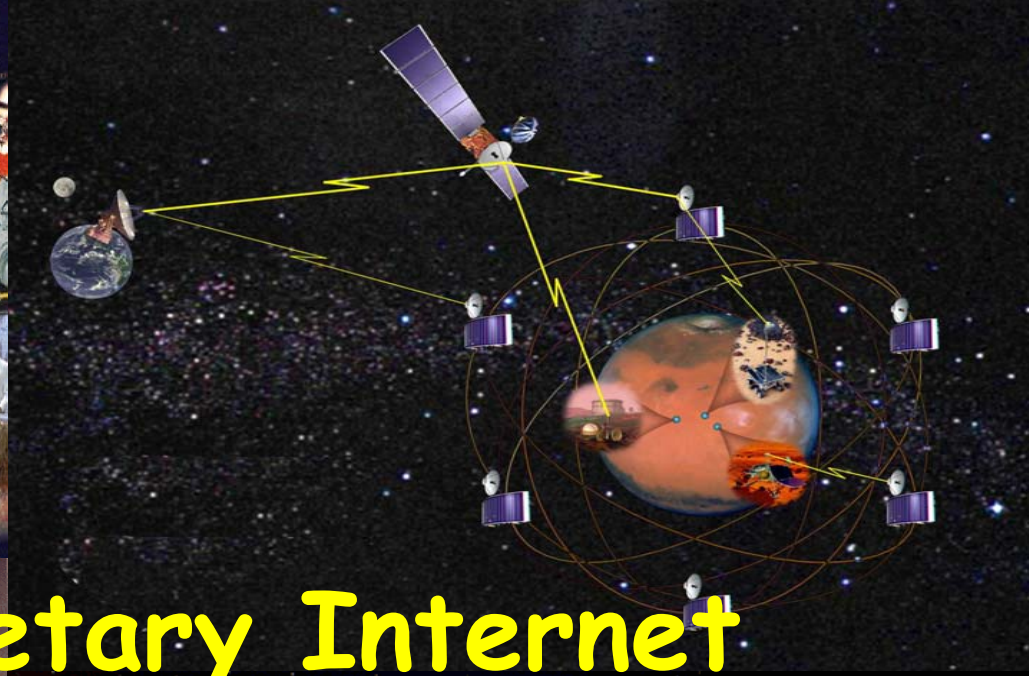


InterPlaNetary Internet

Vint Cerf

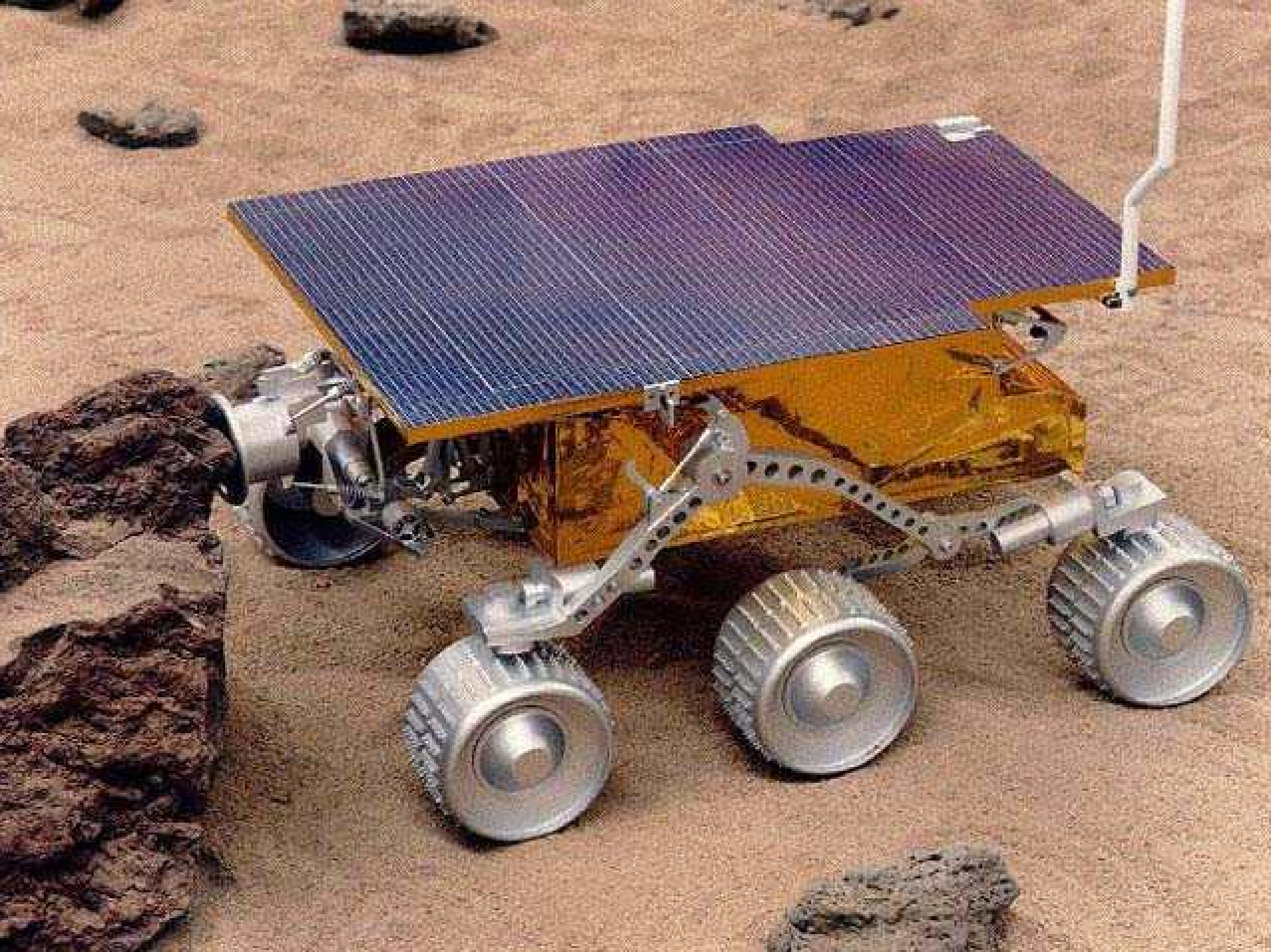
The Aerospace Corporation

9 January 2003

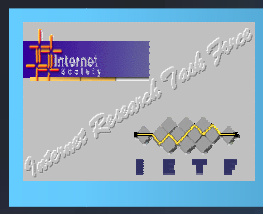
Acknowledgments

- The IPN Team:

- Adrian Hooke, Scott Burleigh, Leigh Torgerson – JPL
- Eric Travis – GST
- Bob Durst, Keith Scott – MITRE
- Howard Weiss – SPARTA
- Kevin Fall – Intel/UC Berkeley
- Vint Cerf - WorldCom



Opportunity for leverage



Terrestrial Internet Standards

Fiber

FTP/TCP/IP

Satellites

Short-haul communications

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

LEO Constellations

Long-haul communications

Ka-band

Space Internet Standards

S-band

X-band

InterPlaNetary Internet Architecture

Historical Conceptual Framework

- Early requirements:
  - pt-pt links, time-slotted access to spacecraft instruments
- Packetized channels (link protocols)
  - Flexible multiplexing, improved error handling
- Simple radio and link level relays
  - DSN to orbiter to lander to rover
- Each communication requirement is a distinct case
  - DSN establishes link to remote target and is scheduled as a series of pt-pt encounters

Conceptual Trends

- Longer mission lifetimes
  - Return to radio-isotopic power
  - Fission reactor power?
- Increasing number of concurrent missions
- Increasing use of sensor *networks*
  - Tandem sensor systems (interferometers)
  - Self-organizing sensor networks on ground communicating among themselves and linking to landers and orbiters by radio
- Increasing use of orbiting communication assets
- Potential for store-and-forward, packet relay operation

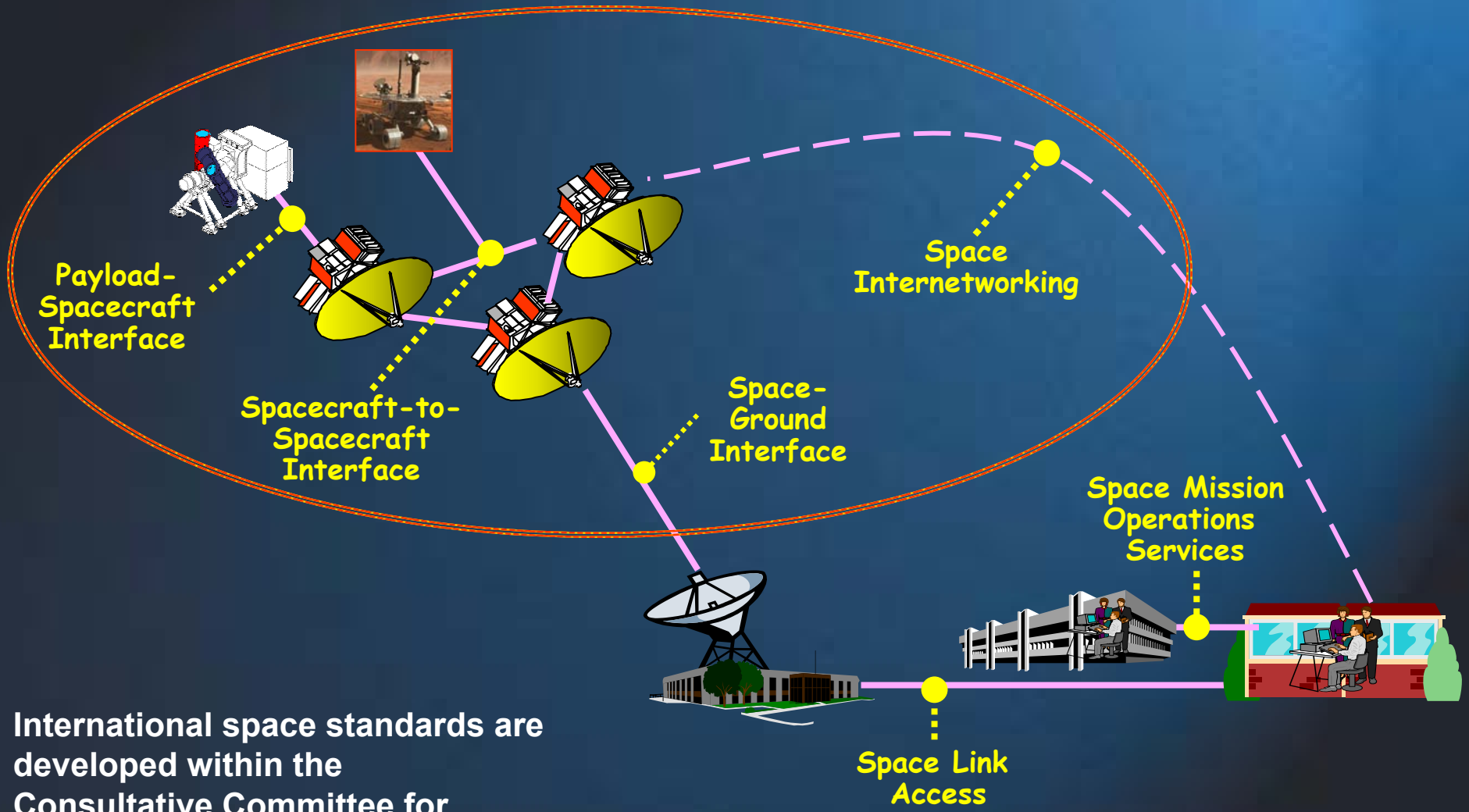
Internet Concepts

- Devices have names and addresses
- Inter-device communication is really inter-process communication (exchanges between running programs)
- Layered protocols, IP core, routing
- Any device can theoretically talk to any over via IP
- Common standards lead to interoperability
- Rich connectivity leads to resilience
- Dedicated links vs episodic links
- Optical communication increases capacity

Critical Notions

- Not all parts of a rich communication architecture need always be engaged
  - e.g. note TCP/IP on Ethernet – no routers!
  - Early arguments about specializing TCP/IP on Ethernet
- “Networking” is increasingly valuable as population of communicating devices/systems increases
- Re-use of communication resources by subsequent missions only works well with standardization
- Network is “accreted” mission-by-mission as assets are flown containing advanced protocol capability
- Potential for persistent links with multiple antennas

The NASA Community: Current IND Standardization Thrusts



International space standards are developed within the Consultative Committee for Space Data Systems (CCSDS)

- *34 space agencies*

Consultative Committee for Space Data Systems

Member Agencies

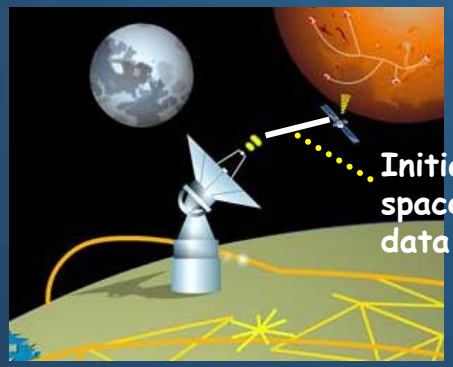
Agenzia Spaziale Italiana (ASI)/Italy.
British National Space Centre (BNSC)/United Kingdom.
Canadian Space Agency (CSA)/Canada.
Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
Centre National d'Etudes Spatiales (CNES)/France.
Deutsche Forschungsanstalt für Luft- und Raumfahrt 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

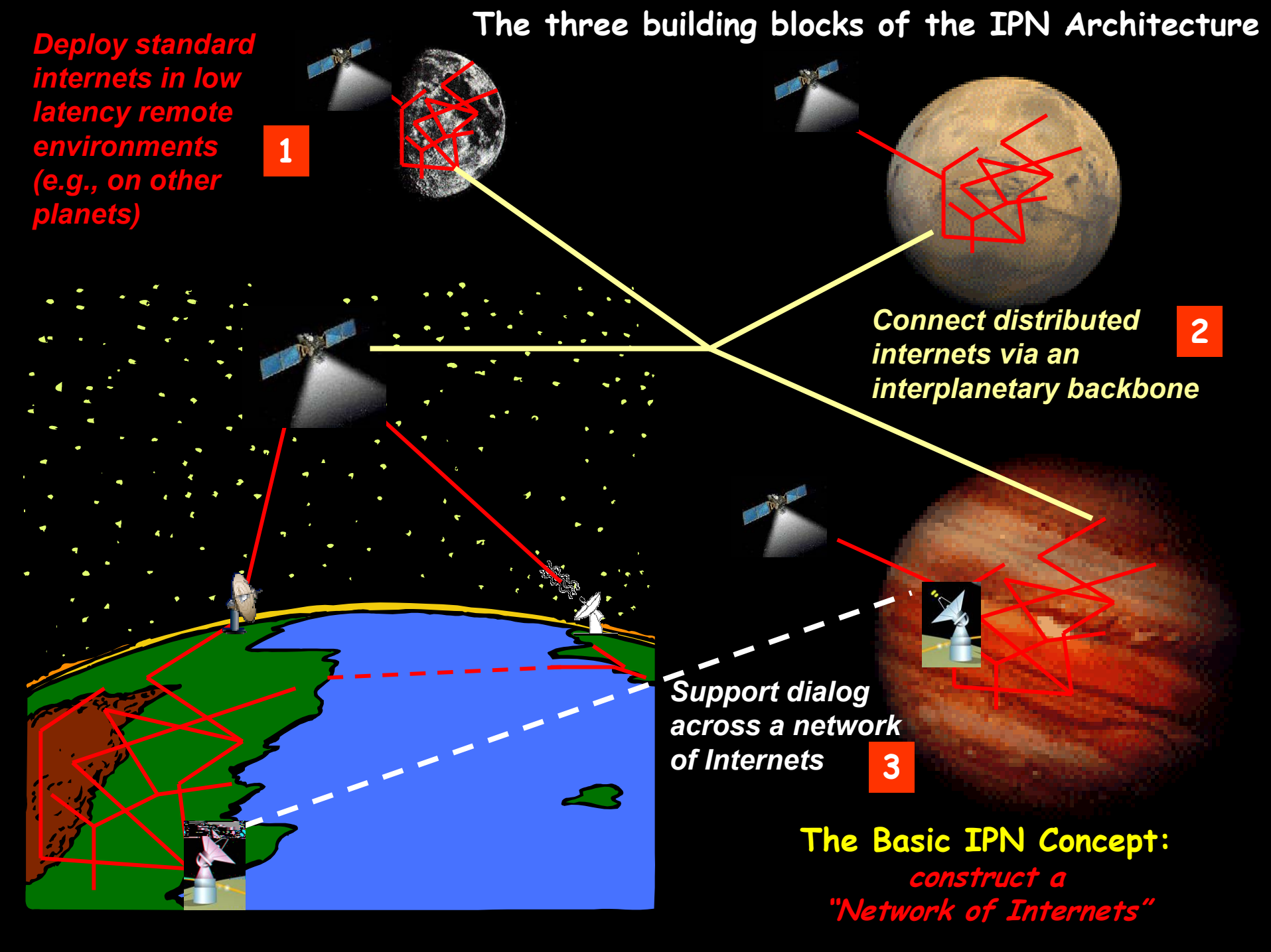
SCPS
Space Communications Protocol Standards
Extending the Internet Into Space
http://www.scps.org

Recent focus: space networking

Clay Frost, MSNBC

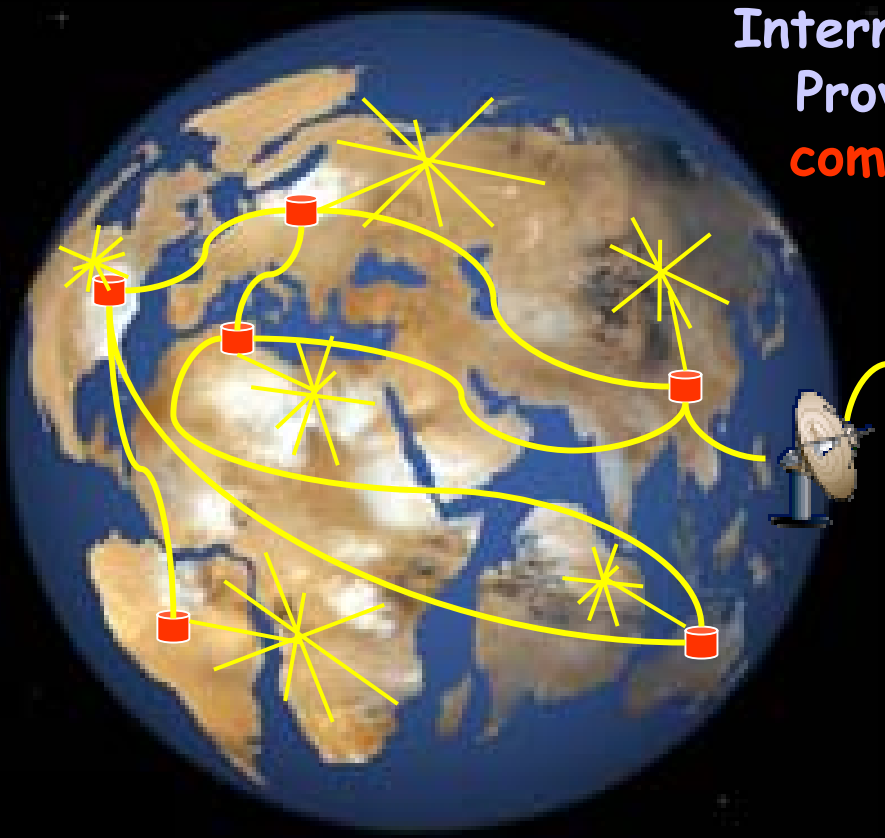

CCSDS:
The Fleet
Space Domain
Spacecraft Platforms
On-Board Systems
Space Qualified ASICs
Astro-E
INTEGRAL
Gravity Probe B
Lunar-A
EOS LAM-2
EOS AM-2
Selene
JASON
SIRTF
MAP (MIDEX-02)
CHAMP
ERS-1
EOS PM-2
Solar-B
ETS-VIII
QuikSCAT
EOS PM-1
SAMPEX (SMEX-1)
Radarsat
EOS LAM-1
Astro-F
Muses-C
EOS CHEM-1
ROSETTA
GALEX (SMEX 7)
Mars 98 Orbiter
Spacelab-Deutsche 2
ERS-2
FAST (SMEX-2)
METOP 1
International Space Station (ISS)
Mars 98 Lander
ROCSAT-1
EURECA
ISO
Planet-B
HESSI (SMEX 6)
VCL (ESSP-01)
IMAGE (MIDEX-01)
Cluster II
STRV-1 A/B
Cassini
STENTOR
Rossi XTE
TEAMSAT
YES
XMM
ALOS
BeppoSAX
CATSAT (STEDI 3)
ENVISAT-1
ABRIXAS
ADEOS-2
Landsat-7
MIR 18 and follow-on missions
NEAR
MGS
EOS AM-1
OERSTED
WIRE (SMEX-6)
TIMED
AXAF-I
TOMS EP-1
MPF
TRMM
DS-1
SNOE
Hotbird 4
EO-1 (NMP-2)
STRV-1 C/D
HTV
TRACE (SMEX-4)
FUSE
Meteor-3M/ SAGE III
SWAS (SMEX-9)
Lunar Prospector
ARIANE 5
Ground Domain
Commercial Ground Networks
Command & Telemetry Data Processing
Space Link Extension Forward and Return Services
CCSDS
Consultative Committee for Space Data Systems
245 missions, and counting

The three building blocks of the IPN Architecture



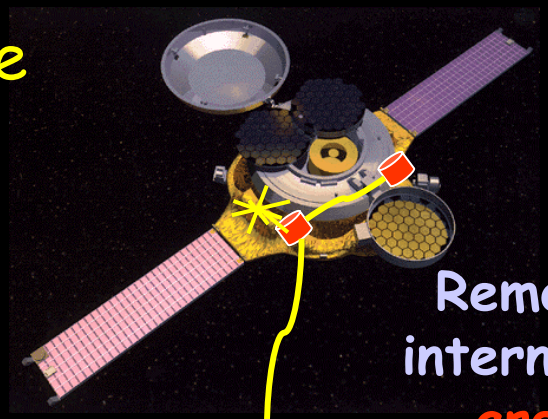
The Basic IPN Concept:
construct a "Network of Internets"

Features of the IPN Architecture



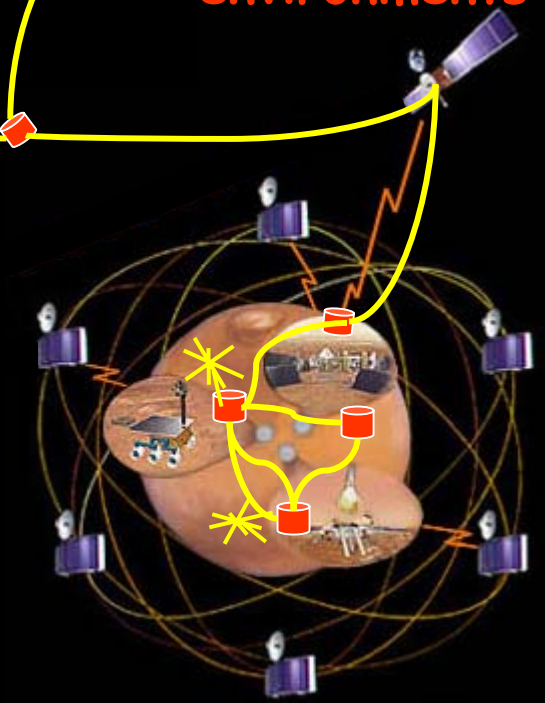
Space exploration becomes fully Internet-based

Missions log-on to the "Interplanetary Internet Service Provider" to communicate

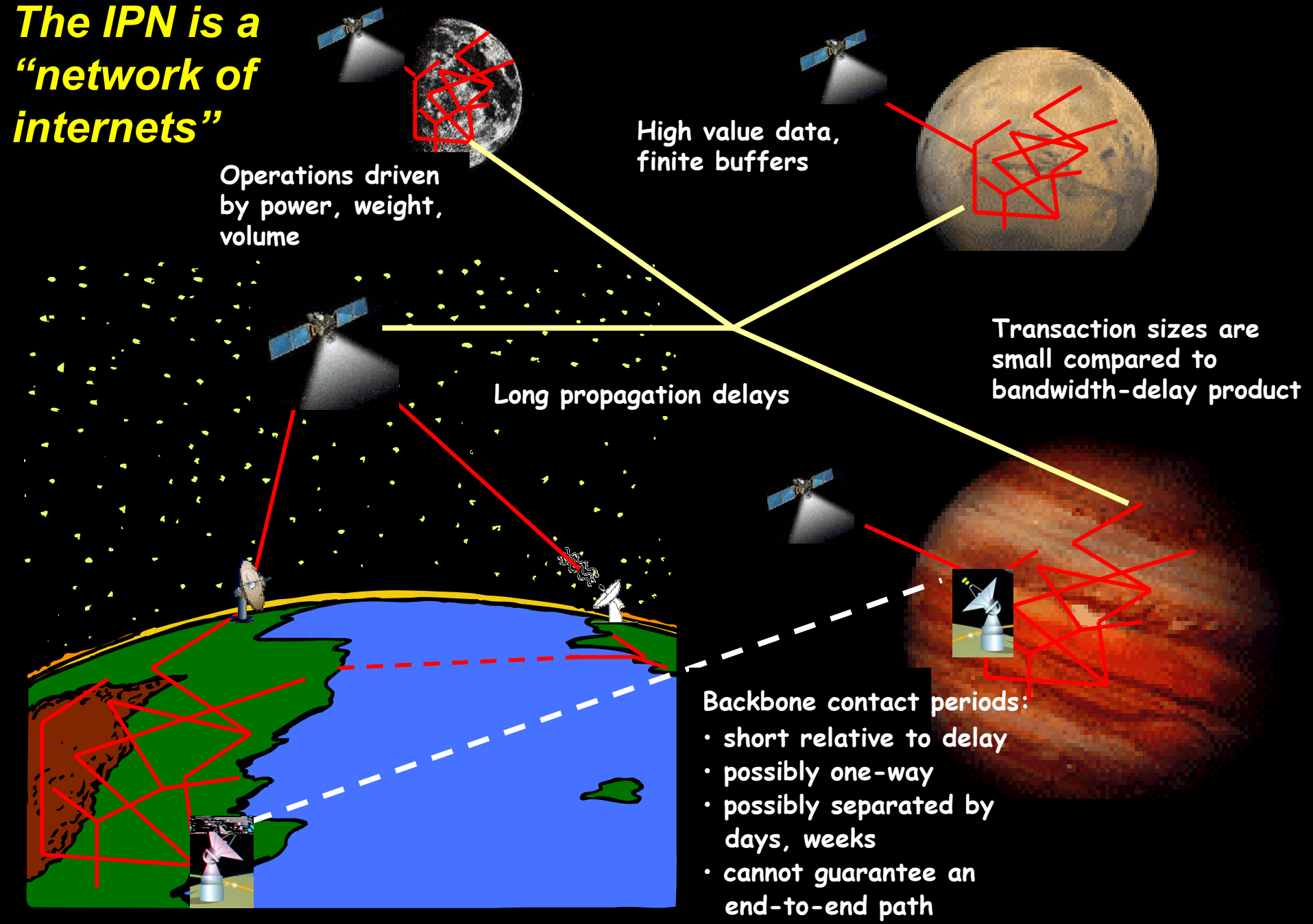


Remote internets are deployed in short delay space environments

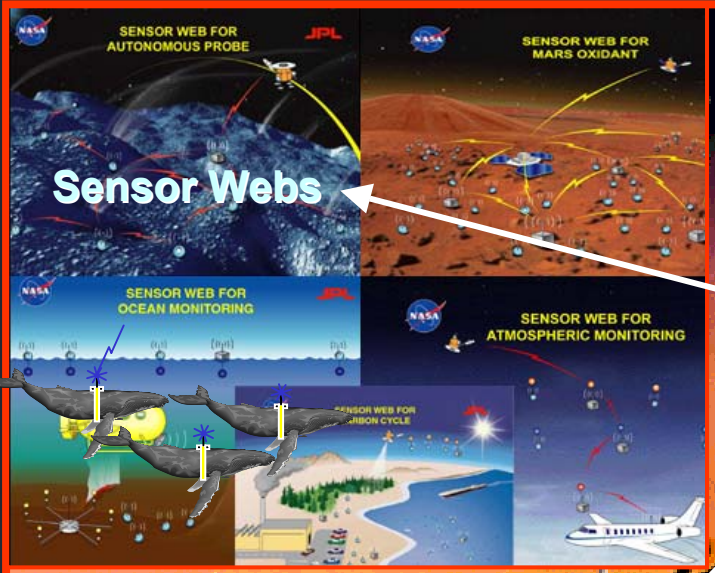
An interplanetary backbone network evolves



The IPN is a "network of internets"



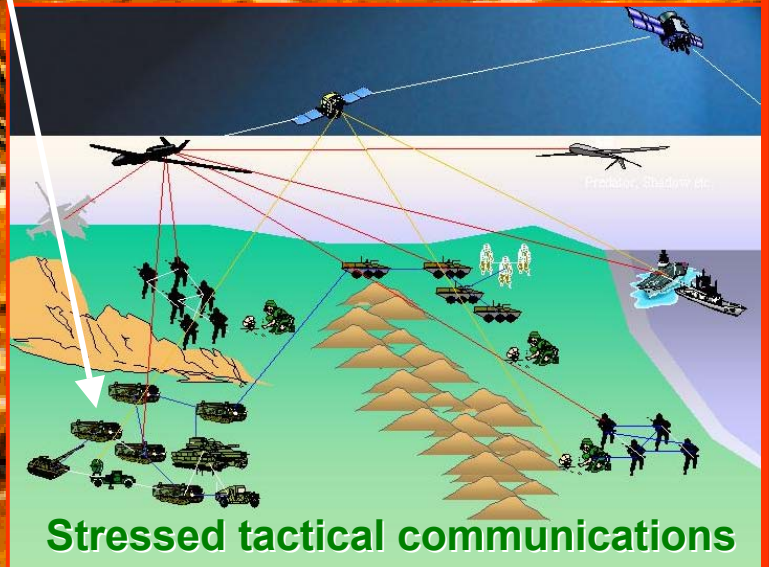
"Delay Tolerant Networking"- reliable communications in highly stressed environments



Sensor Webs

Delay can be introduced by, e.g.,
Propagation
Intermittent connectivity
Lack of resources (power, buffers)
Simplex or asymmetric channels

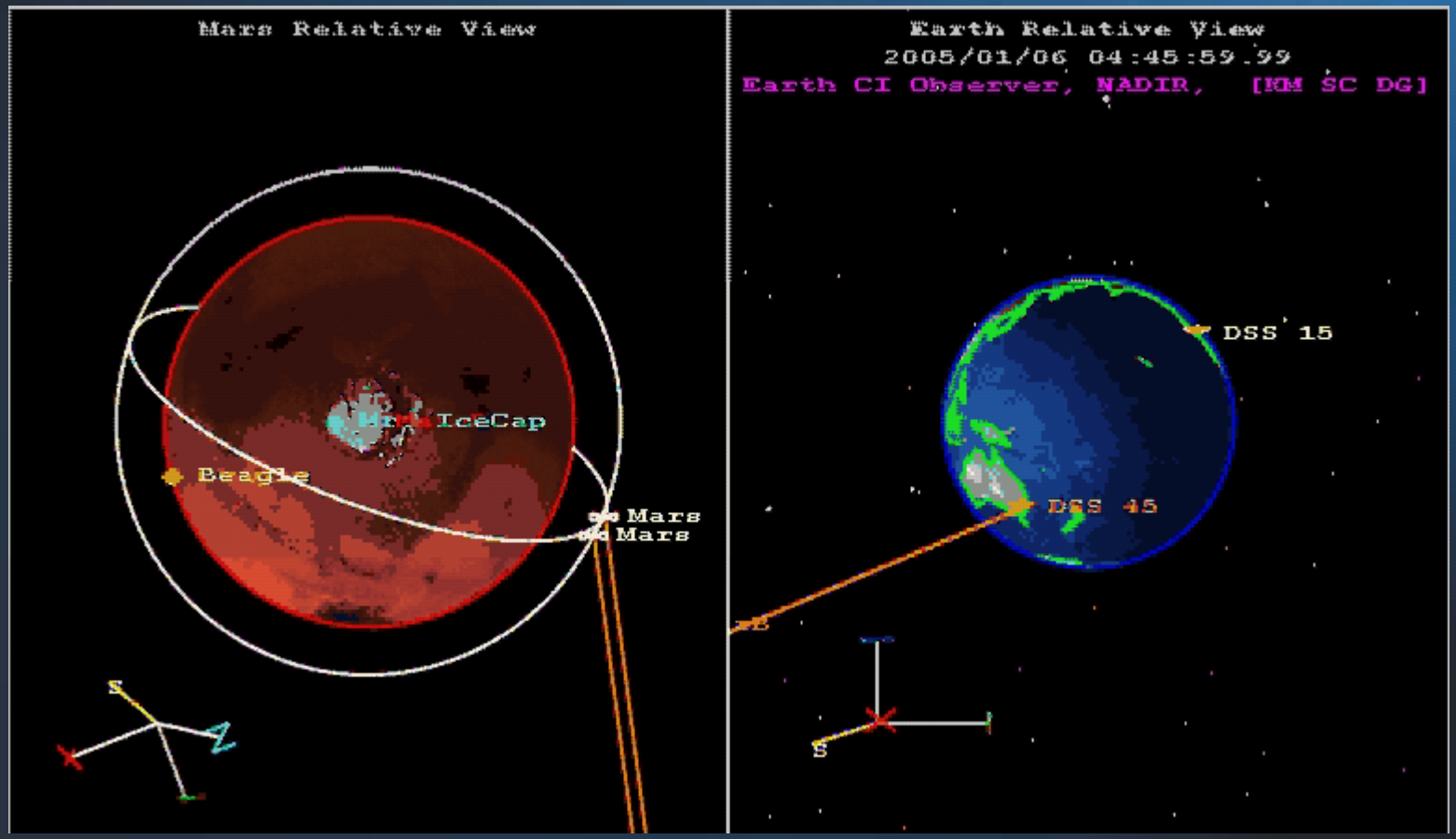
Interplanetary Network



Stressed tactical communications

The Internet is a connected, chatty 'network of networks' based on a wired backbone with negligible delay and errors (with untethered "edges" emerging)

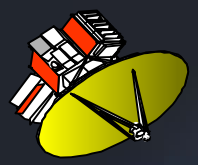
The InterPlaNetary Internet is a disconnected, store-and forward 'network of Internets' based on a wireless backbone with huge delays and error prone links

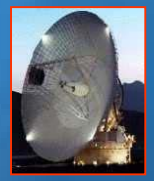


Some of the Hard Problems

- Time synchronization/scheduling
- Antenna pointing(note optical)
- Routing
- Flow Control
- Error handling, retransmission, reassembly
- Persistent communication over operation system reboots
- Mobile robot control in high delay/uncertainty cases
- Naming conventions (DNS doesn’t work: tuples!)
- Mobile spacecraft with multiple “named” processes

Current Space/Ground Communications Protocol Stack





Space Applications

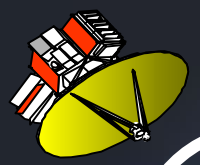
Space Networking

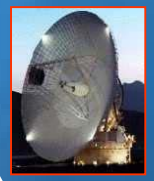
Space Link

Space Channel Coding

Space Wireless Frequency and Modulation

Emerging Space/Ground Communications Protocol Stack





Space Applications

Space File Transfer

Space End-to-End Reliability

Space End-to-End Security

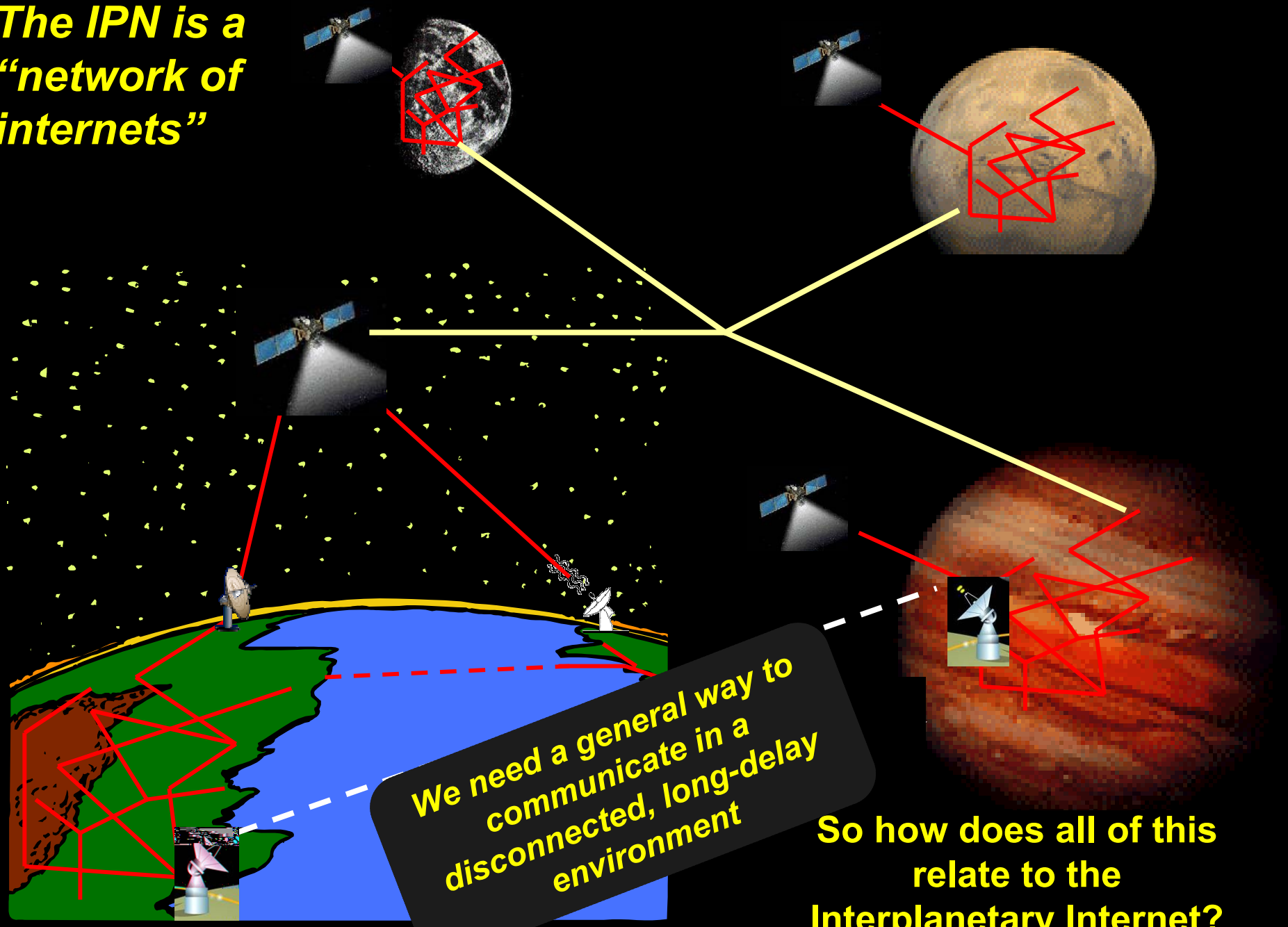
Space Networking

Space Link

Space Channel Coding

Space Wireless Frequency and Modulation

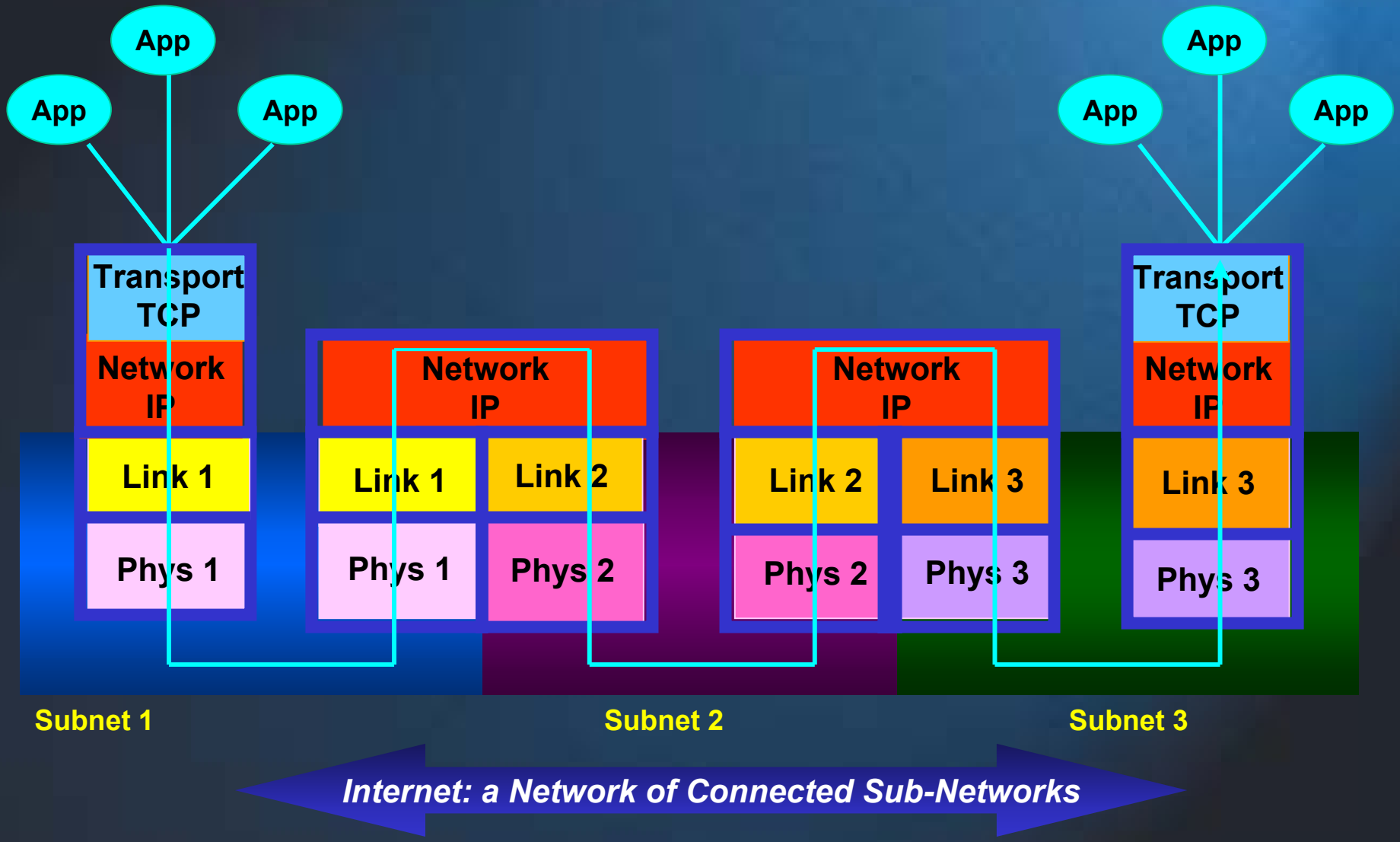
The IPN is a "network of internets"



We need a general way to communicate in a disconnected, long-delay environment

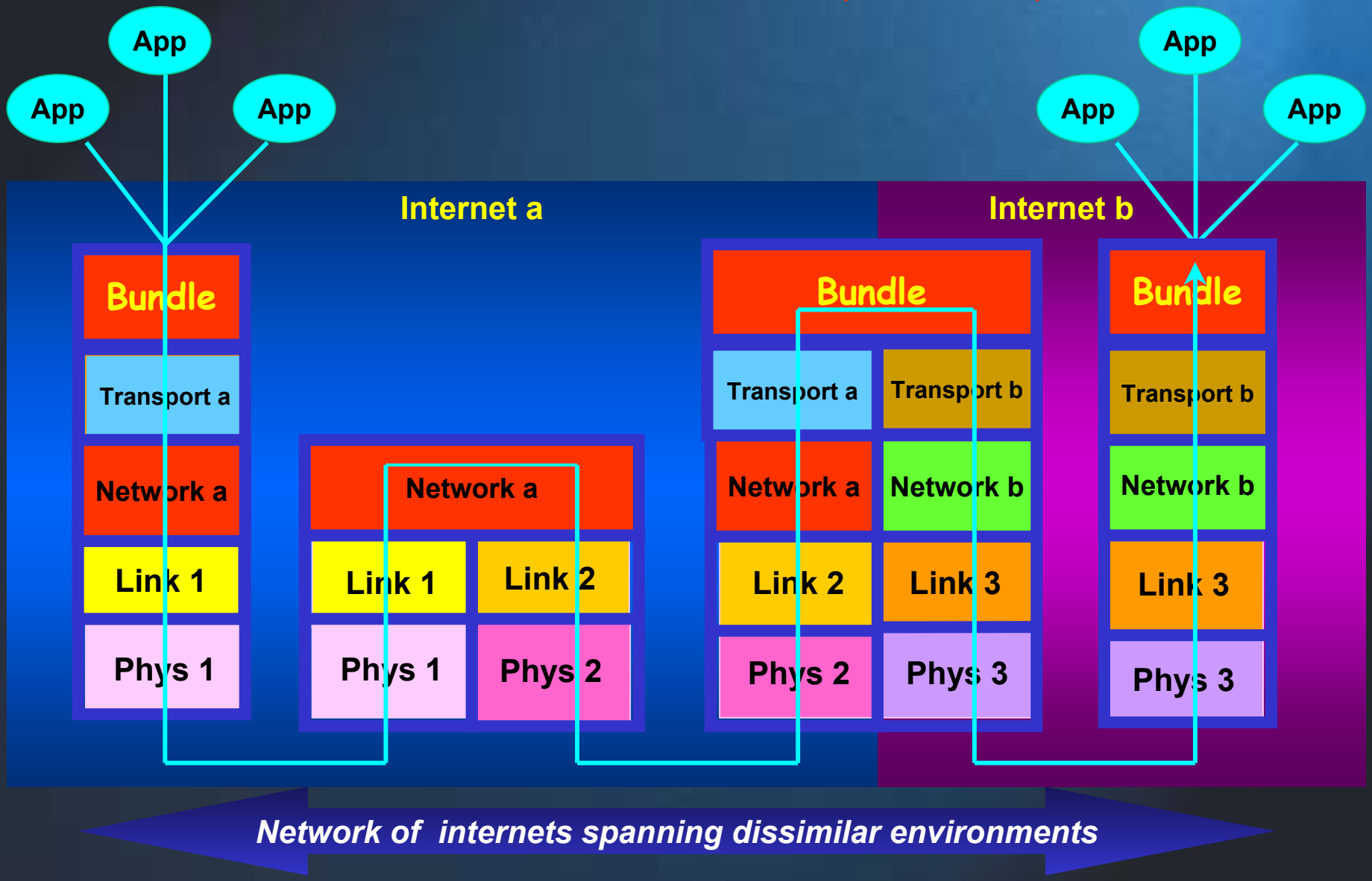
So how does all of this relate to the Interplanetary Internet?

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



Bundles: A Store and Forward Overlay

The "Thin Waist" of the Interplanetary Internet



IPN Architecture
(Internet Draft 1)
May 2001

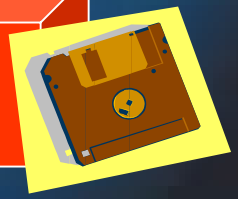
DTN Architecture
(Internet Draft 2)
July 2002

First Draft Bundle Protocol Specification
September 2002

Bundle Specification

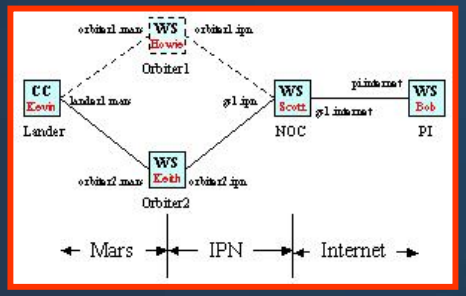
Specifications

Code base



Bundle Prototyping

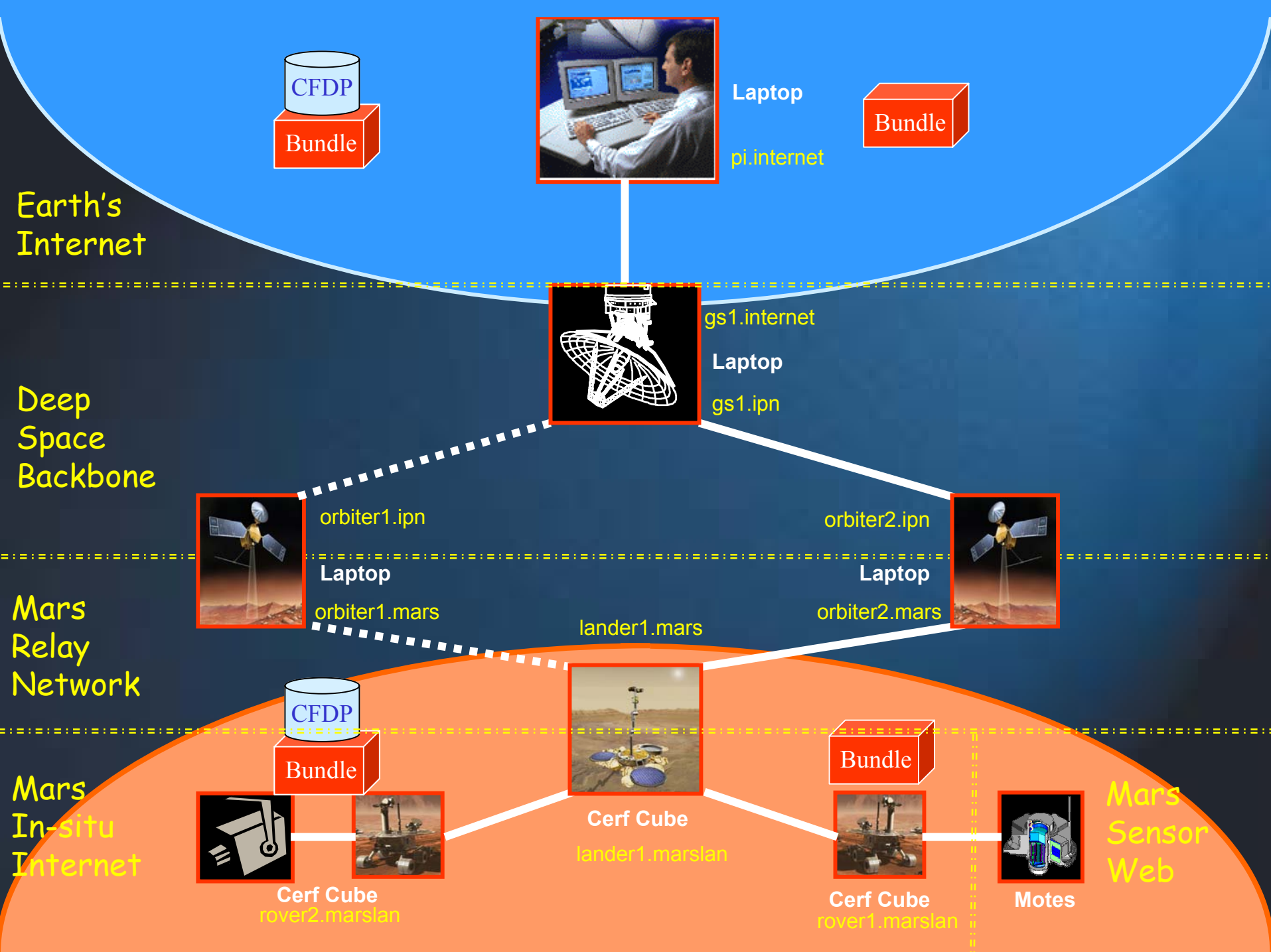
1st. Rough Code August 2000



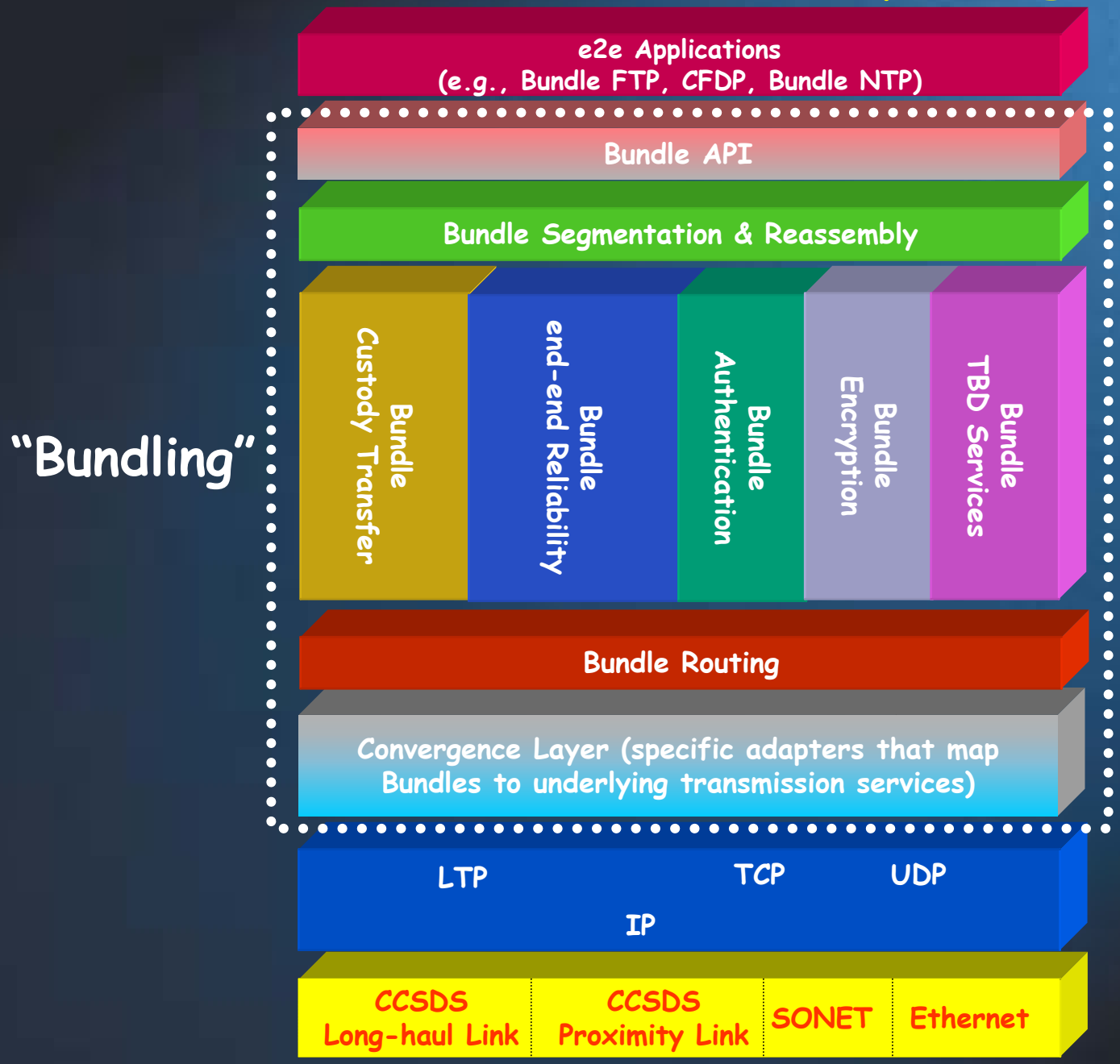
2nd. Prototype Code May 2002

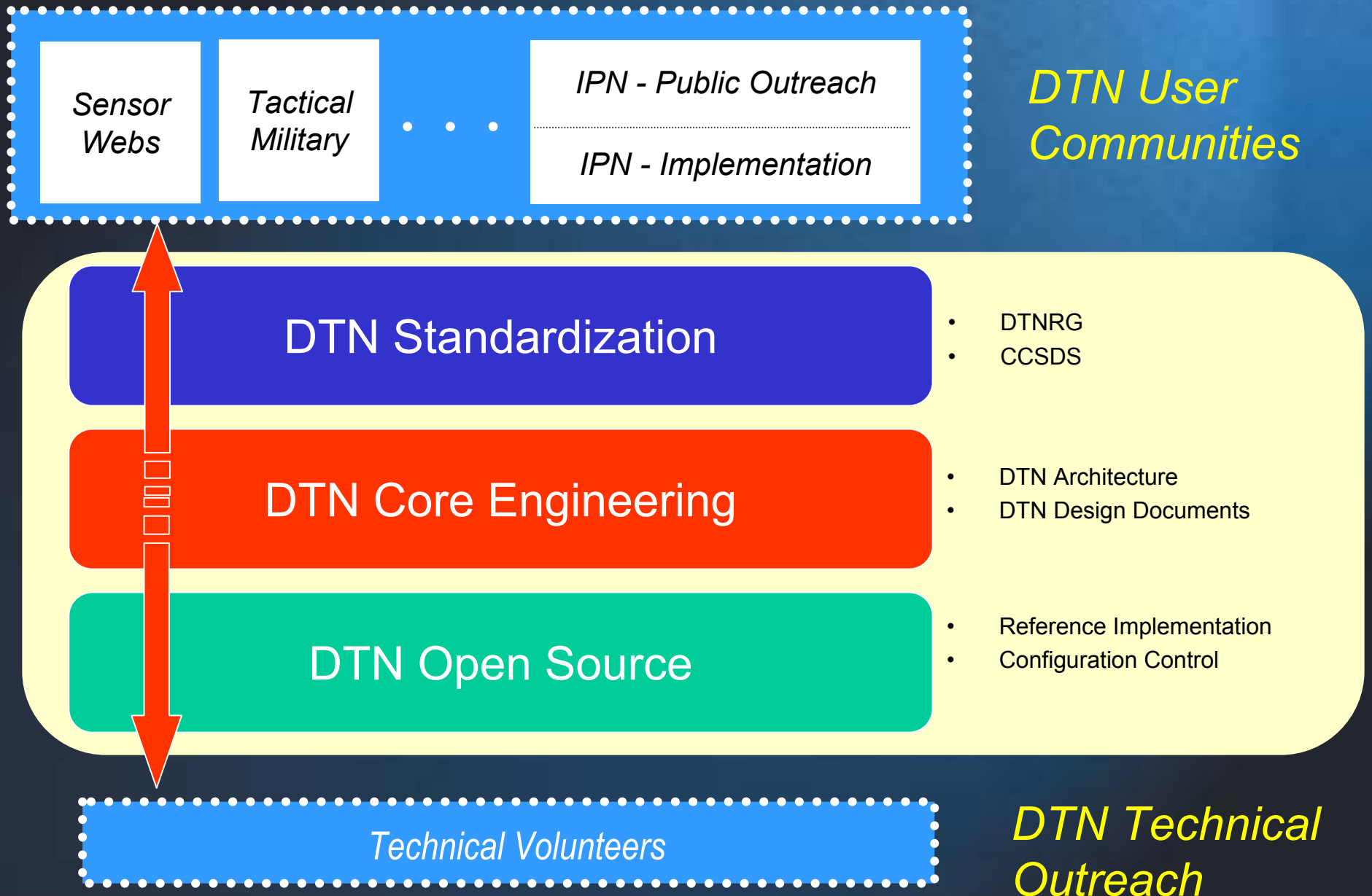
3rd. Prototype Code July 2002

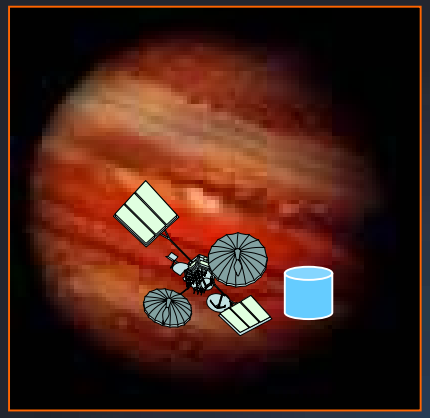
CFDP-over-Bundles Experiment.


Earth's Internet
CFDP
Bundle
Laptop
pi.internet
Bundle
Deep Space Backbone
gs1.internet
Laptop
gs1.ipn
Mars Relay Network
orbiter1.ipn
Laptop
orbiter1.mars
orbiter2.ipn
Laptop
orbiter2.mars
lander1.mars
Mars In-situ Internet
CFDP
Bundle
Cerf Cube
rover2.marslan
Cerf Cube
lander1.marslan
Bundle
Cerf Cube
rover1.marslan
Motes
Mars Sensor Web

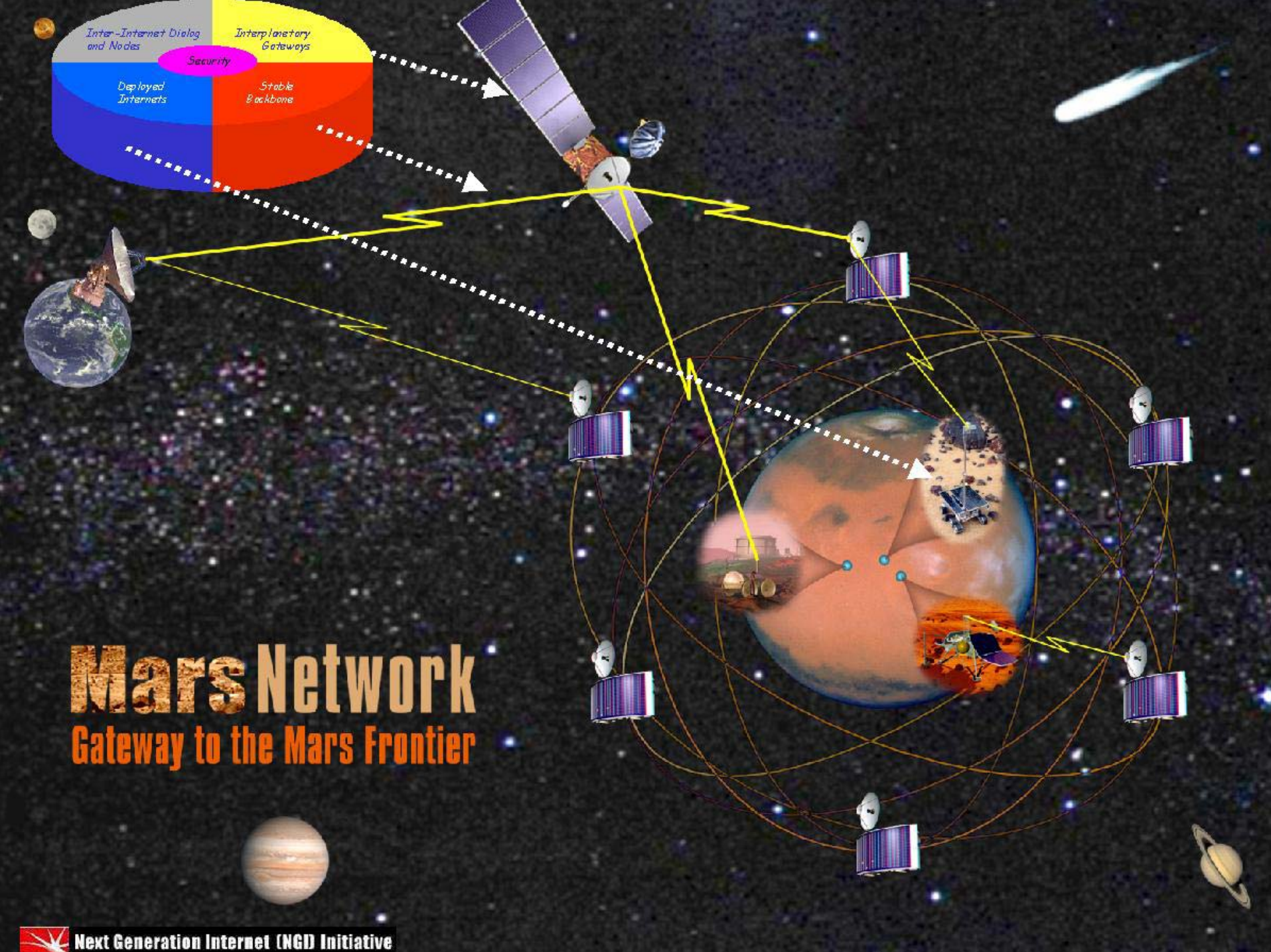
Bundle Service Layering



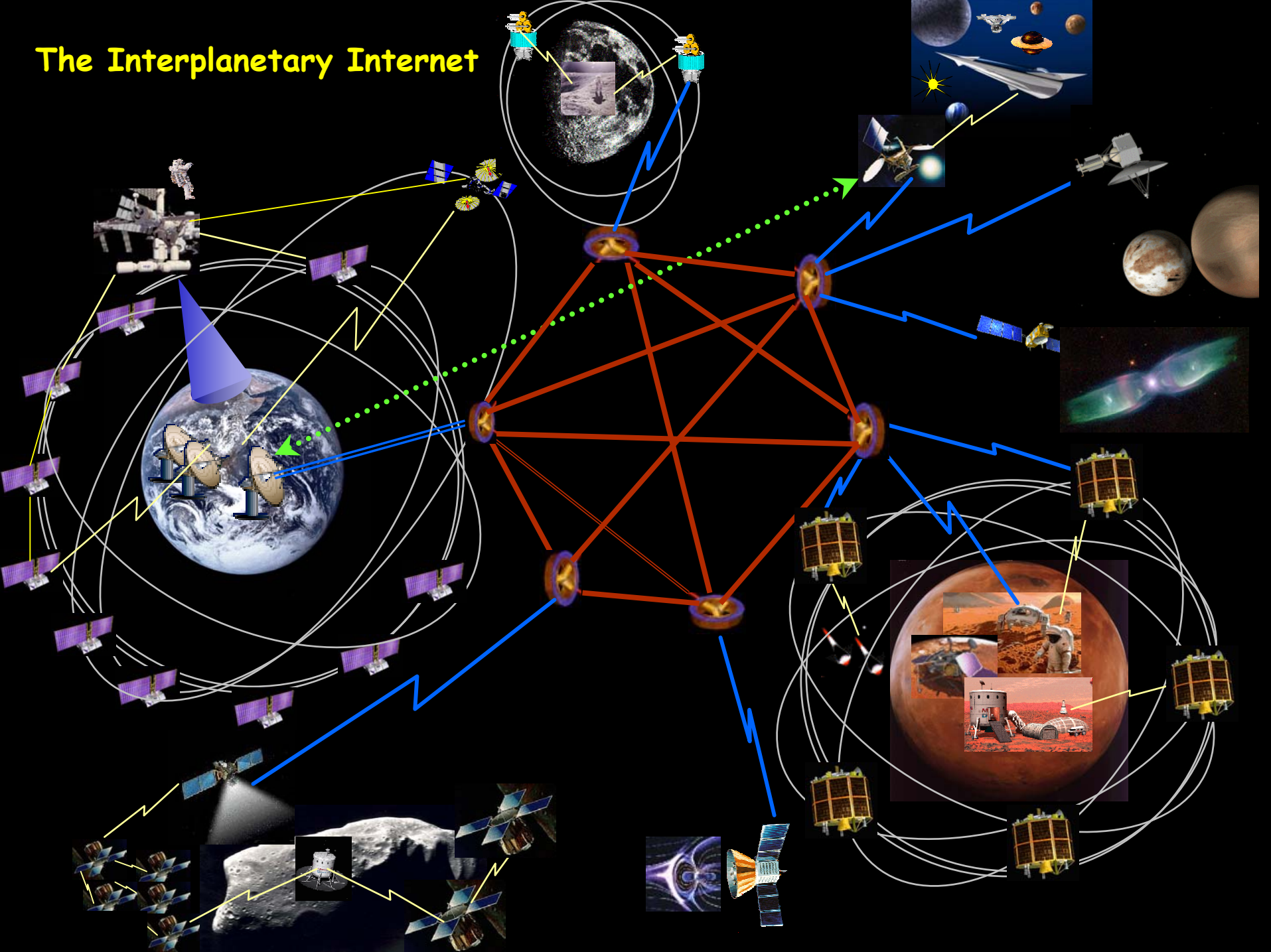

Sensor Webs
Tactical Military
. . .
IPN - Public Outreach
IPN - Implementation
DTN User Communities
DTN Standardization
DTN Core Engineering
DTN Open Source
• DTNRG
• CCSDS
• DTN Architecture
• DTN Design Documents
• Reference Implementation
• Configuration Control
Technical Volunteers
DTN Technical Outreach



The 5 year Scenario: fully automated end to end space mission data transfer


Inter-Internet Dialog and Nodes
Interplanetary Gateways
Security
Deployed Internets
Stable Backbone
Mars Network
Gateway to the Mars Frontier
Next Generation Internet (NGI) Initiative

The Interplanetary Internet



For more information…..

… http://www.ipnsig.org