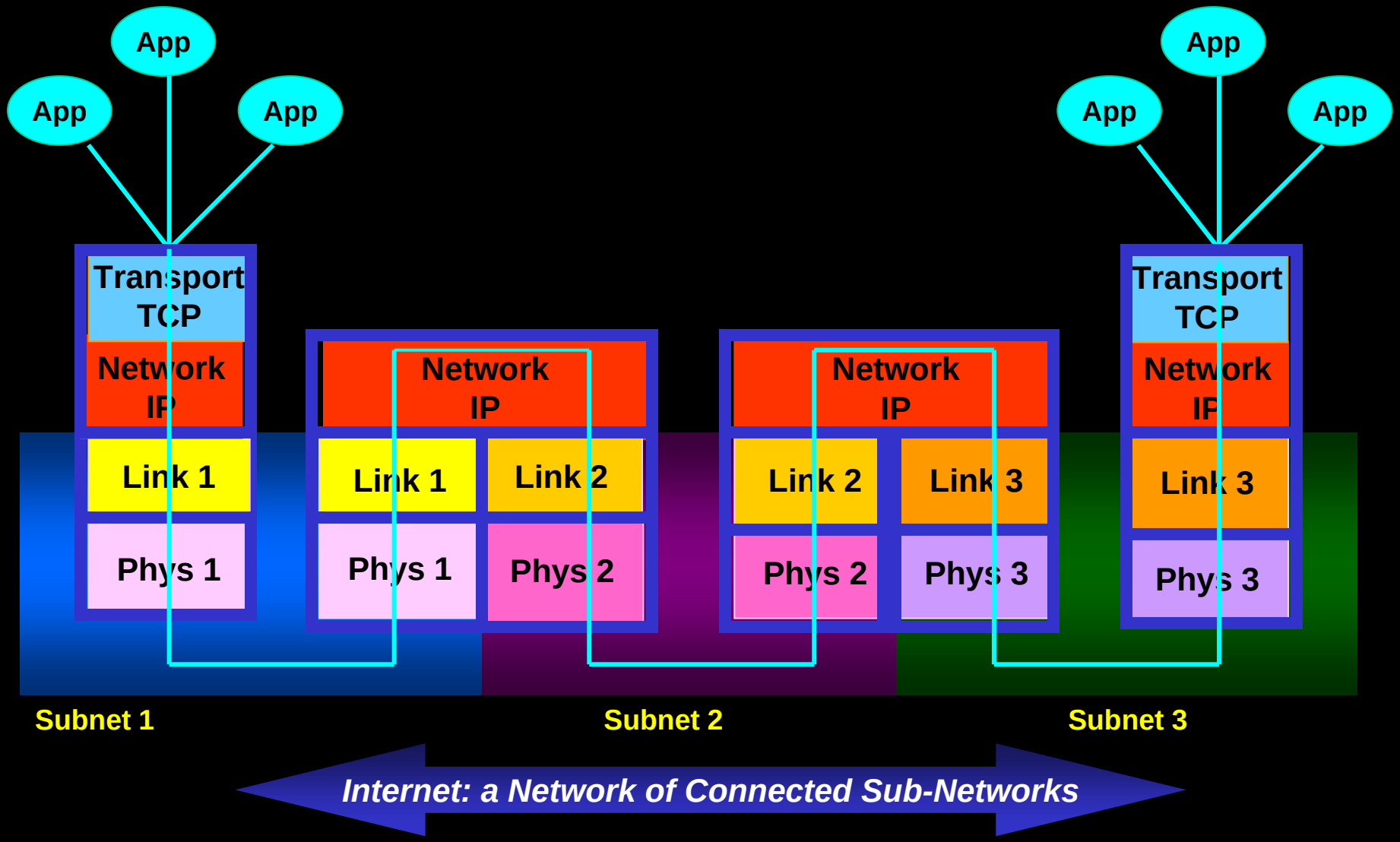
Interplanetary Dialogs: Design Principles

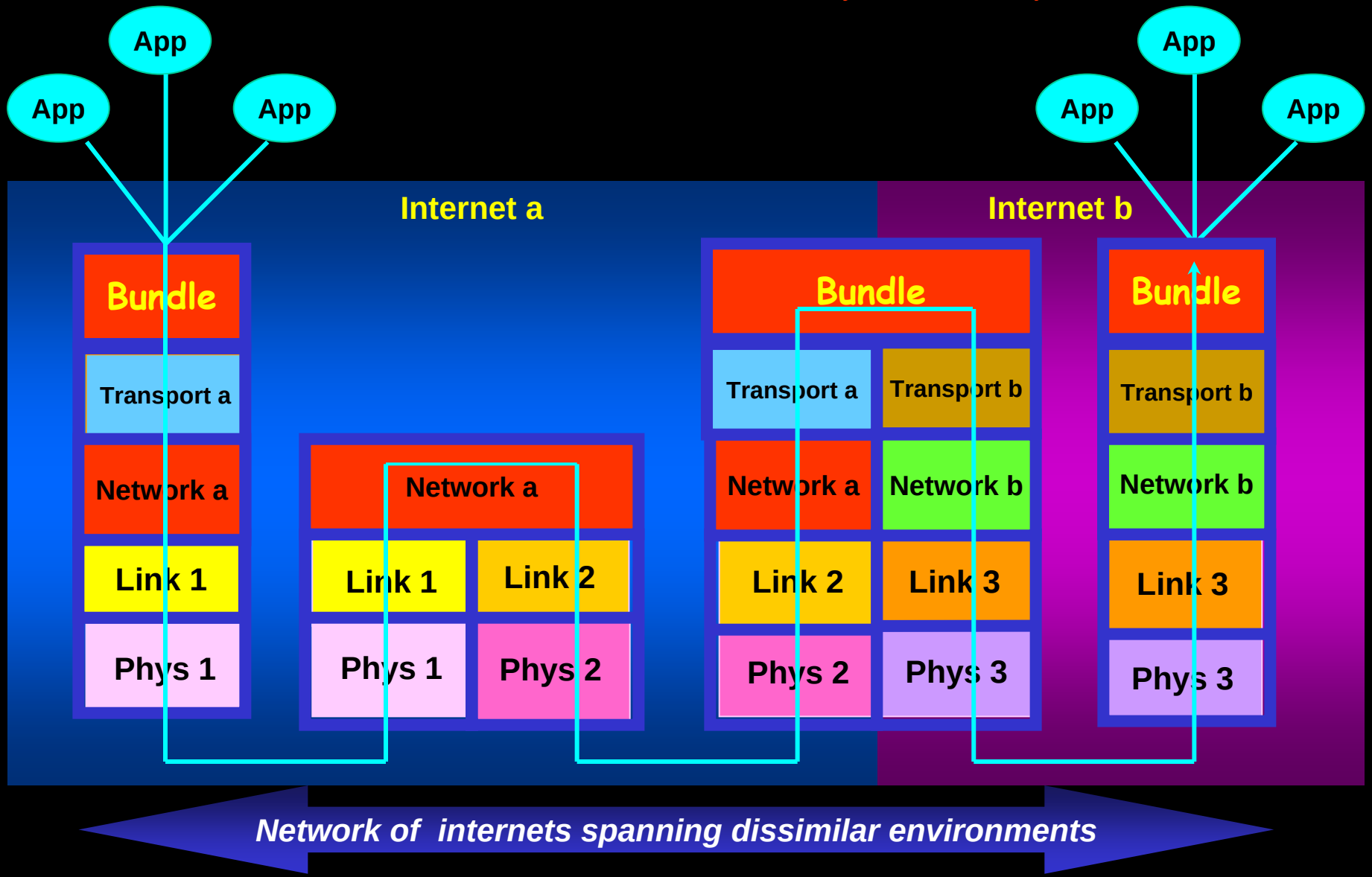
- ***Intermittent connectivity suggests an Email-like architecture***
  - **Common "Handling Instructions" for a data collection**
  - **Network must accommodate the persistence and transfer of state**
- ***Names (not addresses) are the means of reference***
  - **Names have two parts: a *routing* part (specifies the IPN region) and an *administrative* part (specifies the DNS name)**
  - **Routing between IPN regions based upon routing part of the name**
- ***Late-Binding***
  - **Separate addressing domains for each internet; administrative names converted to local addresses only at the destination IPN region**
- ***Indirection***
  - **Inherent dependence on intermediate relay agents**
- ***Custodial transfer***
  - **Intermediate nodes assume possibly-long-term responsibility for data forwarding**
  - **"Bundles" as a common end-to-end transfer mechanism**

IP:
the "Thin Waist" of the Earth's Internet

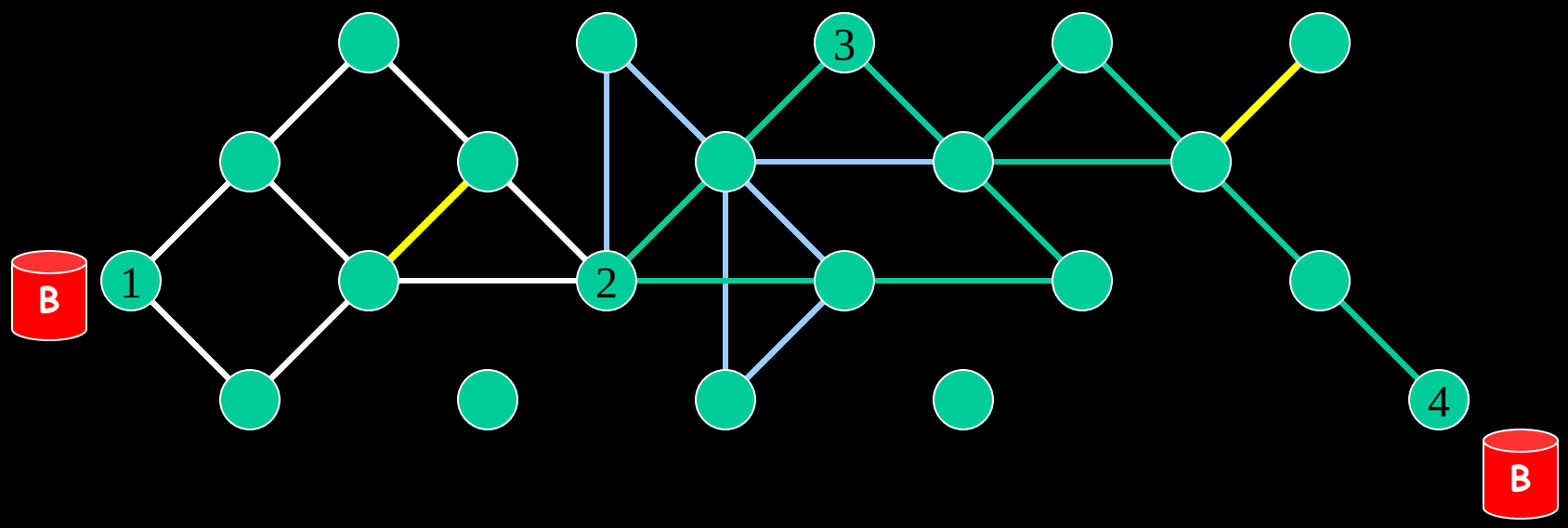


Bundles: A Store and Forward Overlay

The "Thin Waist" of the Interplanetary Internet

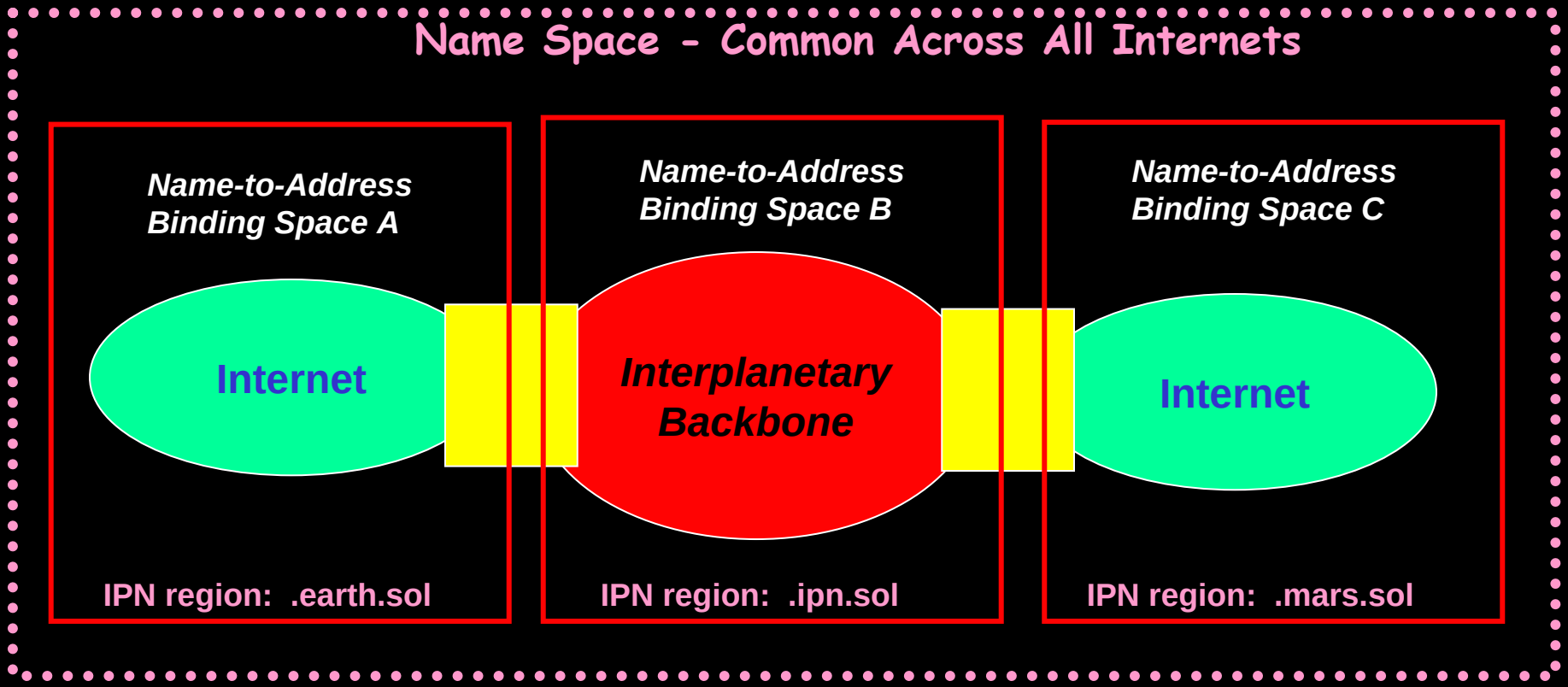


Bundling Spans Temporal Discontinuities Between Networks



"Persistence of Vision"
provides the illusion of
End-to-End connectivity

Single Name Space, Late Name-to-Address Binding(s)



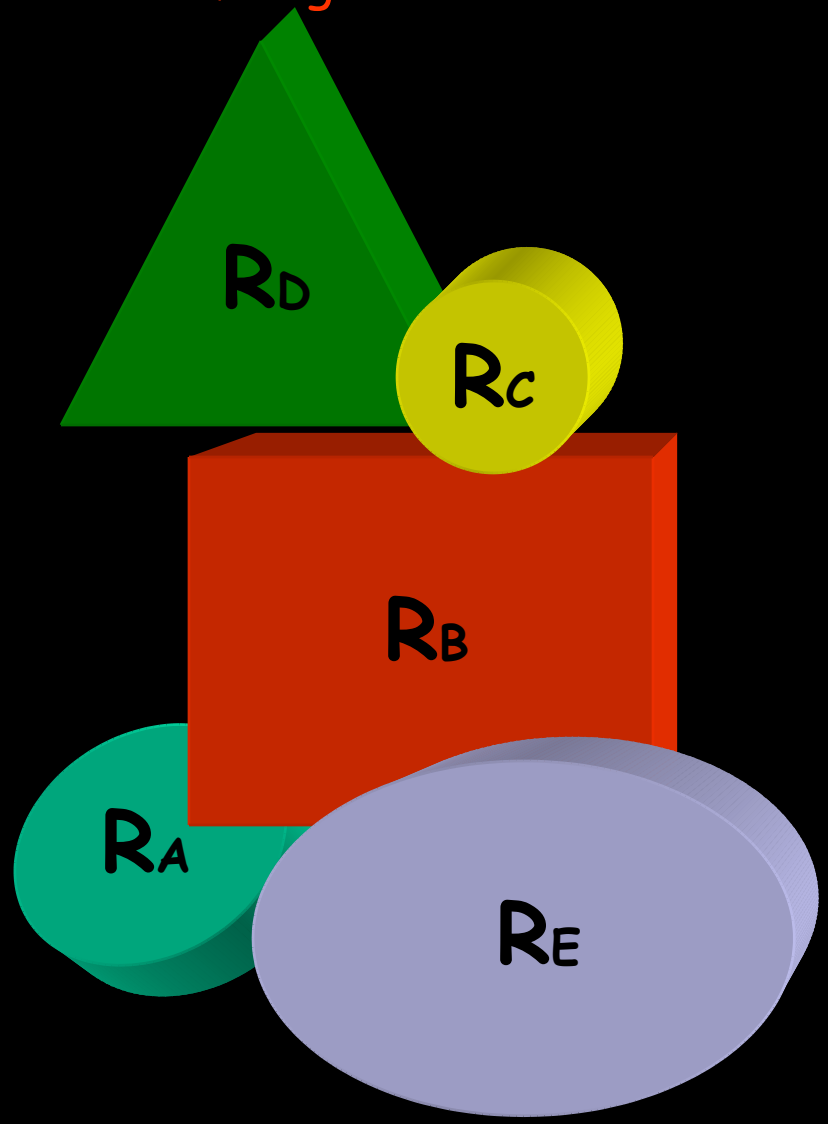
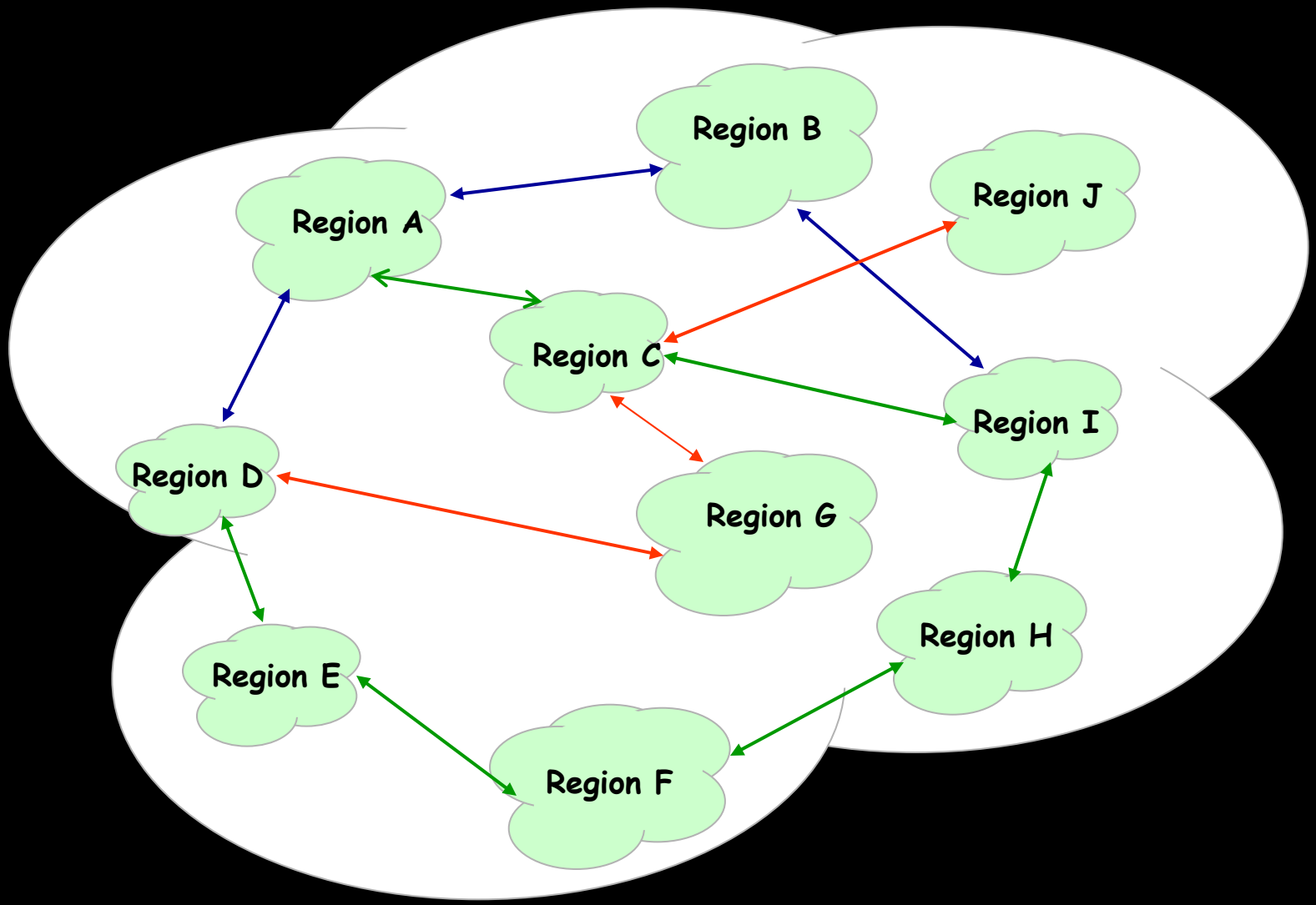
Name: {admin part: www.bughunter.org,
routing part: earth.sol }
Local Address: 137.79.10.232

Name: { admin part: www.rockshop.com,
routing part: mars.sol}
Local Address: 137.79.10.232

The Interplanetary Internet:

An overlay network for interconnection of regional internets

- A *region* is an area where the relevant characteristics of communication are homogeneous
- One can define regions that are based upon:
  - Communications capability
  - Quality of Service Peerings
  - Security (levels of trust)
  - Degree of resource management
  - Etc.
- Traversal of two or more regions will affect the nature of communications



Interplanetary Dialogs In a Terrestrial Context