National Aeronautics and Space Administration

Integrated Radio and Optical Communications (iROC)

SPACE COMMUNICATIONS AND NAVIGATION

"Keeping the universe connected."

SCaN Industry Days Presentation

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Integrated Radio and Optical Communication (iROC) Challenges:
An Attempt to Merge Two Seemingly Disparate Systems

Optical Systems:

- Low prime powers
- Low mass and small telescopes
- Facilitate high data rates
- Weather dependency requires foreknowledge for link scheduling
- Strict pointing requirements
- Requires fine surface finesse on apertures

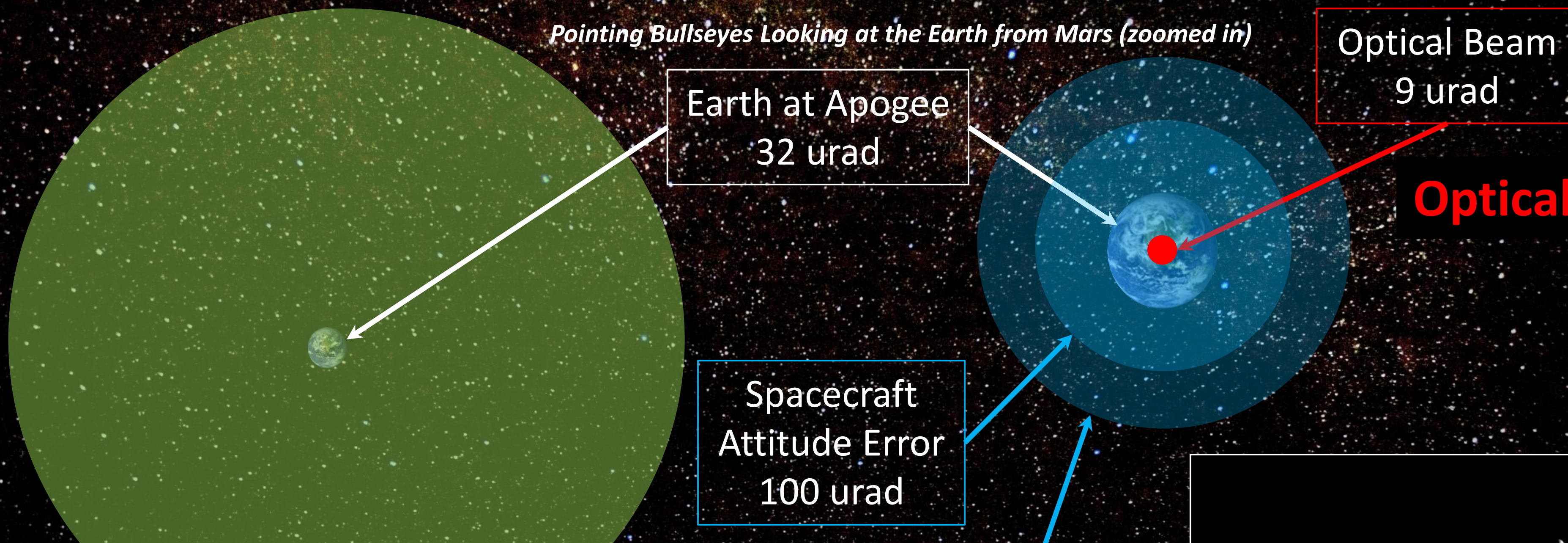
RF Systems:

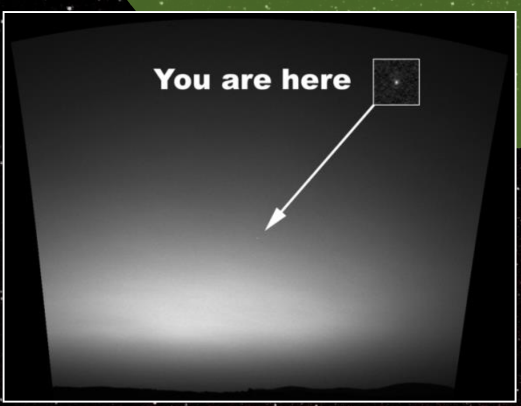
- High efficiencies due to development heritage
- High availability due to existing DSN ground infrastructure
- Relaxed pointing requirements
- Large prime powers
- Large mass and large antennas

Merging two seemingly conflicting systems is difficult, but the combined system may capitalize on the benefits of the individual systems while minimizing the penalties. In addition, the complimentary features may present the best option for reliability.

The RF/Optical Pointing Challenge:

Two Very Different Beam Patterns



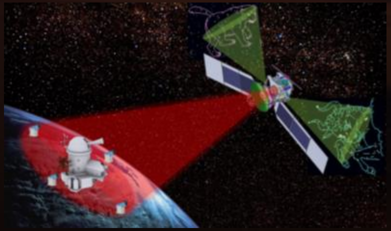
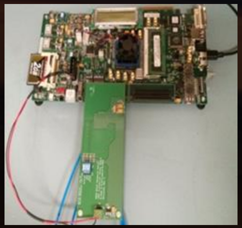
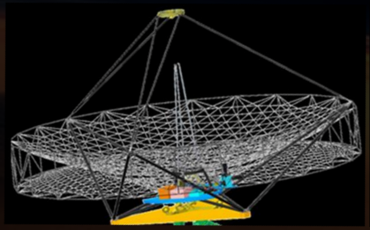
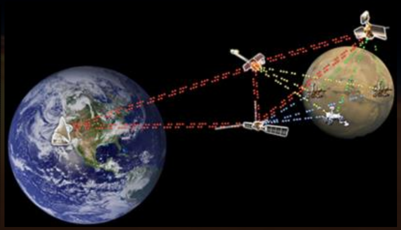


Actual image of Earth as seen from Mars taken by the Spirit rovers' panoramic camera in 2004.

Actual image of the crescent Earth and Moon on October 3, 2007, taken by the HiRISE instrument of the NASA's Mars Reconnaissance Orbiter.

Project Goal and Objectives

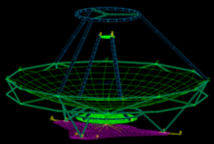
Goal: Develop and demonstrate new, high payoff space technologies that will promote mission utilization of optical communications, thereby expanding the capabilities of NASA's exploration, science, and discovery missions.

- Combine the paramount features of select deep space RF and optical communications elements into an integrated system, scalable from deep space to near earth
- Realize Ka-band RF and 1550 nanometer optical capability within the MRO payload envelope
- Prototype and demonstrate performance of key components to increase to TRL5, leading to integrated hybrid communications system demonstration

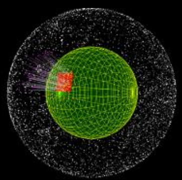
Combining RF & optical for minimal SWaP

Focusing on 4 Key Enabling Technology Areas Recommended for Integration



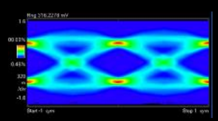
Combined RF/optical Teletenna

- Co-boresighting simplifies comm payload integration with spacecraft
- Maximizes line of sight availability between aperture and earth



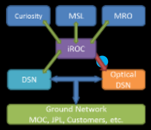
Precision beaconless pointing / navigation through sensor fusion

- Increases spacecraft autonomy and capability
- Permits flexibility in telescope aperture selection (i.e. no minimum aperture size required to detect dim beacon)
- Uplink beacons will be challenging to implement and operate in locations where high speed ground infrastructure is located



RF/optical Software Defined Radio (SDR)

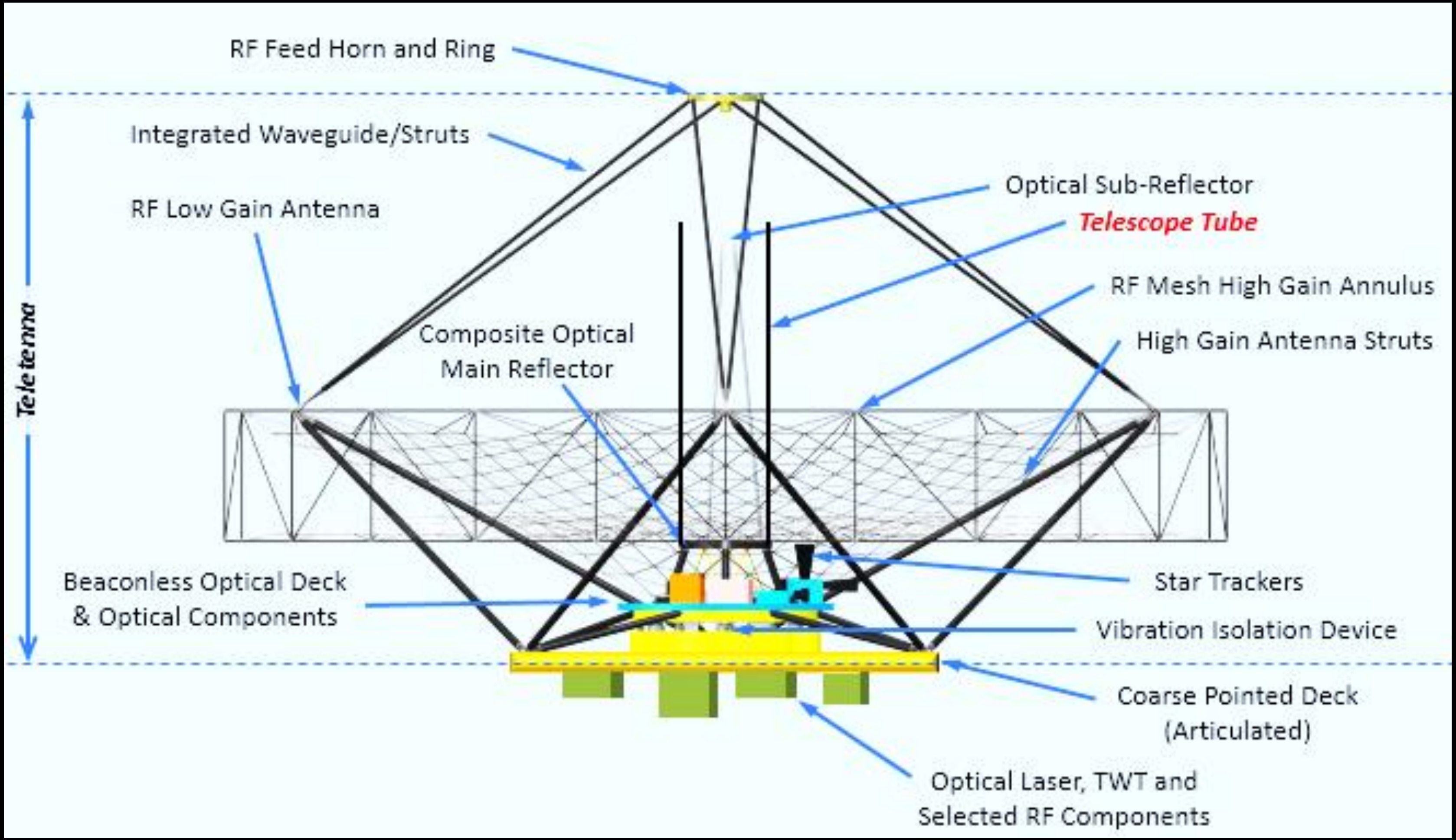
- Provides reconfigurability for evolving mission requirements and developing infrastructure



Networked RF/optical link management

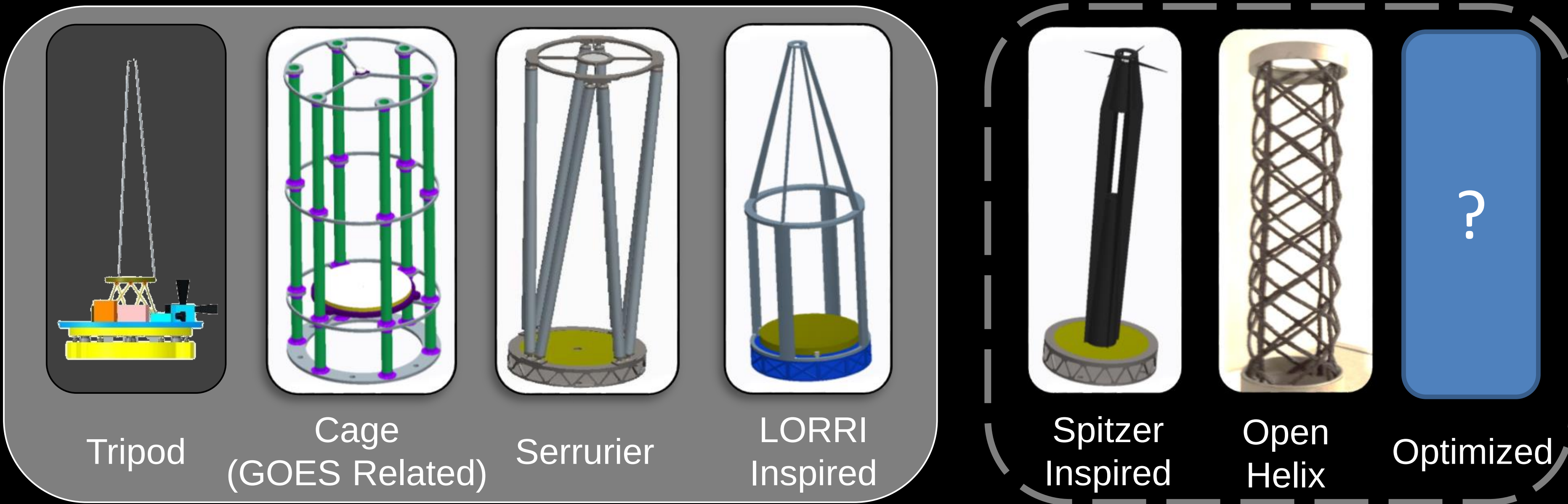
- Enables automation of the system, transparent to the user
- Provides quality of service and security
- Utilizes network nodes in an optimal manner

Teletenna Concept



Features: co-boresighted telescope and antenna (telescope contributes to rf aperture), mechanically isolated optical system, 3 m mesh reflector mass=8 kg compared to 20 kg MRO 3 m dish

Design Variations and Drivers



Current Focus

Design Drivers

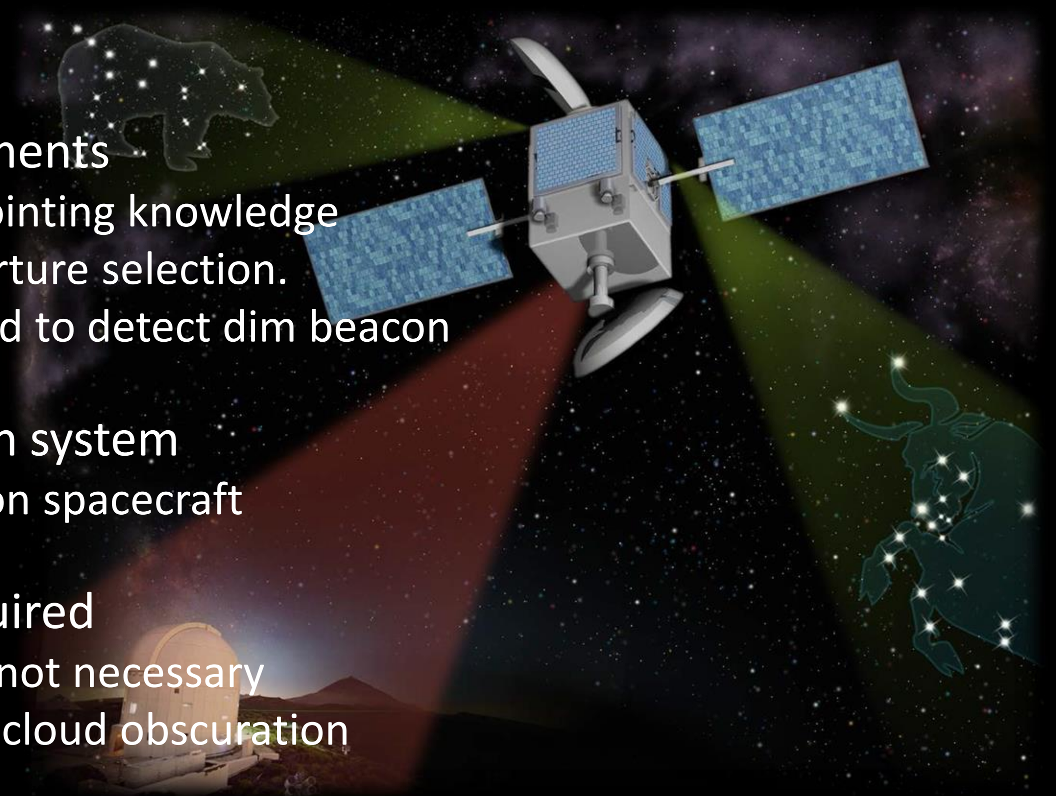
- Minimize Structural Displacements
  - Minimize Variations due to Thermal
  - Natural Frequencies above ~70 Hz
- Athermalized Design
- Maximize Photon Density at Earth
- RF Compatible Design
- Low Mass Center Location
  - Near Isolation Platform
- Operational Over Spacecraft Orbit Environment, Launch Loads etc.

iROC Beaconless Pointing

Autonomous Precision Attitude Determination & Pointing

Beaconless Pointing Advantages

- Increased spacecraft autonomy
- Eliminates beacon receive requirements
  - Optimize aperture, laser power, pointing knowledge
  - Permits flexibility in telescope aperture selection. No minimum aperture size required to detect dim beacon
- Eliminates on-board receive beacon system
  - No need to receive a dim beacon on spacecraft
- High-power uplink beacon not required
  - Laser clearing house coordination not necessary
  - Operation independent of beacon cloud obscuration
  - Increased operational uptime
- Design extensible to other applications



RF and Optical Transmit Waveforms

Optical

- Peak data rate: 267 Mbps
- Link Distance: 0.55 AU
- Modulation: SCPPM-16
- Code rate: 2/3
- Guard time: 4 slots
- Slot clock: 0.5 ns
- Lucent laser:
  - *PRF: 10-110 MHz
  - Peak power: 700 Watts
  - Average power: 13 Watts
  - Wavelength: 1550 nm

RF

- Peak data rate: 85 Mbps
- Link distance: 0.55 AU
- Modulation: GMSK
- Coding: LDPC or Turbo
- Code rate: 1/2
- TWTA: 75 Watts
- Antenna size: 3 Meters
- *Bandwidth: 200 MHz
- Frequency: 32 GHz

* Indicates the limiting constraint

RF/Optical SDR Design Parameters

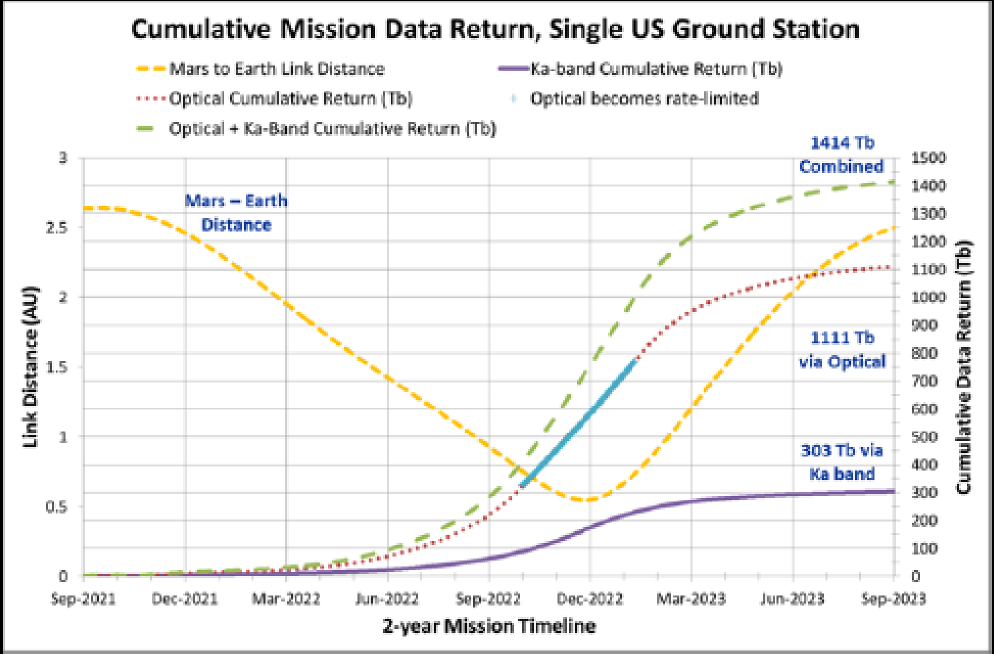
- Vendor provides the SDR hardware, STRS OE, test waveforms, documentation
- NASA develops the application waveform
- Separate RF and optical slices, easily modified to have one or both slices
- Simultaneous or individual RF/optical operation
- Focus is on high rate RF/optical transmitter, also low rate RF receiver
- Deep space (Mars) missions
- Mass: 4.0 kg
- Power: ~30-50 W

iROC and MRO Comparisons

- **Articulated iROC exceeds MRO's 34 Tb data return goal by 7x via RF, or by 26x via optical**
- **iROC is comparable to MRO telecom mass**
- **iROC matches MRO 359 W peak prime power**
  - Utilizes 13 W laser and 75 W TWTA
  - Combined RF and optical simulcast is enabled for missions unconstrained by power.
- **Technology investment: Preliminary Estimate ~ $60M NRE above MRO as reference ($720M)**
- Current cost of data return via MRO $720M/53 Tb or $13.58/Tb
- New cost of data return via iROC $780M/1414 Tb or $0.55/Tb

Destination	Estimated Range (AU)	Limitation	Potential Peak RF Data Rates	Potential Peak Optical Data Rates
Mars	0.4 – 2.7	Power and Hardware	0.6-84 Mb/s via DSN (32 GHz Ka-band)	5-267 Mb/s
Lunar	0.00257	Bandwidth	1Gb/s via NEN (26 GHz K-band)	10 Gb/s

Total Mission Data Return for up to 480 min/day contact



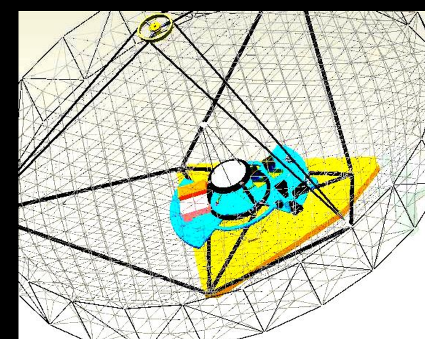
	Raw Mass (kg)	2-year Mission Data Return (Tb)	Metric (Tb/kg)
MRO Telecom Subsystem	63	34 - 53	0.54 – 0.84
iROC Subsystem	69	303 via RF 1111 via Optical	4.4 RF 16.1 Optical

Daniel J. Zeleznikar, Jennifer M. Nappier, and Joseph A. Downey, "Ka-band Link Study and Analysis for a Mars Hybrid RF/Optical Software Defined Radio"

iROC
Estimated Return-on-Investment

- Current Deep-Space Capability
  - ≈3 m X-band rigid reflector (MRO peak data rate was 6 MBPS)
    - 35 W Ka-band experiment via MRO
  - Voyager spacecraft, using a fixed 3.7 m dish, transmitted 115 KBPS at X-band to a 70 m dish.
  - Galileo nominal design data rate was 134 KBPS via deployable 4.6 m dish
  - The 6 m L-band SMAP reflector was launched on January 29, 2015. The engineering model of that Astromesh reflector was characterized at GRC to 50 GHz and exhibited an efficiency of 58%.
  - DOT/DSOC in development promises 267 MBPS at Mars perigee using a 22 cm telescope and a 4 W laser
- New method:
  - 3M *Ka-band* reflector with integral 12.2 cm telescope, software defined PSK and PPM digital core, and beaconless pointing system
- Benefits
  - Potentially ≈60 X data return (≈350 MBPS from Mars perigee)
- Technology investment is $?? M development (NRE)
- Beneficiary: High data rate deep space missions, particularly future outer planet missions and future Mars missions.

Merged RF & optical waveform control on COTS development board



Teletenna system employing 3 m mesh reflector and nominal 25 cm composite mirror supported atop custom vibration isolation platform

Networked RF/Optical Link Management

Needs and Goals

Needs

- Increase network data throughput to meet future user needs - don't let communications capability constrain the science on our missions.
- Accelerate the infusion of optical communications and high data rate RF systems into the operable network.
- Develop solutions spanning commercial utility and broad US government multifunction applications.

Goals

- Develop and demonstrate new, high payoff space technologies that will promote mission utilization of optical and high rate RF communications, thereby expanding the capabilities of NASA's exploration, science, and discovery missions.
- Provide reconfigurable store, forward and routing capabilities to support evolving mission requirements and developing infrastructure, and provide feedback paths to enable the foundations for realizing system cognition and autonomy.
- Implement proactive and reactive link management solutions to utilize network nodes in an optimal manner.

High Data Rate Architecture (HiDRA)

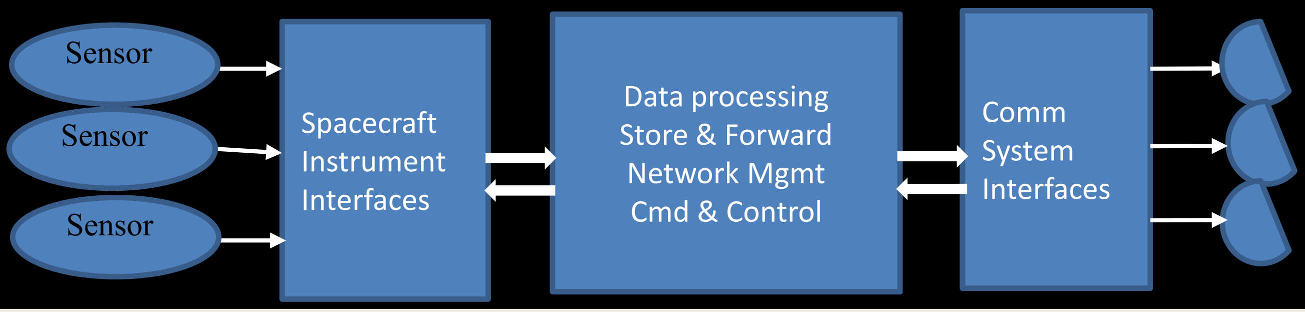
Technology and Standards Division (TSD) Objectives

- Provide a buffering and routing flight data interface servicing an array of scientific instruments reaching 10 Gbps transfer rates; capable of supplying one or more high rate communications radios with extensibility to 200 Gbps.
- Serve as a space networking node, and demonstrate advanced protocols and concepts enabling daily 100 TB information transfers.
- Prototype and demonstrate performance of key components to increase to TRL5, leading to integrated system demonstration
- Characterize and quantify system performance over a variety of relevant parameters and conditions.
- Recommend architecture, implementation options, data storage sizing strategies, interface specifications, standards adherence, and reliability parameters for future operational systems.

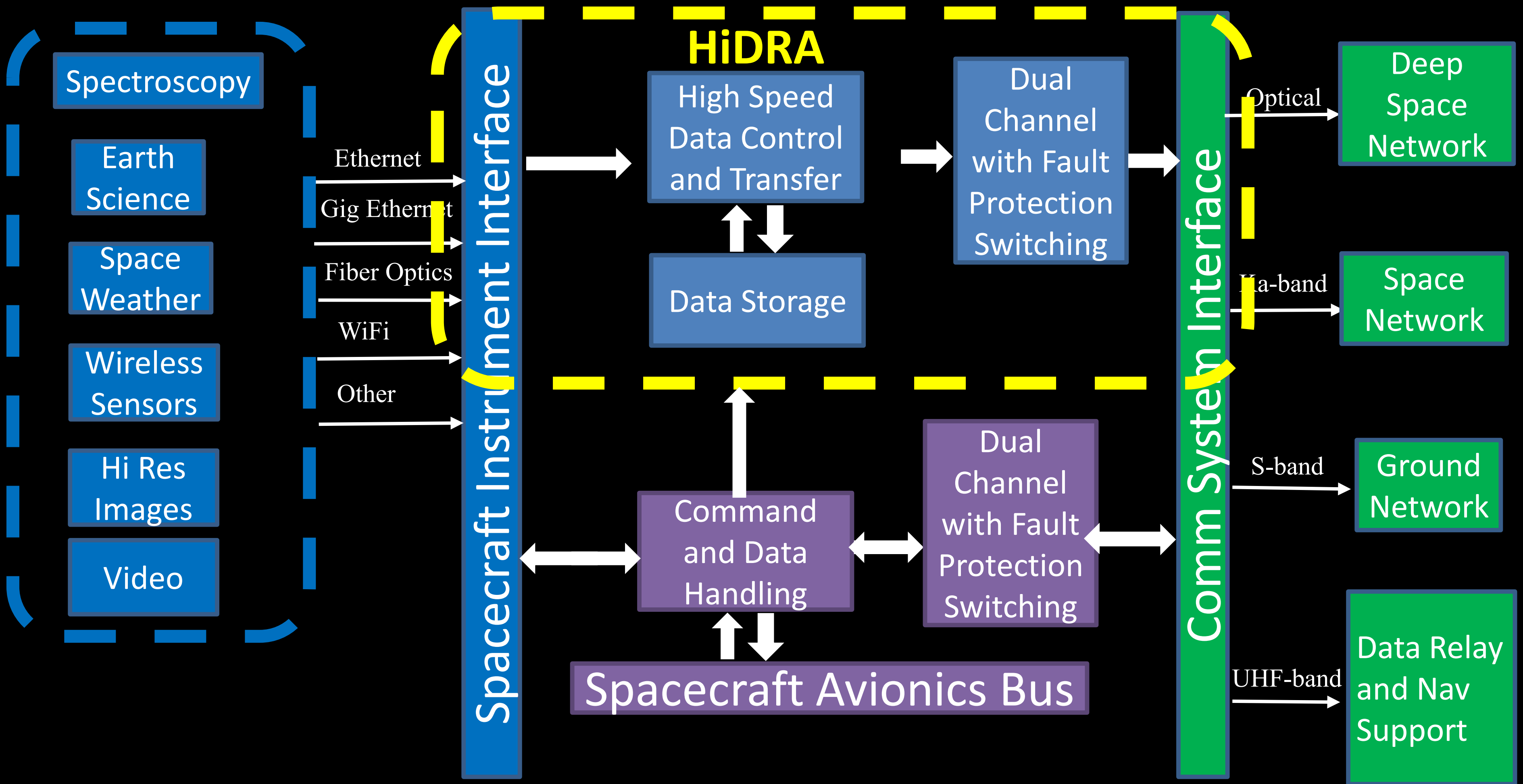
Enabling High Rate RF & Optical Communication Links

High Data Rate Architecture

- Scope of Work
  - As scientific space instruments and space communications systems increase data rates, a key technology need is high speed reliable data flow between these systems.
  - A high performance computing architecture is needed that is suitable for a range of flight applications.
- High Performance Computing Architecture Considerations
  - Store and forward for data rate mismatches and relay outages, multi-user support on input and output
  - Network Management
    - Addition of DTN and different bundle sizes
    - Quality of Service (BER, Latency), storage size
    - Security and Encryption
  - Architecture Considerations
    - Scalability and extensibility, Interfaces and Multiple Users
    - Command and control
  - Implementation and Cost
    - Hardware, software, testing, operation
    - Reliability, priority, availability and redundancy
    - Sparing, switching, SWaP and path to flight



Notional Spacecraft Avionics with HiDRA Architecture



Architecture needs to address integration of C&DH with HiDRA high speed data path

High Data Rate Architecture Return-on-Investment (ROI)

Previous Method for Instrument Interface with Comm System

- Integrated C&DH subsystem within spacecraft avionics
- One sensor at a time connected to the communication system
- Operations are scheduled and switched from the ground

New Method:

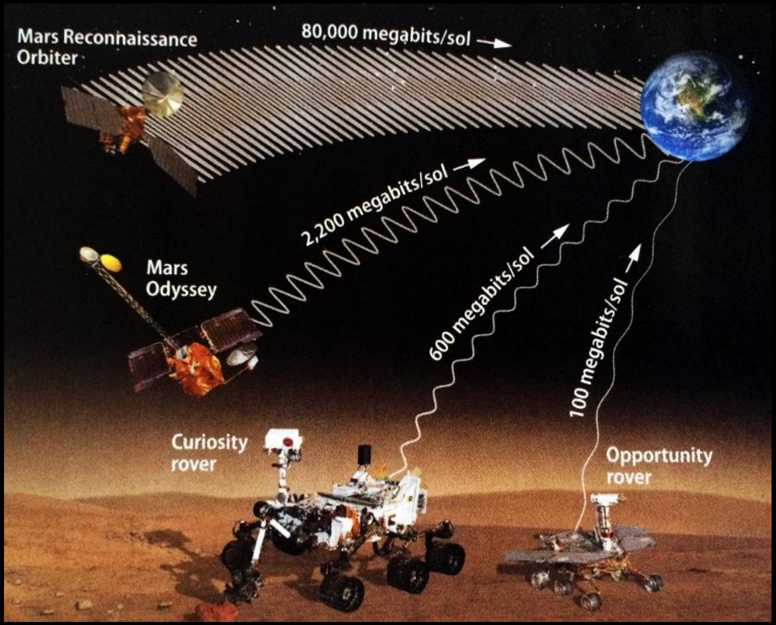
- High performance data computing architecture suitable for range of flight applications; increases data rate and multi-user support
- Store and forward capability supports data rate mismatches and outages
- Network Management (with DTN) enables automation of simultaneous data delivery from multiple sensors to (multiple) comm system(s)

Technology investment:

- $TBD development NRE to be calculated during **Return on Investment**
- Increased mission data return
- Operational transparency through network management

Beneficiary: High Data Producing Missions

- As scientific space instruments and space communications systems increase data capacity, high speed reliable data flow between these systems increases the amount of data returned to the investigators
- Architecture supports multiple future customers which spreads the NRE to reduce the impact for each future mission
- Commercialize results to obtain lower cost systems



Question: Given costs across different mission classes and their information returned, what is the cost of a bit?

ROI will be calculated based on expected performance increase (aggregate data return) accomplished with HiDRA (across a range of mission scenarios) and estimated NRE

Research Publications

- Karl B. Fielhauer, Bradley G. Boone and Daniel E. Raible, "**Concurrent Systems Engineering and Risk Reduction for Dual-Band (RF/Optical) Spacecraft Communications**," IEEE Aerospace Conference, Big Sky, Montana, March 2012.
- Daniel E. Raible and Alan G. Hylton, "**Integrated RF/Optical Interplanetary Networking Preliminary Explorations and Empirical Results**," 30th AIAA International Communications Satellite Systems Conference, Ottawa, Canada, September 2012.
- Alan G. Hylton and Daniel E. Raible, "**On Applications of Disruption Tolerant Networking to Optical Networking in Space**," 30th AIAA International Communications Satellite Systems Conference, Ottawa, Canada, September 2012.
- Jing Li, Alan Hylton, James Budinger, Jennifer Nappier, Joseph Downey, and Daniel Raible,"**Dual-pulse Pulse Position Modulation (DPPM) for Deep-Space Optical Communications: Performance and Practicality Analysis**," NASA Technical Memorandum 2012-216042, November 2012.
- Daniel J. Zeleznikar, Jennifer M. Nappier, and Joseph A. Downey, "**Ka-band Link Study and Analysis for a Mars Hybrid RF/Optical Software Defined Radio**," 32nd AIAA International Communications Satellite Systems Conference (ICSSC), San Diego, CA, 2014.
- Alan G. Hylton and Daniel E. Raible, "**Networked Operations of Hybrid Radio Optical Communication Satellites**," 32nd AIAA International Communications Satellite Systems Conference (ICSSC), San Diego, CA, 2014.
- Daniel E. Raible , Robert R. Romanofsky, James M. Budinger, Jennifer M. Nappier, Alan G. Hylton, Aaron J. Swank, and Anthony L. Nerone, "**On the Physical Realizability of Hybrid RF and Optical Communications Platforms for Deep Space Applications**," 32nd AIAA International Communications Satellite Systems Conference (ICSSC), San Diego, CA, 2014.