# On the Development and Application of High Data Rate Architecture (HiDRA) in Future Space Networks

*"Keeping the universe connected."*

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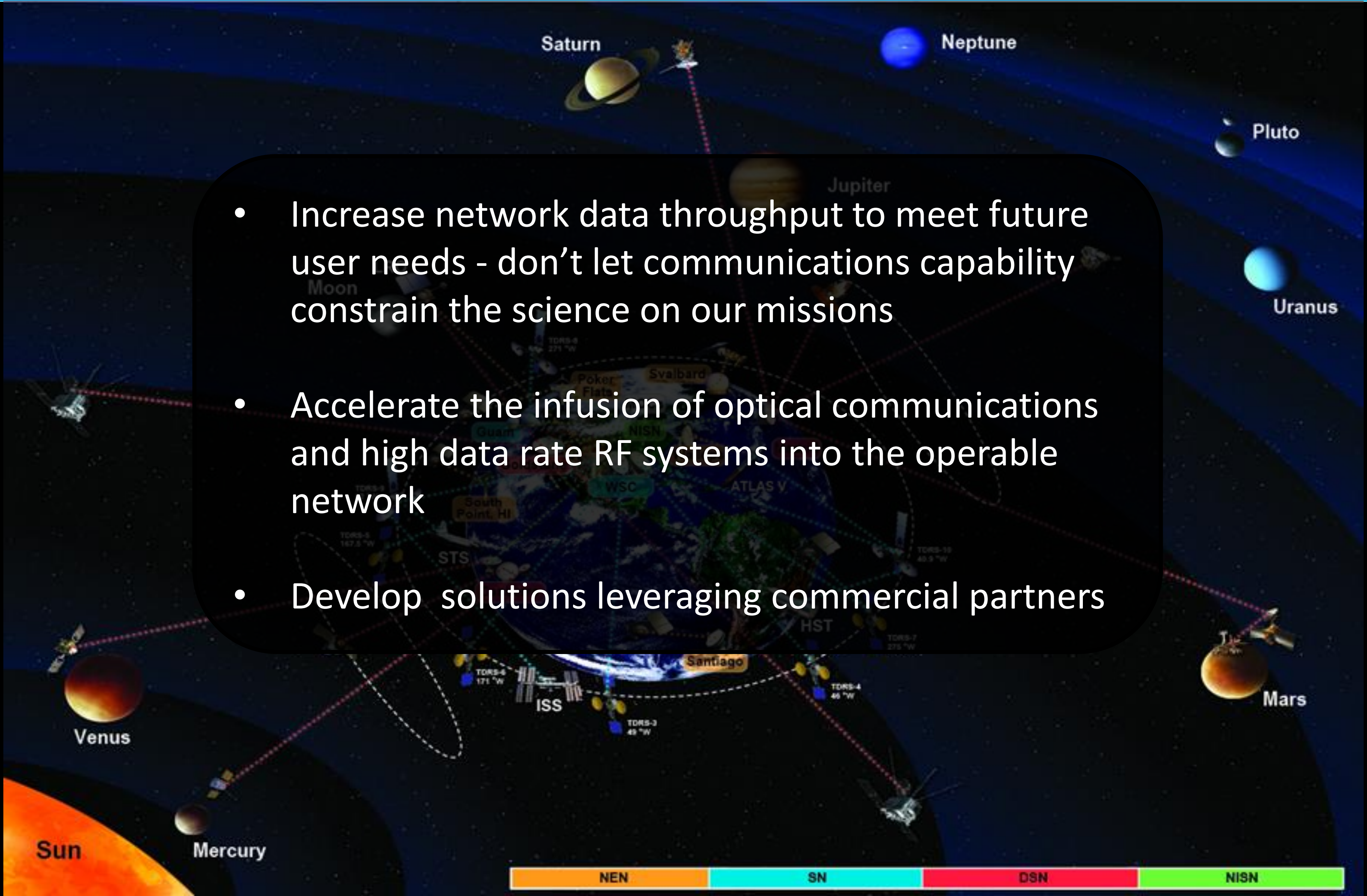
Gilbert Clark

***ICSSC 2017***

# NASA Needs

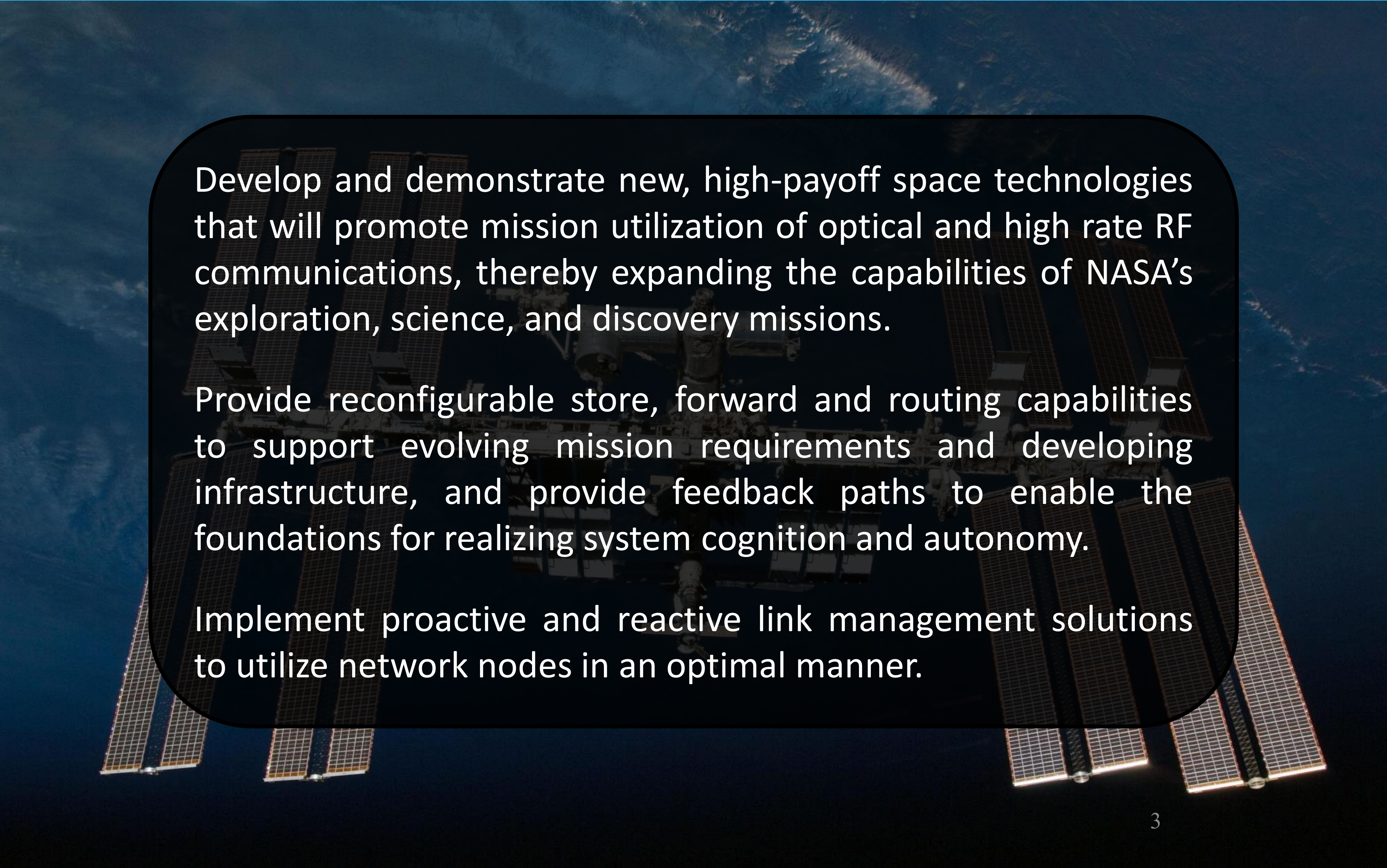


- Increase network data throughput to meet future user needs - don’t let communications capability constrain the science on our missions

- Accelerate the infusion of optical communications and high data rate RF systems into the operable network

- Develop  solutions leveraging commercial partners

# HiDRA 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.

# HiDRA

## Technology and Standards Division (TSD) Objectives

- Provide a buffering and routing flight data architecture 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

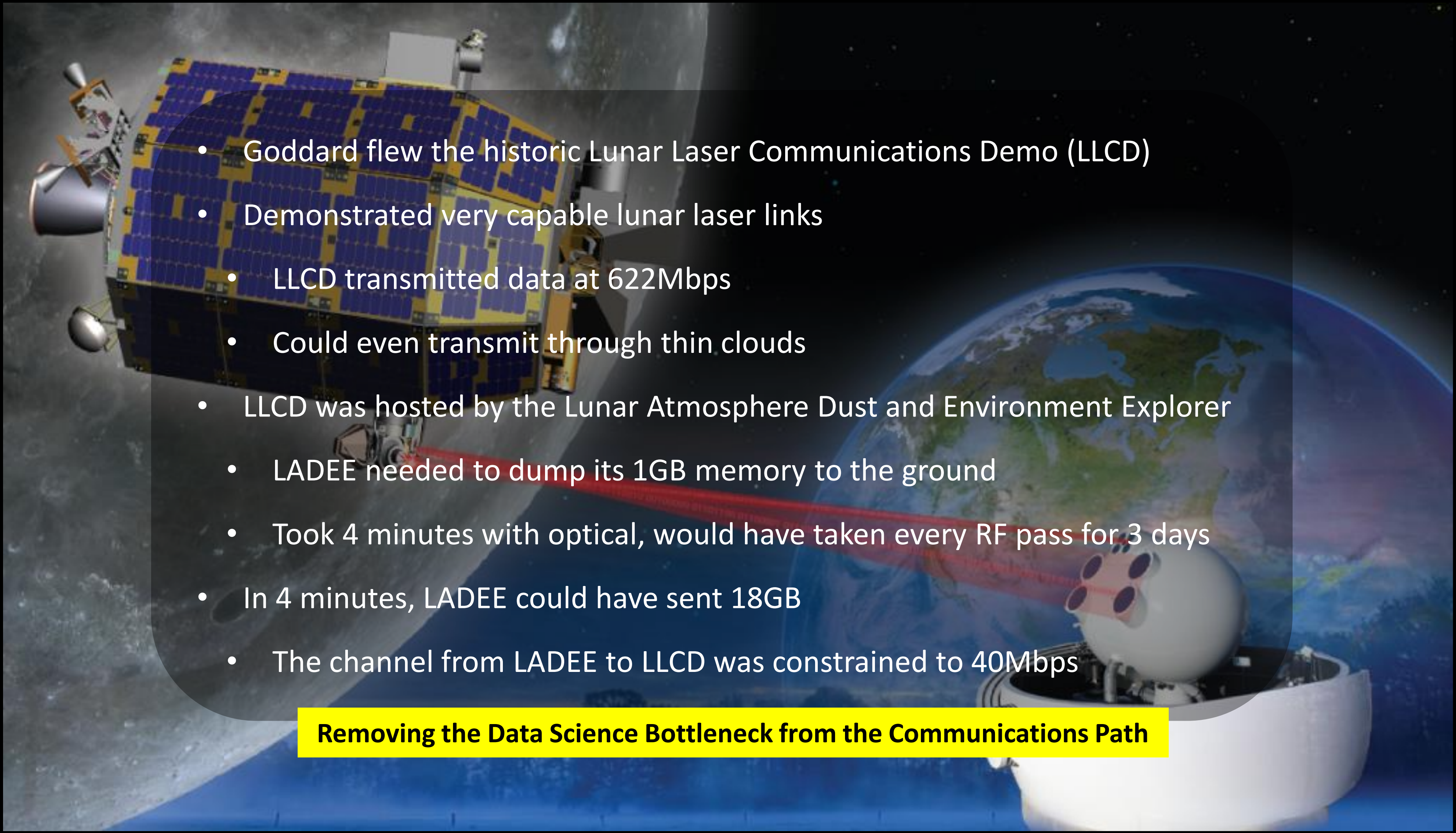
- Characterize and quantify system performance over a variety of relevant parameters and conditions.

- 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**

# HiDRA

## Citing Precedent - LLCD

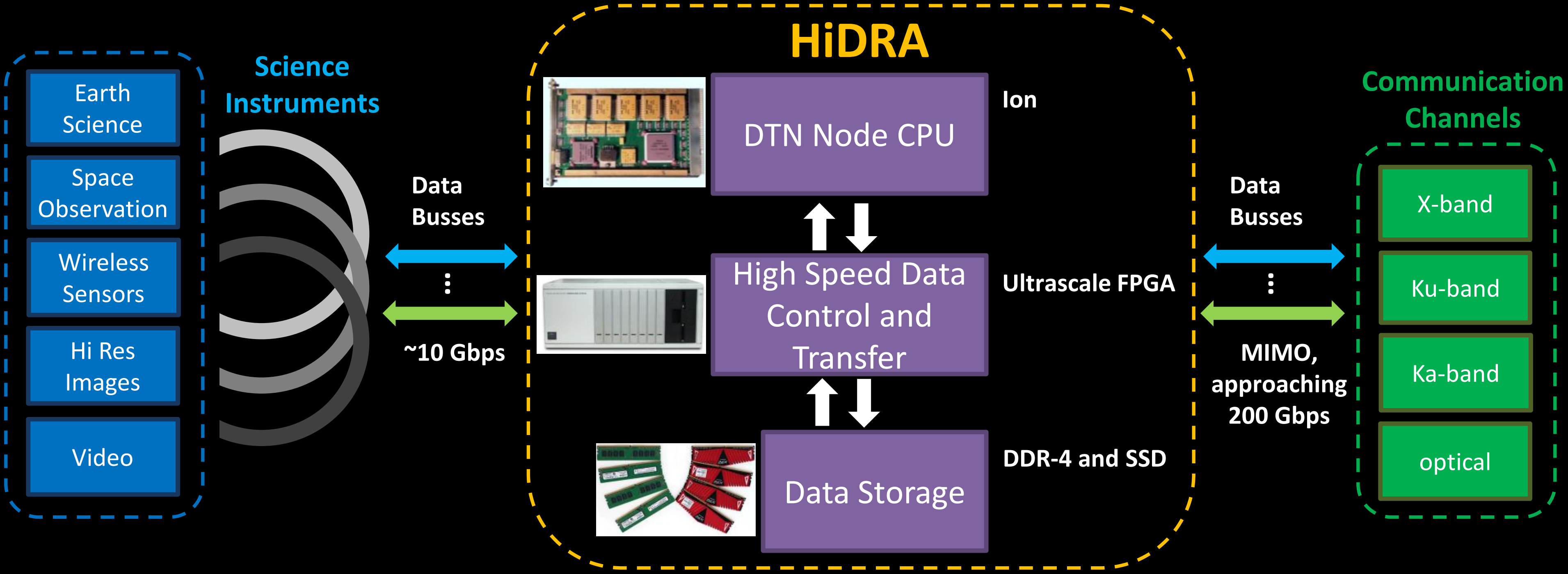


- Goddard flew the historic Lunar Laser Communications Demo (LLCD)
- Demonstrated very capable lunar laser links
  - LLCD transmitted data at 622Mbps
  - Could even transmit through thin clouds
- LLCD was hosted by the Lunar Atmosphere Dust and Environment Explorer
  - LADEE needed to dump its 1GB memory to the ground
  - Took 4 minutes with optical, would have taken every RF pass for 3 days
- In 4 minutes, LADEE could have sent 18GB
  - The channel from LADEE to LLCD was constrained to 40Mbps

**Removing the Data Science Bottleneck from the Communications Path**

# Generalized HiDRA

*Designing for Portability and Scalability Facilitating Commercialization*



Science Instruments

Earth Science

Space Observation

Wireless Sensors

Hi Res Images

Video

Data Busses

~10 Gbps

HiDRA

DTN Node CPU

Ion

High Speed Data Control and Transfer

Ultrascale FPGA

Data Storage

DDR-4 and SSD

Data Busses

MIMO, approaching 200 Gbps

Communication Channels

X-band

Ku-band

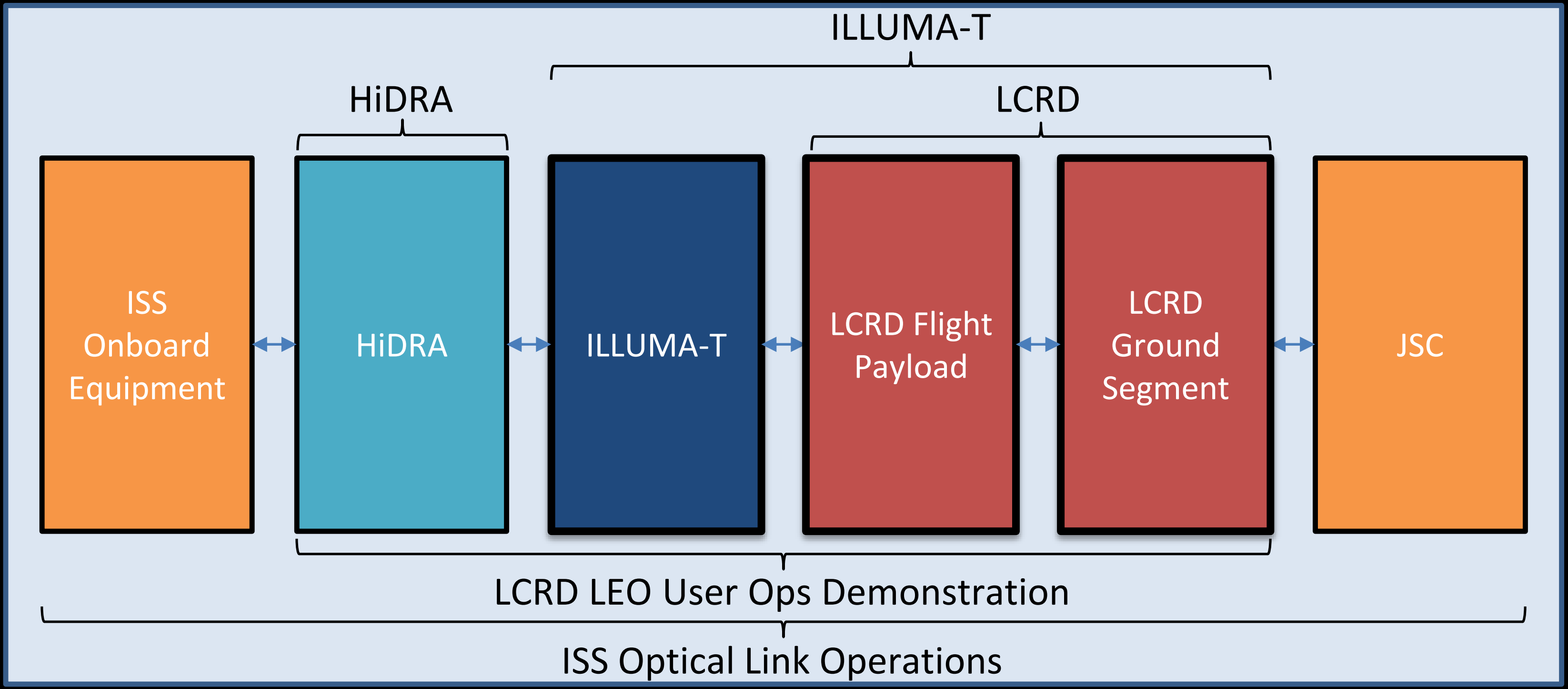
Ka-band

optical

- ○ **Features simultaneous read and write capability**
- ○ **Supports the capability to store, carry and forward 100 Tb of data daily**

**Prototyped systems currently operating in the laboratory**

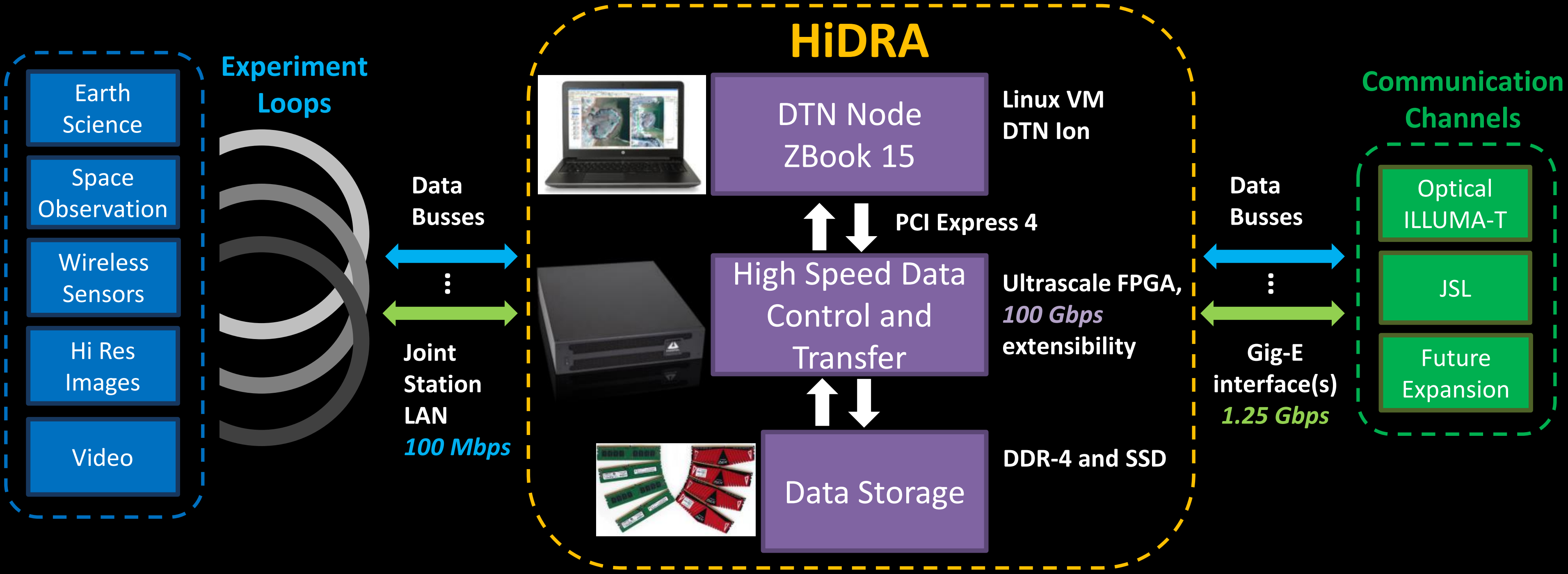
# ISS Optical Link Operations (Courtesy of NASA GSFC)



- Objective
  - Provide optical link path for ISS data delivery
- Minimum Success
  - Delivery of ISS data via LCRD

# HiDRA Implementation on ISS

*Providing a High Speed Interface for the ILLUMA-T Payload Linking to LCRD*



Experiment Loops

Earth Science

Space Observation

Wireless Sensors

Hi Res Images

Video

Data Busses

⋮

Joint Station LAN *100 Mbps*

## HiDRA

DTN Node ZBook 15

Linux VM
DTN Ion

PCI Express 4

High Speed Data Control and Transfer

Ultrascale FPGA, *100 Gbps* extensibility

Data Storage

DDR-4 and SSD

Data Busses

⋮

Gig-E interface(s) *1.25 Gbps*

Communication Channels

Optical ILLUMA-T

JSL

Future Expansion

○ **Features simultaneous read and write capability**

○ **Supports the capability to store, carry and forward *30 Tb* of data daily**

**Focus on hardware & software implementation to increase data rates**

# HiDRA
# Evolution

HiDRA began…

- As a spinoff of iROC
- As an effort to create a path for advances in communications
  - At all levels – networking, optical…

HiDRA is still these things, and…

- We are using FPGAs to implement a *water tower of data* approach
  - This allows us to transcend internal bus arbitration and so forth
  - It also lets work with various vintages of communications

The current focus…

- Put HiDRA on the ISS to work with ILLUMA-T
- Add SDN capability
- Work with industry

# HiDRA

## *Software and Hardware*

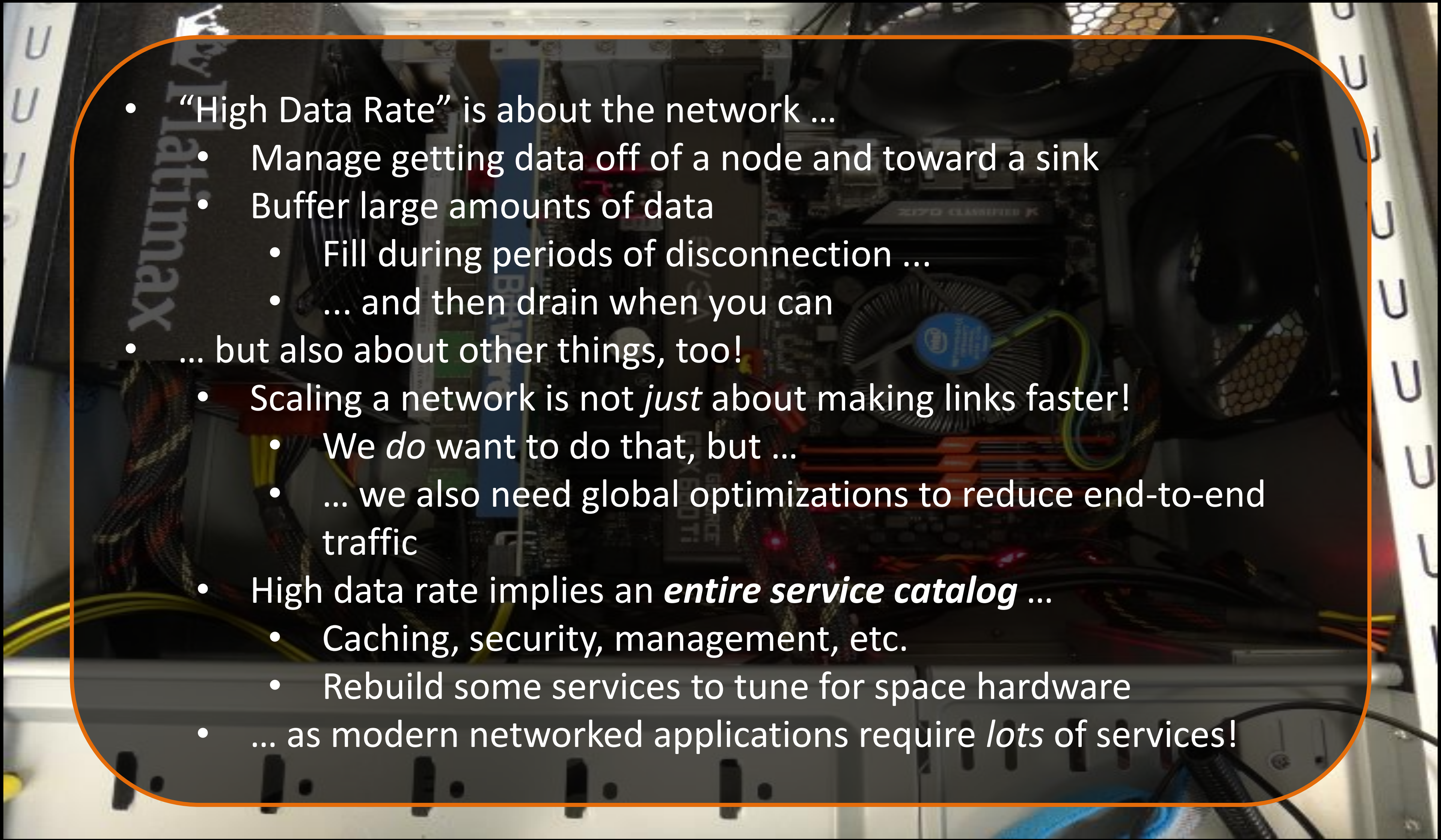
Software

- We are building a driver to flow data between BittWare cards
  - We can treat our current HiDRA as NICs
  - We have the capability to store, carry, and forward data
- Right now we use Ethernet/Aurora
  - We are investigating software support for 10G / 25G IP core
- We are constructing web-based software for operation visualization
  - Shows statistics and provides data for network management

Hardware

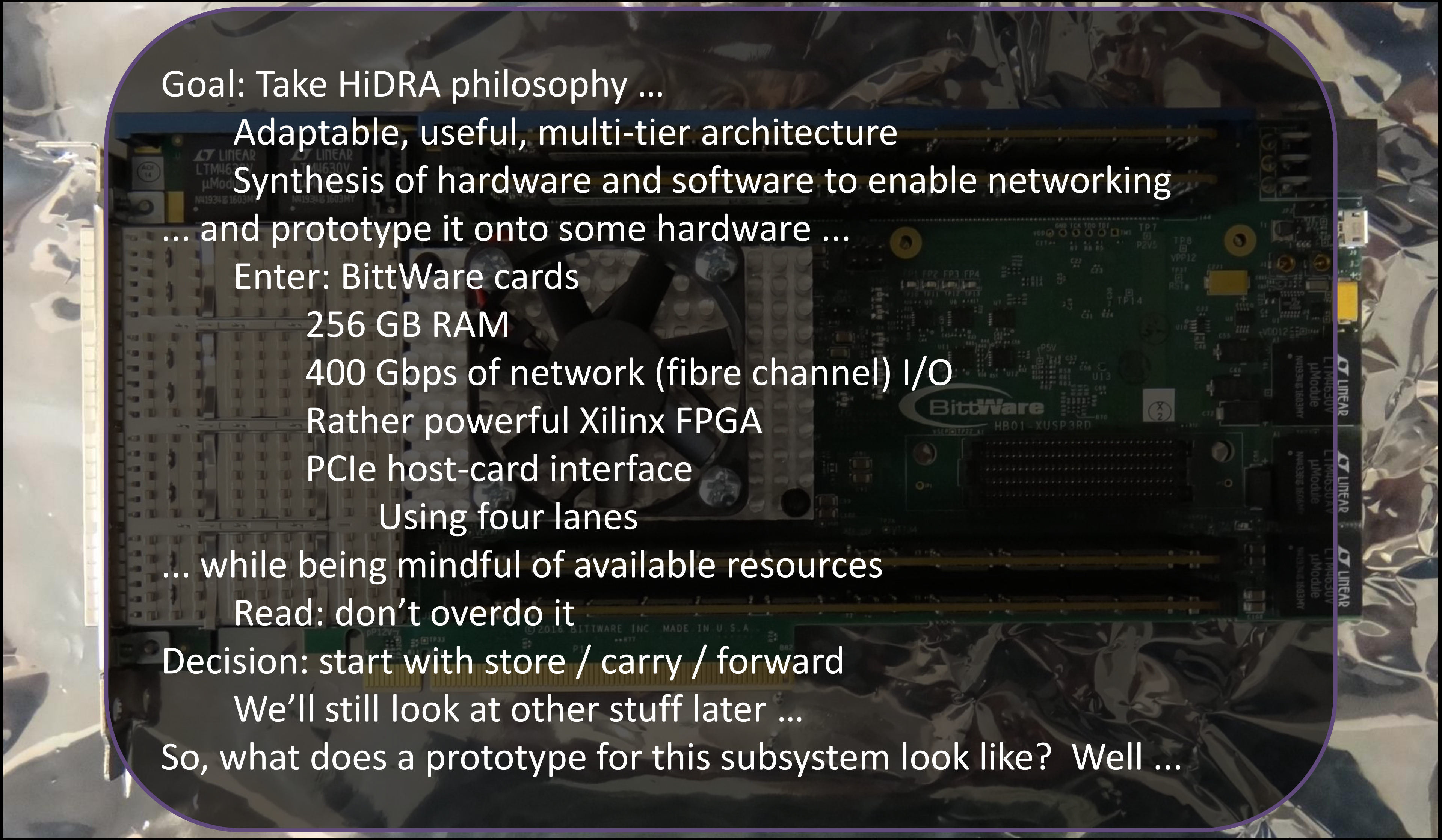
- Our hardware supports the capability above
- We are procuring a 10G/25G IP core for FPGA
  - While we wait for the PR, we are using a demo license
- Researching available instrumentation

# Philosophy



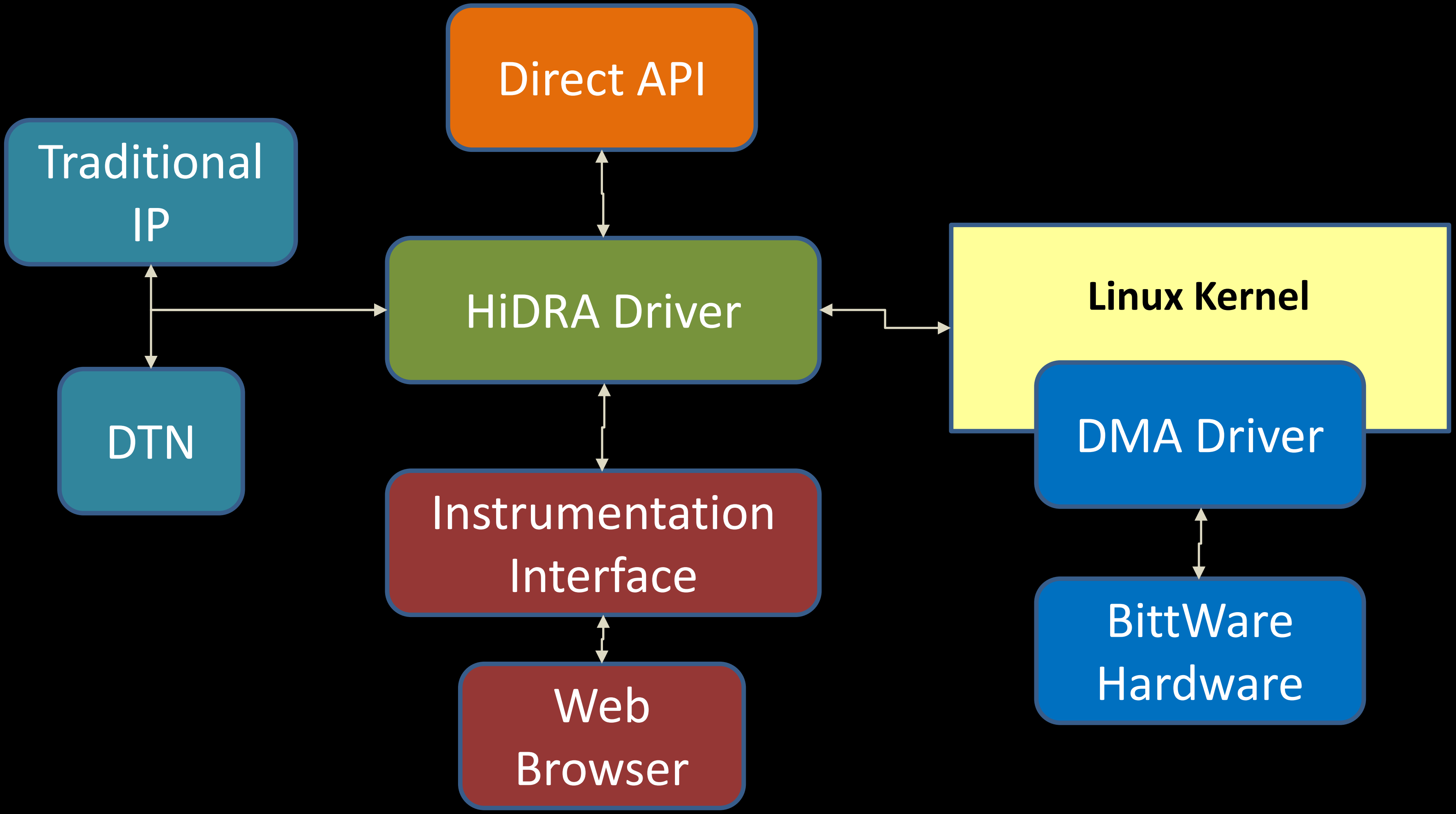
- “High Data Rate” is about the network …
  - Manage getting data off of a node and toward a sink
  - Buffer large amounts of data
    - Fill during periods of disconnection ...
    - ... and then drain when you can
- … but also about other things, too!
  - Scaling a network is not *just* about making links faster!
    - We *do* want to do that, but …
    - … we also need global optimizations to reduce end-to-end traffic
  - High data rate implies an ***entire service catalog*** …
    - Caching, security, management, etc.
    - Rebuild some services to tune for space hardware
  - … as modern networked applications require *lots* of services!

# Implementation



- Goal: Take HiDRA philosophy …
  - Adaptable, useful, multi-tier architecture
  - Synthesis of hardware and software to enable networking
- … and prototype it onto some hardware …
  - Enter: BittWare cards
    - 256 GB RAM
    - 400 Gbps of network (fibre channel) I/O
    - Rather powerful Xilinx FPGA
    - PCIe host-card interface
      - Using four lanes
- … while being mindful of available resources
  - Read: don’t overdo it
- Decision: start with store / carry / forward
  - We’ll still look at other stuff later …
- So, what does a prototype for this subsystem look like?  Well …

# Current Software

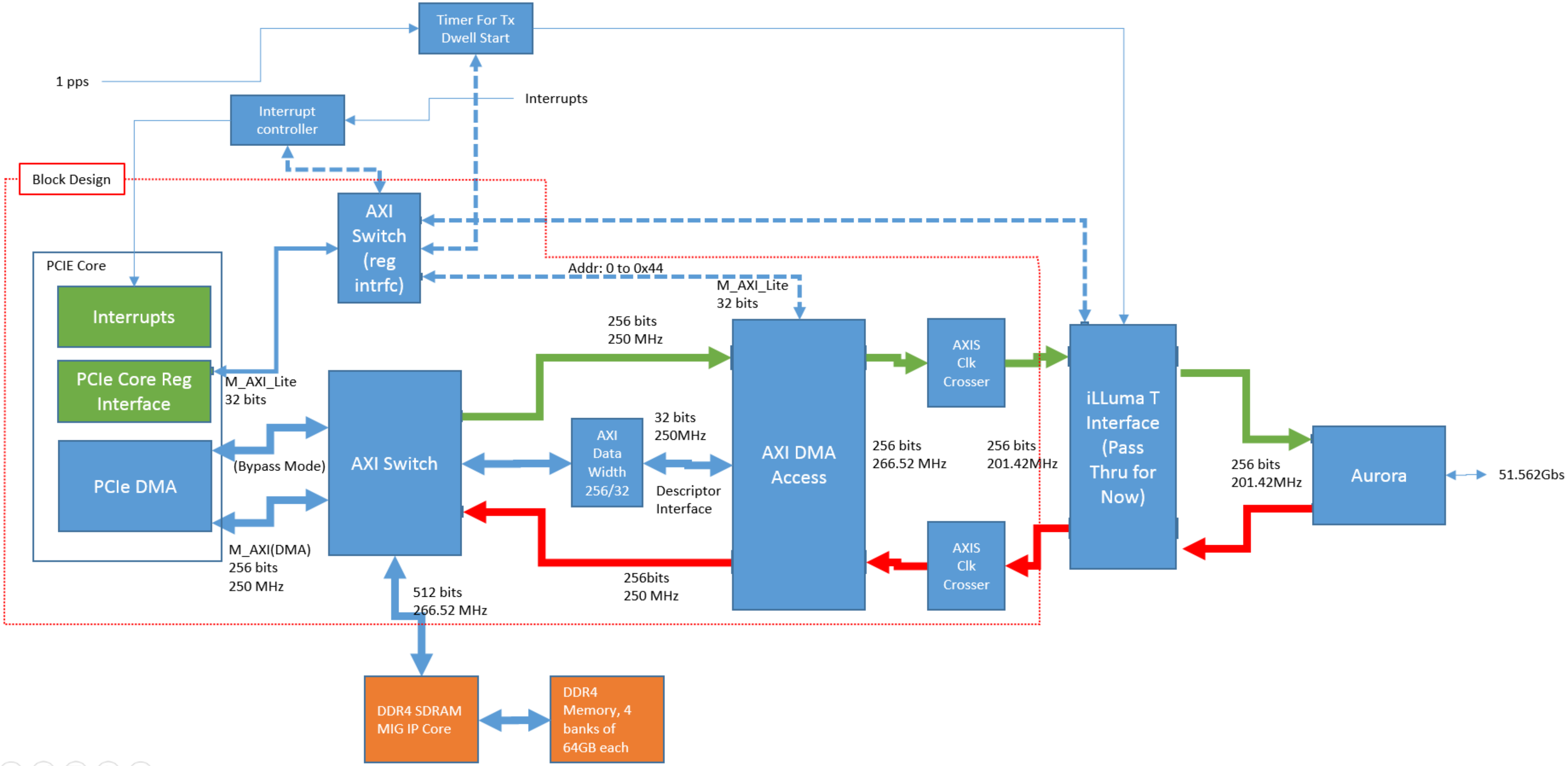


# HiDRA: Status

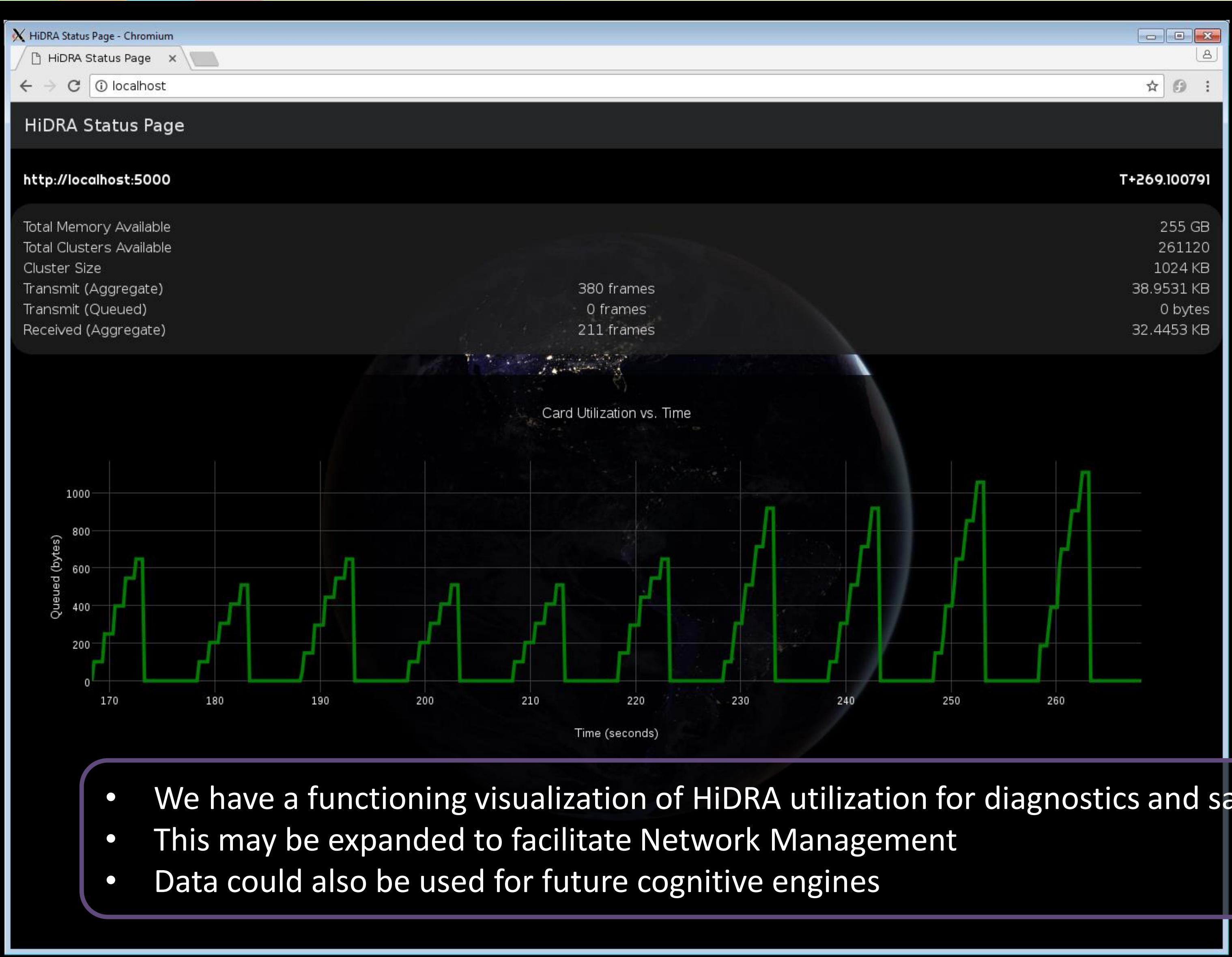
- First iteration of core software is completed
  - Quick prototype intended to demonstrate functionality
- Next iteration will take longer
  - Ideal case: build custom drivers
    - Drivers are a significant bottleneck in proof-of-concept
  - Build instrumentation / monitoring user interface
- Also: add hardware acceleration paths to FPGA
  - Build specific functions into FPGA that can be invoked
  - Need to talk about hw / sw interface for this …
  - ... as well as the specific functions to be included ...
    - … which will likely grow over time

# Current Hardware

## ISS Reference Implementation



# HiDRA
# Visualization of HiDRA Status



HiDRA Status Page - Chromium

HiDRA Status Page

localhost

HiDRA Status Page

http://localhost:5000 T+269.100791

| | | |
|---|---|---|
| Total Memory Available | | 255 GB |
| Total Clusters Available | | 261120 |
| Cluster Size | | 1024 KB |
| Transmit (Aggregate) | 380 frames | 38.9531 KB |
| Transmit (Queued) | 0 frames | 0 bytes |
| Received (Aggregate) | 211 frames | 32.4453 KB |

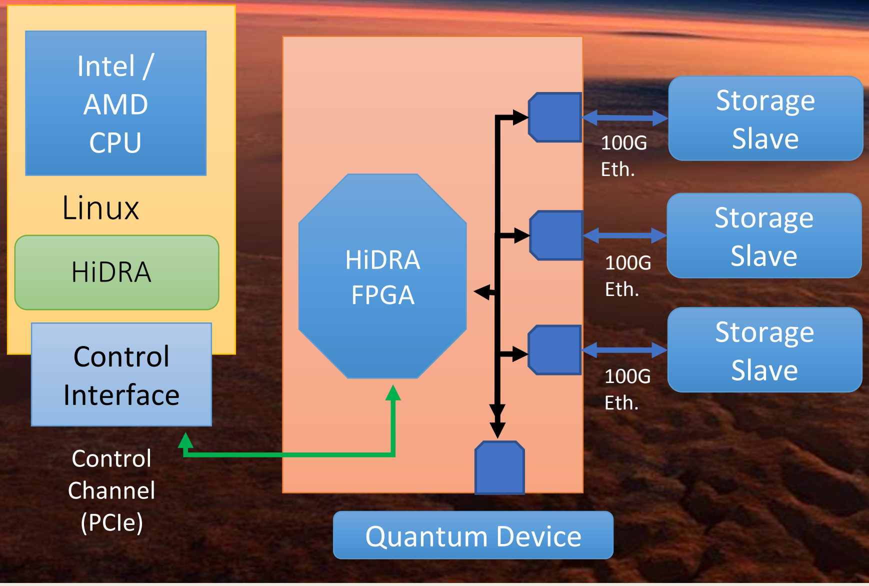
- We have a functioning visualization of HiDRA utilization for diagnostics and sanity checking
- This may be expanded to facilitate Network Management
- Data could also be used for future cognitive engines

# HiDRA and Quantum Key Distribution

## QSwitch

### *QSwitch:*

- A prototype network device capable of digitizing, framing, time-stamping, and storing high-rate instrument data.
- It includes a customized reference implementation of HiDRA built on top of an UltraScale+ FPGA for data plane processing & digitization.
- Linux-based control and monitoring software is included as well.



### *HiDRA Cross-Project Collaboration*

- Project need: Quantum Key Distribution
  - Time-stamping
  - Store raw data for now, for post-processing
  - Integrate with real-time processing in the future
  - High-rate instrument data storage
  - High-rate instrument data networking
- Approach
  - Uses existing hardware and software
    - BittWare boards, HiDRA control prototype
  - Some extension is necessary
    - Digitization, framing, and timestamps
      - Reusable for other projects!
    - Real-time quantization and pre-processing
  - Horizontal scaling to support high-rate storage
  - Should not require one-off work to execute
    - HW and SW is on path for both projects
- Benefits
  - Avenue to prove viability of HiDRA and QKD
    - Naturally evolves both projects
  - Offers real value to ongoing experiment
  - Low additional effort and cost

# HiDRA

## *Next Steps*

- Implement HiDRA solution for ISS
- Test 10/25 Gbps Ethernet connection
- Survey of discovery protocols for local networks
  - Prototype of our own should be done within next month or so
  - LLDP-based capability advertisements
  - Close coordination with STRS to enumerate radio capabilities
- Integration of SDN platform in HiDRA
  - Exploring hierarchical software-defined networking approach
  - Determine architectures to address a range of mission classes