High Performance Communications Based on Dynamic Lightpaths: OMNInet and OptIPuter

Joe Mambretti, Director, (j-mambretti@northwestern.edu)
International Center for Advanced Internet Research (www.icair.org)
Director, Metropolitan Research and Education Network (www.mren.org)
Partner, StarLight/STAR TAP, PI-OMNINet (www.icair.org/omninet)

JET Workshop on Optical Network Testbeds
National Science Foundation
Arlington, Va.

April 19, 2005

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Introduction to iCAIR:

Accelerating Leading Edge Innovation and Enhanced Global Communications through Advanced Internet Technologies, in Partnership with the Global Community

- **Creation and Early Implementation of Advanced Networking Technologies - The Next Generation Internet All Optical Networks, Terascale Networks**
- **Advanced Applications, Middleware, Large-Scale Infrastructure, NG Optical Networks and Testbeds, Public Policy Studies and Forums Related to NG Networks**

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Forum Issues

- Optical Network Testbed Attributes
- Research Goals
- Topology
- Equipment
- Schedule
- Current Status
- Thoughts on Major Considerations/Issues for JET Member Plans for Network Evolution
  - Observe ONT Results
  - Follow the Lightpaths

Designing a New Communications Architecture

- Multiple vs One Network
- Core Infrastructure: a Distributed Optical Infrastructure Not a Traditional Network
- Distributed vs Centralized Control
- Distributed vs Centralized Management
- Elimination of Traditional Hierarchy
- Provide for Transparency
- Utilize All Layers vs L3 Only
- Utilize Potential of Advanced Optic
- Timeline for Implementation Began Several Years Ago

The Move to Data-Intensive Science & Engineering-e-Science Community Resources

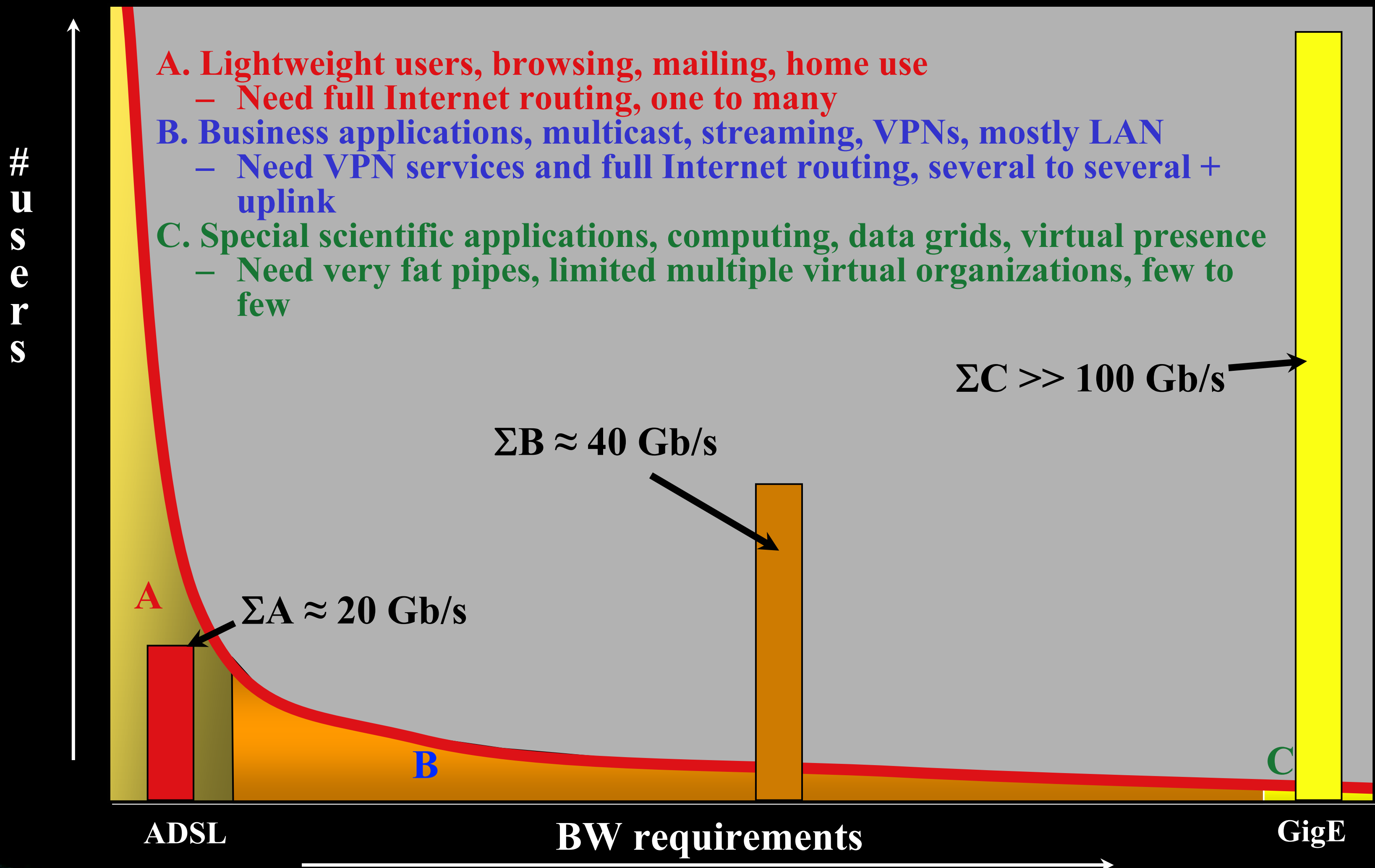
Source: Larry Smarr

Perspective: Segmented Bandwidth Requirements

A. Lightweight users, browsing, mailing, home use
- Need full Internet routing, one to many

B. Business applications, multicast, streaming, VPNs, mostly LAN
- Need VPN services and full Internet routing, several to several + uplink

C. Special scientific applications, computing, data grids, virtual presence
- Need very fat pipes, limited multiple virtual organizations, few to few



Courtesy of Cees de Laat, Univ of Amsterdam

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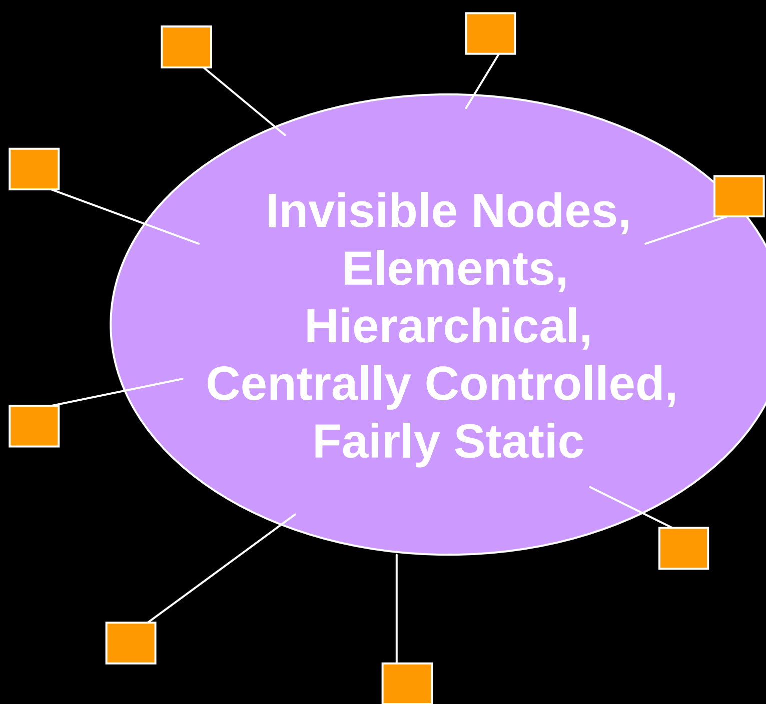
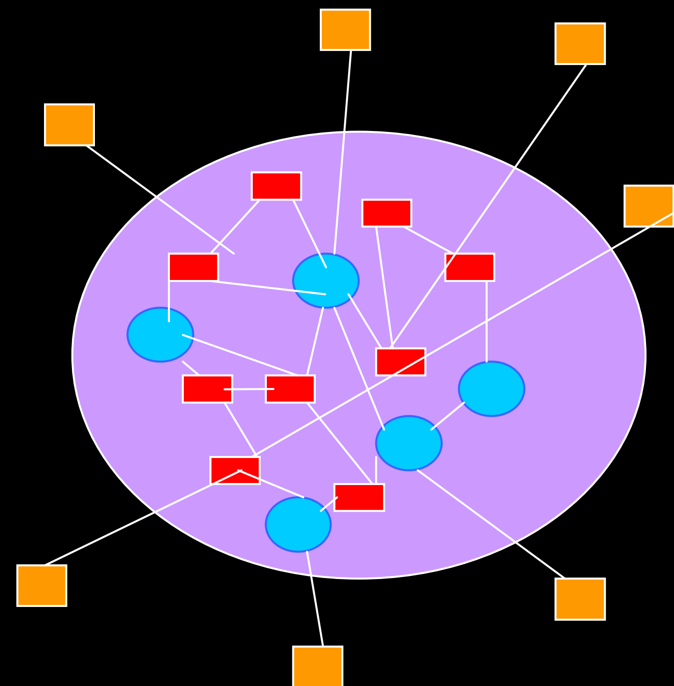
LambdaGrid Control Plane Paradigm Shift

Traditional Provider Services: Invisible, Static Resources, Centralized Management

Distributed Device, Dynamic Services, Visible & Accessible Resources, Integrated As Required By Apps



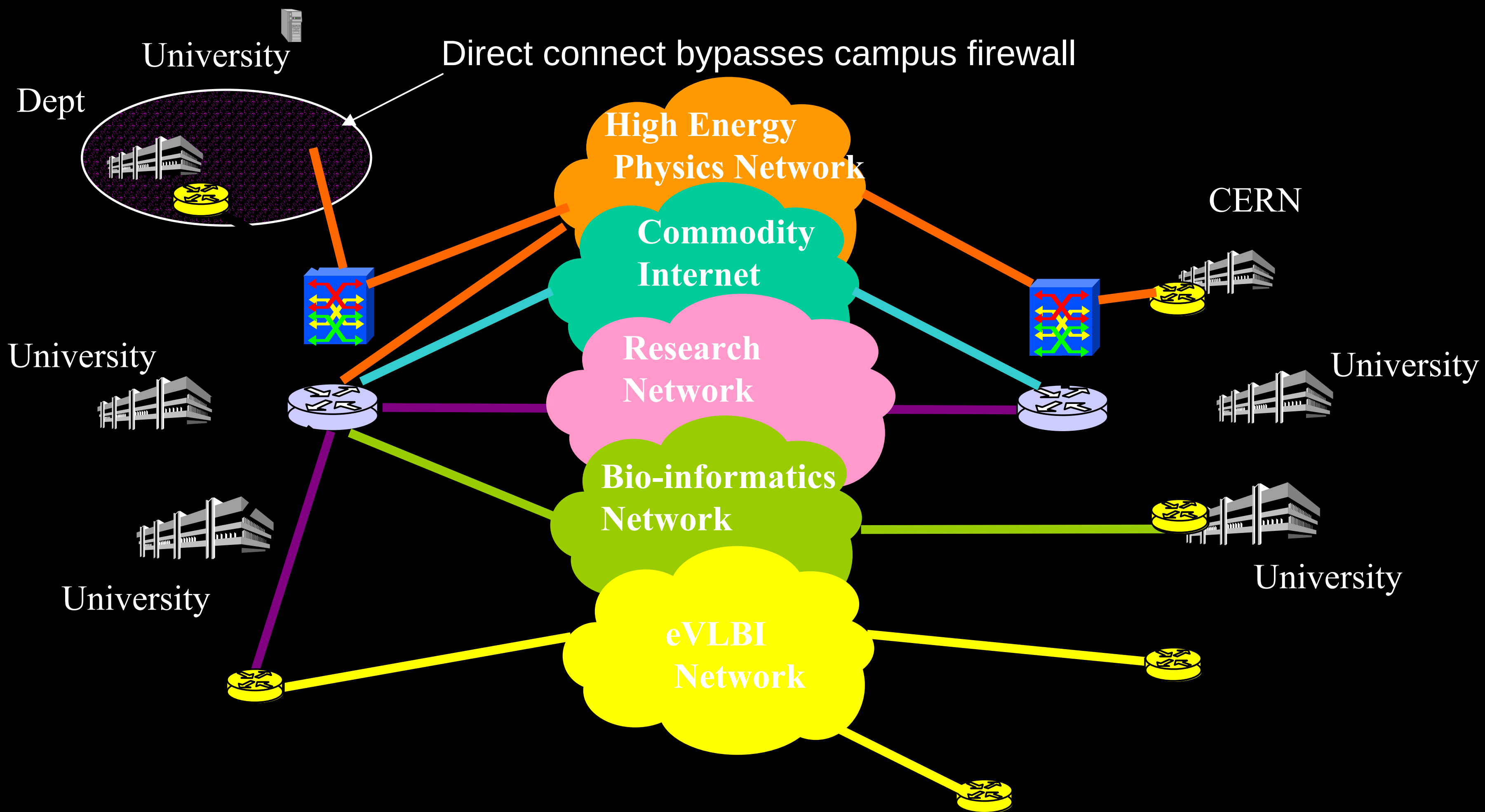
Limited Functionality, Flexibility



Unlimited Functionality, Flexibility

Ref: OptIPuter Backplane Project, UCLP

Creation of Application Optical VPNs



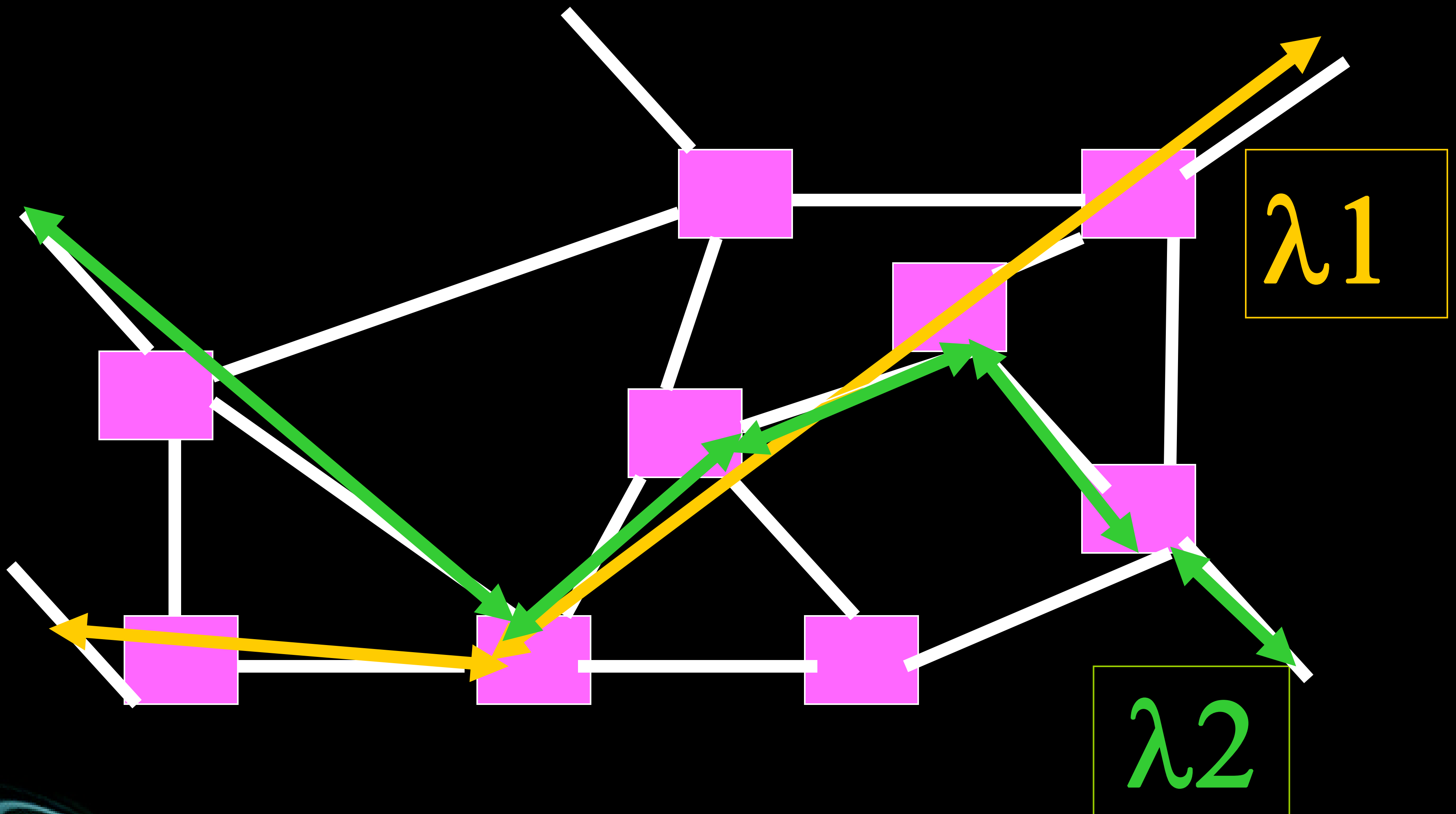
Source: Bill St. Arnaud

Lightpath Data Channels Within Fiber

- **Data Over Light – Technologies That Enable *Dynamic* vs Static Lightpaths**

Dynamic DWDM With Sophisticated Signaling and Control

Prototyping The Global Lambda Grid in Chicago:
A Photonic-Switched Experimental Network of Light Paths



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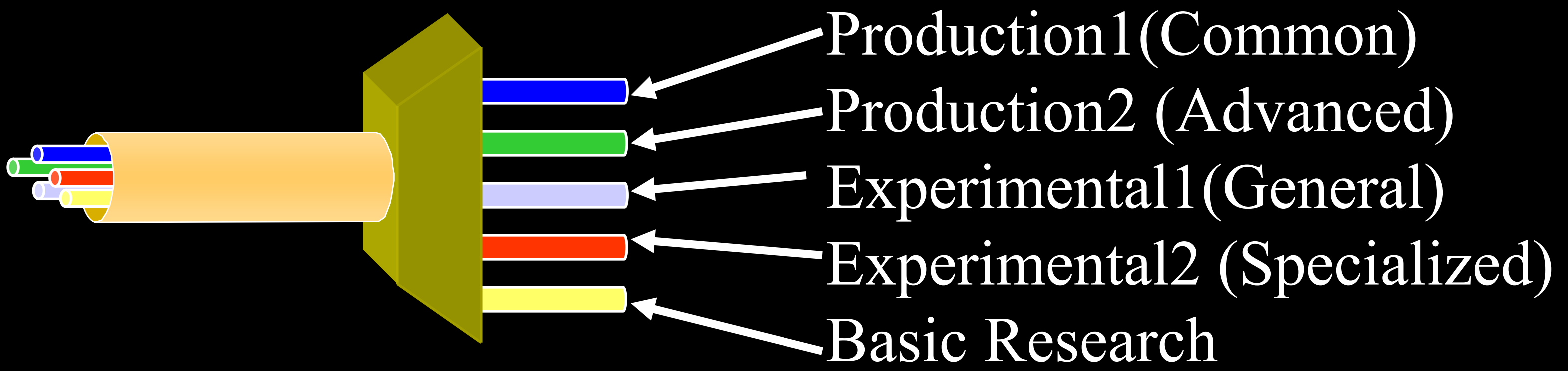
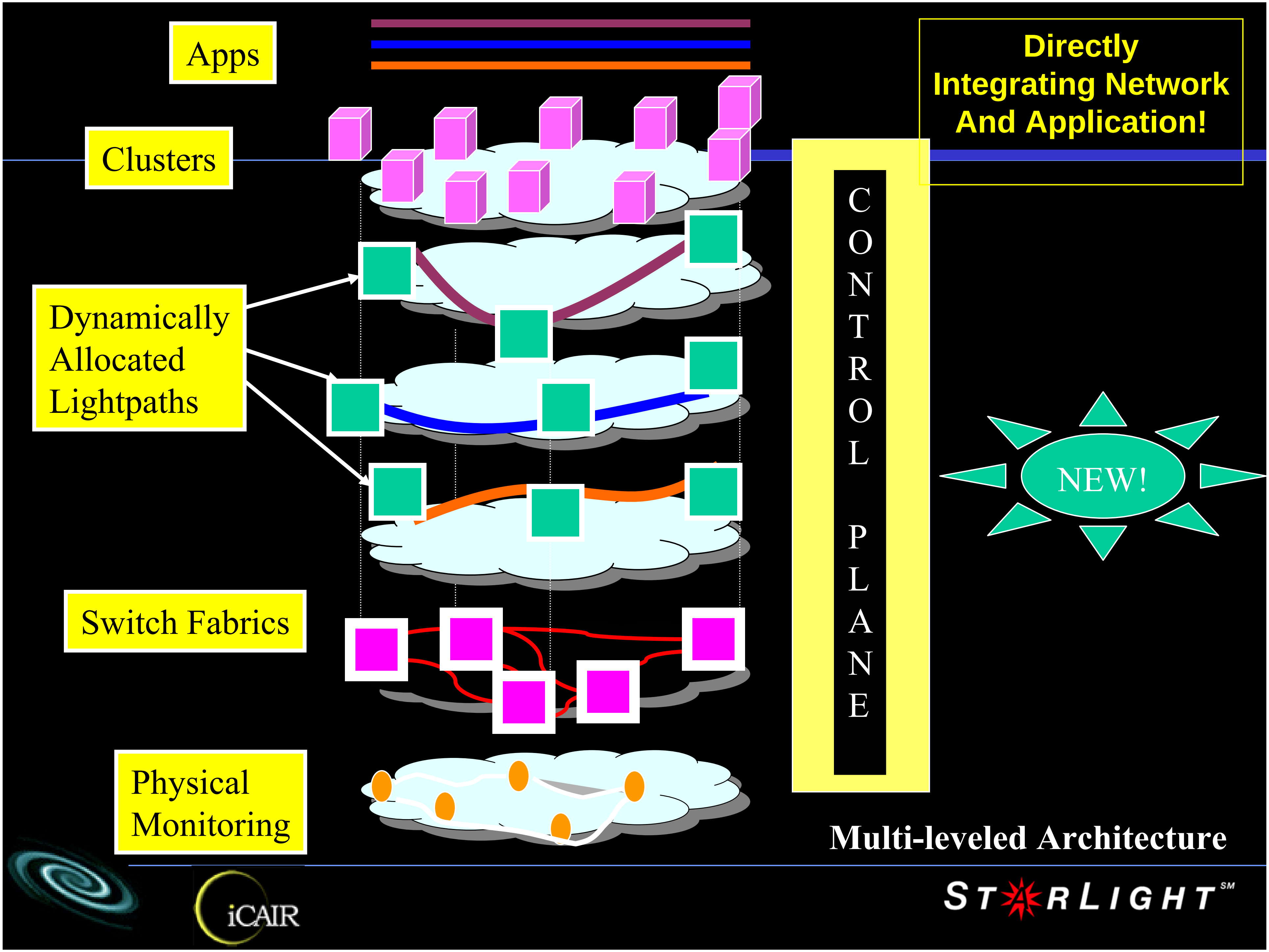
Lightwave Networking



Eg, Experimental2 Could Be Provisioned From Remote Instruments In Other Countries Directly to University Labs –
Finally, Separate Networks On the Same Infrastructure!


Apps
Clusters
Dynamically Allocated Lightpaths
Switch Fabrics
Physical Monitoring
CONTROL PLANE
Directly Integrating Network And Application!
NEW!
Multi-leveled Architecture
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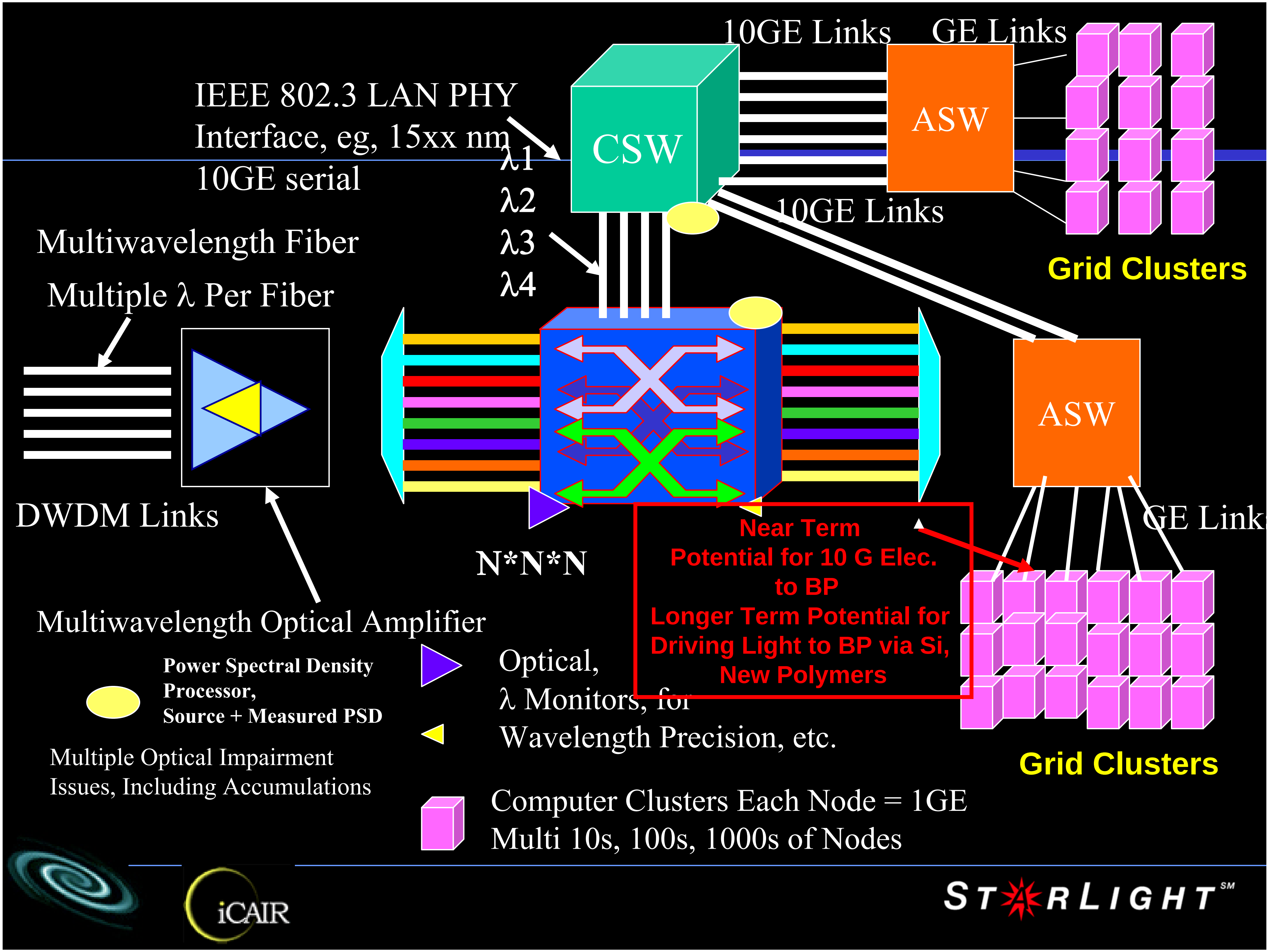
STARLIGHT SM



10GE Links
GE Links
IEEE 802.3 LAN PHY
Interface, eg, 15xx nm
10GE serial
CSW
ASW
λ1
λ2
λ3
λ4
10GE Links
Multiwavelength Fiber
Multiple λ Per Fiber
Grid Clusters
DWDM Links
N*N*N
ASW
GE Links
Near Term
Potential for 10 G Elec.
to BP
Longer Term Potential for
Driving Light to BP via Si,
New Polymers
Multiwavelength Optical Amplifier
Power Spectral Density
Processor,
Source + Measured PSD
Optical,
λ Monitors, for
Wavelength Precision, etc.
Multiple Optical Impairment
Issues, Including Accumulations
Grid Clusters
Computer Clusters Each Node = 1GE
Multi 10s, 100s, 1000s of Nodes
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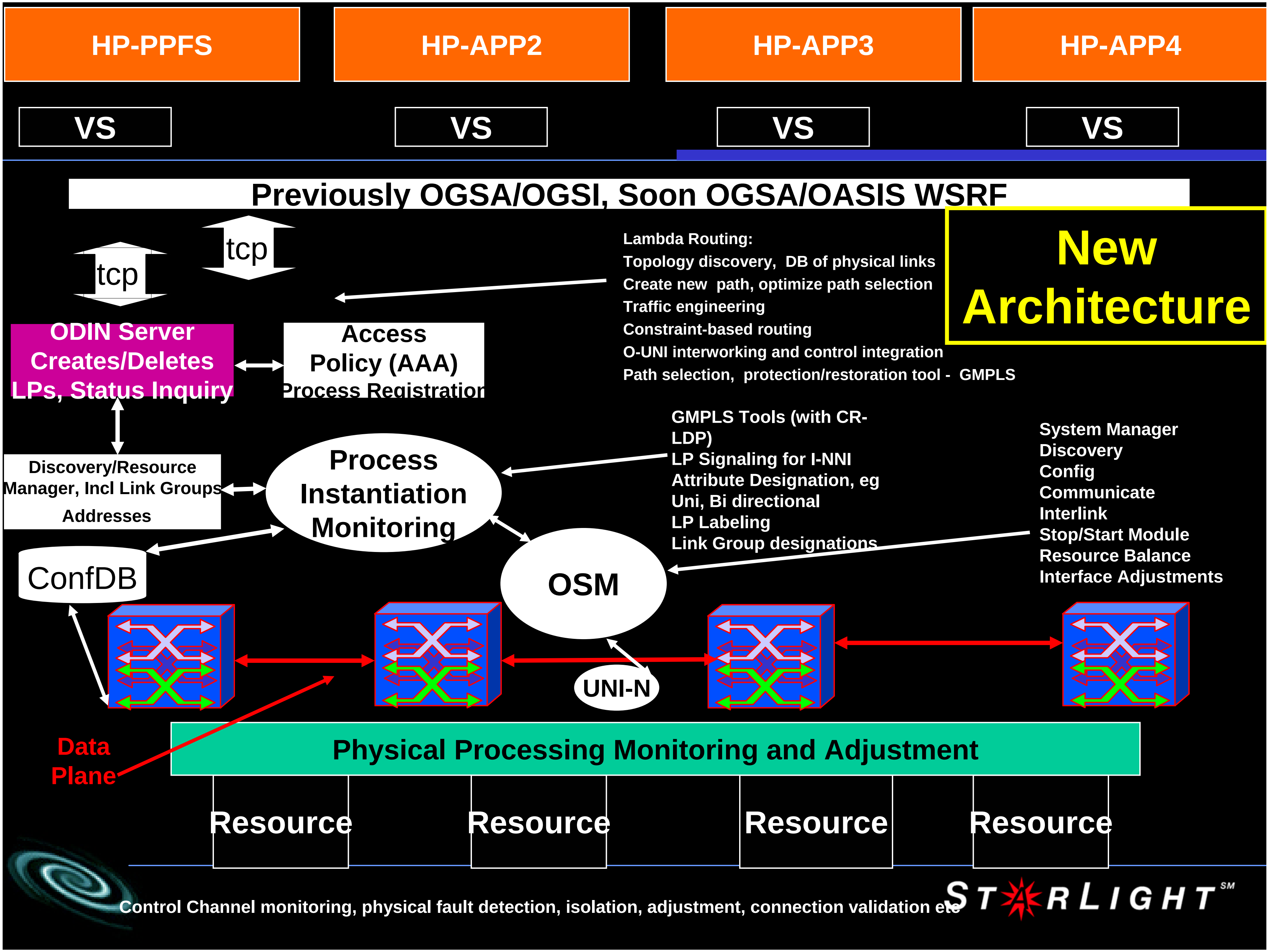

HP-PPFS
HP-APP2
HP-APP3
HP-APP4
VS
VS
VS
VS
Previously OGSA/OGSI, Soon OGSA/OASIS WSRF
New Architecture
tcp
tcp
Lambda Routing:
Topology discovery, DB of physical links
Create new path, optimize path selection
Traffic engineering
Constraint-based routing
O-UNI interworking and control integration
Path selection, protection/restoration tool - GMPLS
ODIN Server Creates/Deletes LPs, Status Inquiry
Access Policy (AAA) Process Registration
GMPLS Tools (with CR-LDP)
LP Signaling for I-NNI
Attribute Designation, eg
Uni, Bi directional
LP Labeling
Link Group designations
System Manager
Discovery
Config
Communicate
Interlink
Stop/Start Module
Resource Balance
Interface Adjustments
Discovery/Resource Manager, Incl Link Groups Addresses
Process Instantiation Monitoring
ConfDB
OSM
UNI-N
Data Plane
Physical Processing Monitoring and Adjustment
Resource
Resource
Resource
Resource
Control Channel monitoring, physical fault detection, isolation, adjustment, connection validation etc
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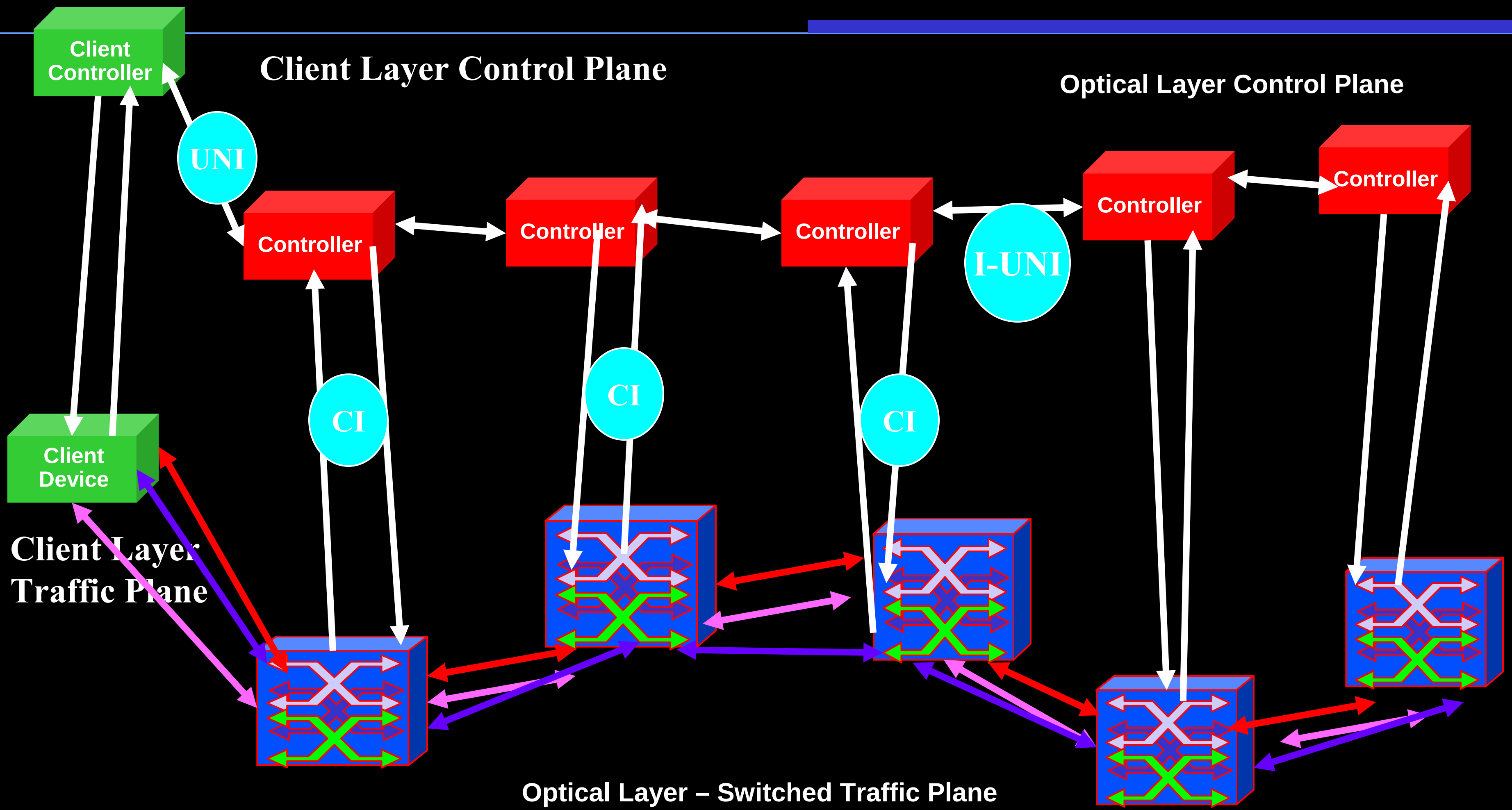
Optical Layer Control Plane



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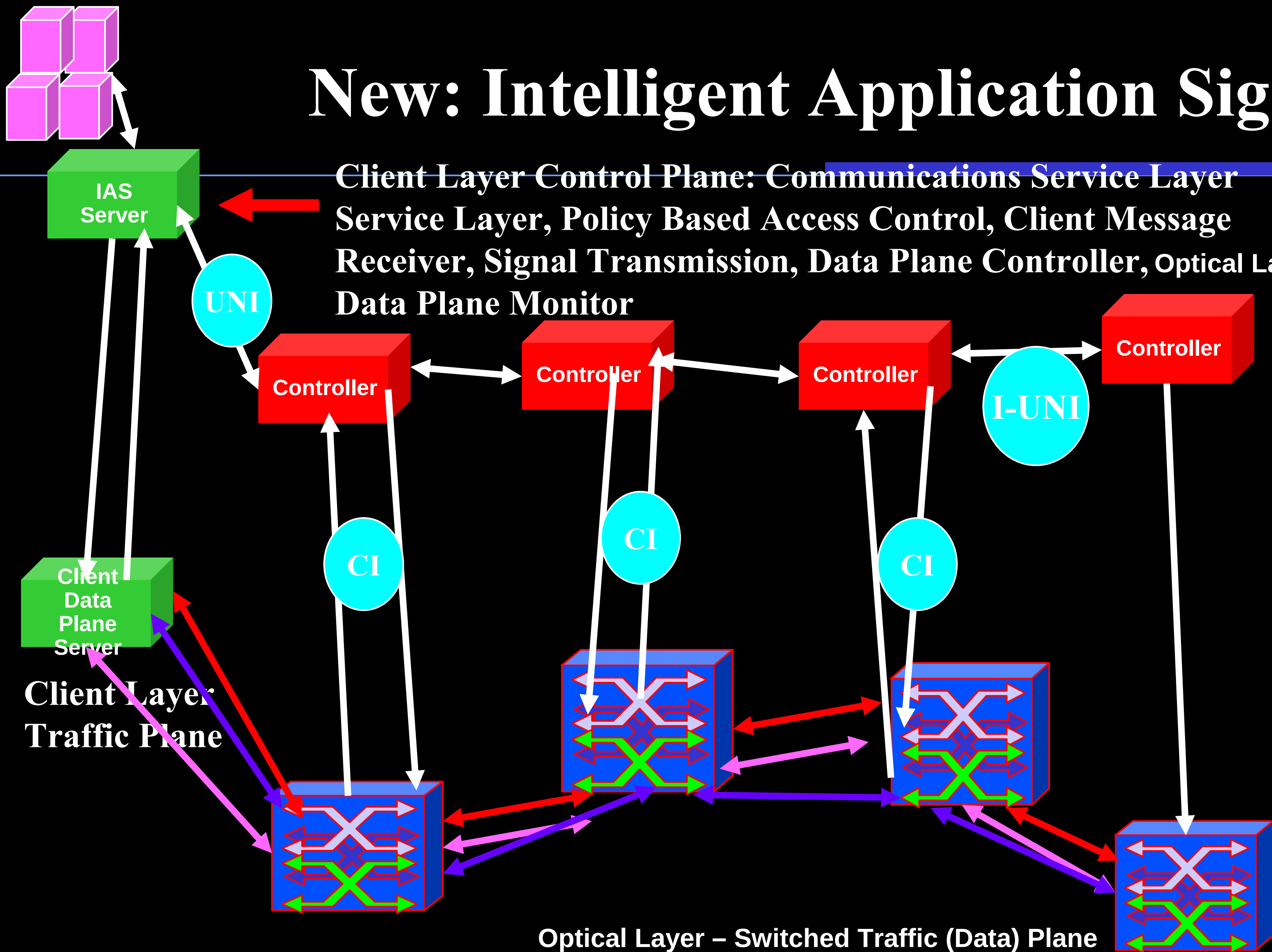
New: Intelligent Application Signaling *

Client Layer Control Plane: Communications Service Layer Service Layer, Policy Based Access Control, Client Message Receiver, Signal Transmission, Data Plane Controller, Optical Layer Control Plane Data Plane Monitor



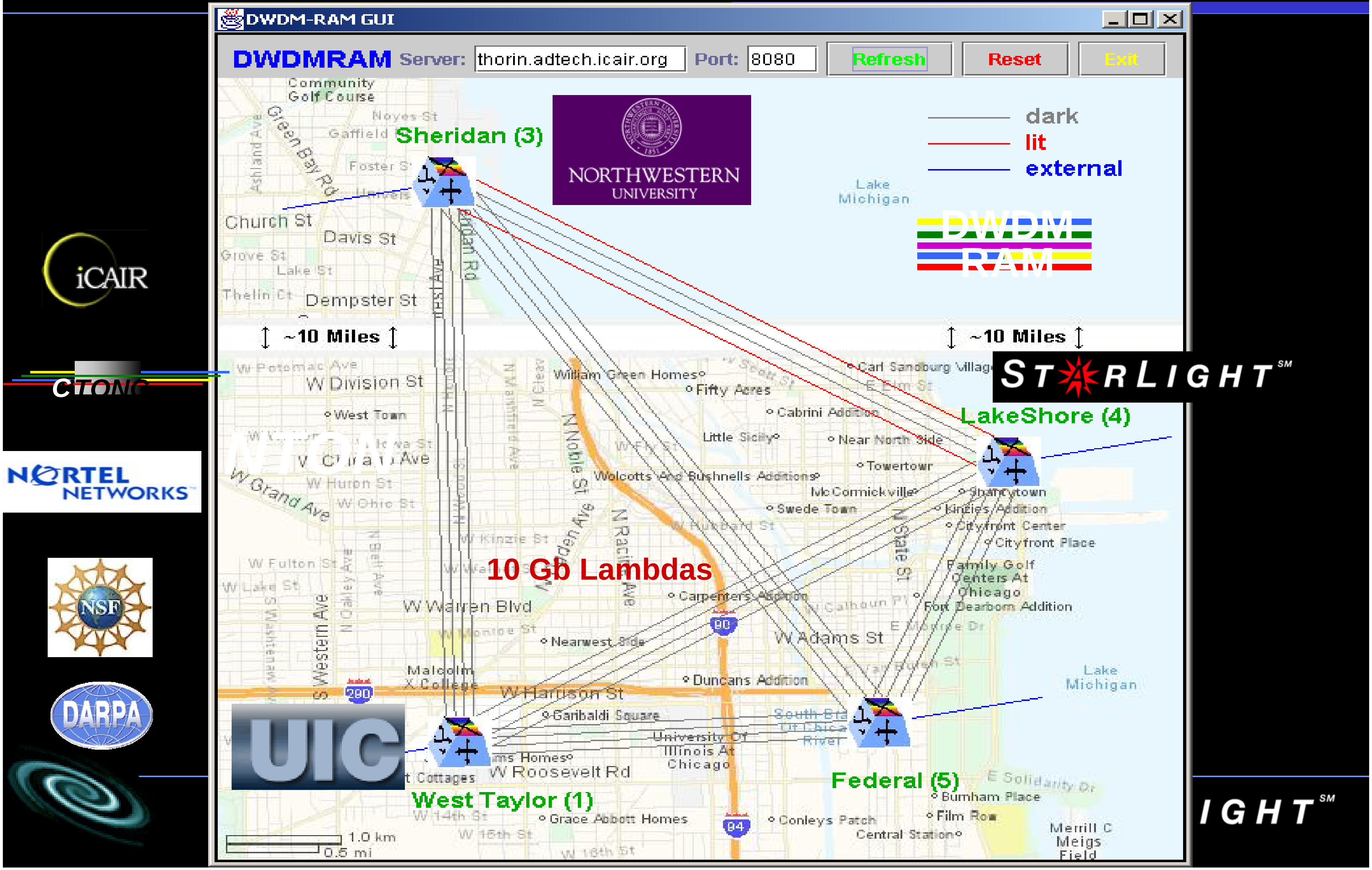
Optical Layer – Switched Traffic (Data) Plane
Multiiservice: Unicast, BiDirectional, Multicast, Burst Switching

* Also Control Signaling, et al

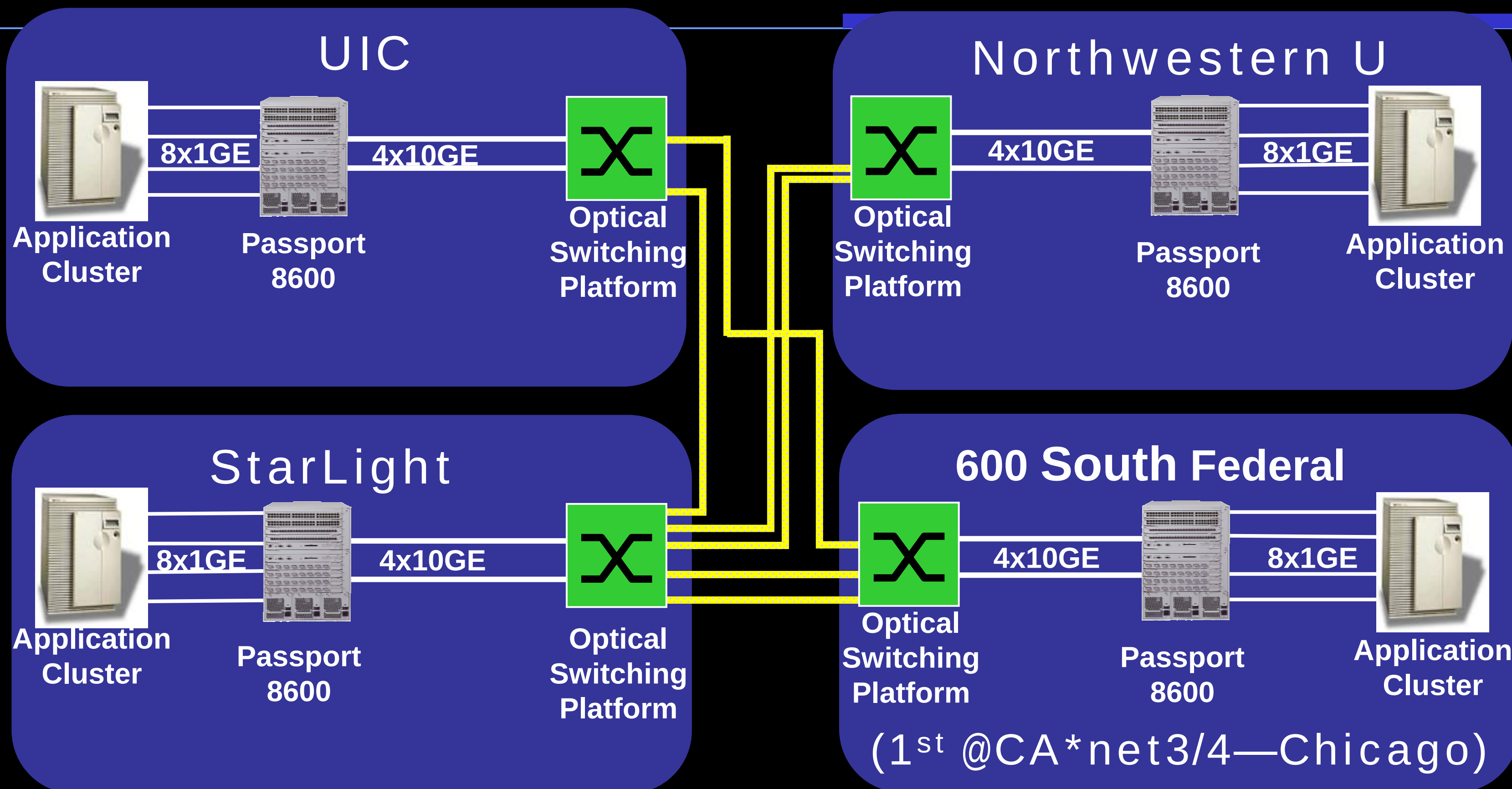
Example Control Plane Signaling Functions

- Multi-Dimensional Signal Processing (Distributed)
- Signal Processing From Clients, e.g., Application, Systems, Device, Including Ad Hoc Demand for Resources
- Signalling ⇔ Management Plane, e.g., Provisioning, Restoration
- Signally ⇔ Resource Management, Including Resource Discovery, Scheduling/Reservation (IETF RSVP Extensions), Resource Contention Resolution
- Lightpath Provisioning (E2E), Deletion, Characterization
  - Via Signaling to Device Interfaces, e.g., Optical Switch Configuration with Tl1, GMPLS, et al
- Data Plane Signal Processing, e.g., Resource Advertisements
- Signaling ⇔ Data Plane, e.g., Wavelength Assignment, Wavelength Routing
- Signaling ⇔ Data Plane Management Systems
- Optimization Signaling ⇔ IETF Extensions for OSPF for Optical Routing
- Et al
- Implications for Signaling Related to Optical Packet Switching

OMNInet
The Metro Area OOO Tesbed



OMNInet Technology Trial: January 2002-05



- Four-site Chicago network world's first 10GE dynamic DWDM based <u>service</u> trial! SONET – Free Zone - individually addressable wavelengths, Step Toward G. 709, and beyond
- A advanced photonic based test bed for all-optical switching and advanced high-speed services
- Partners: SBC, Nortel, iCAIR at Northwestern, EVL, CANARIE, ANL

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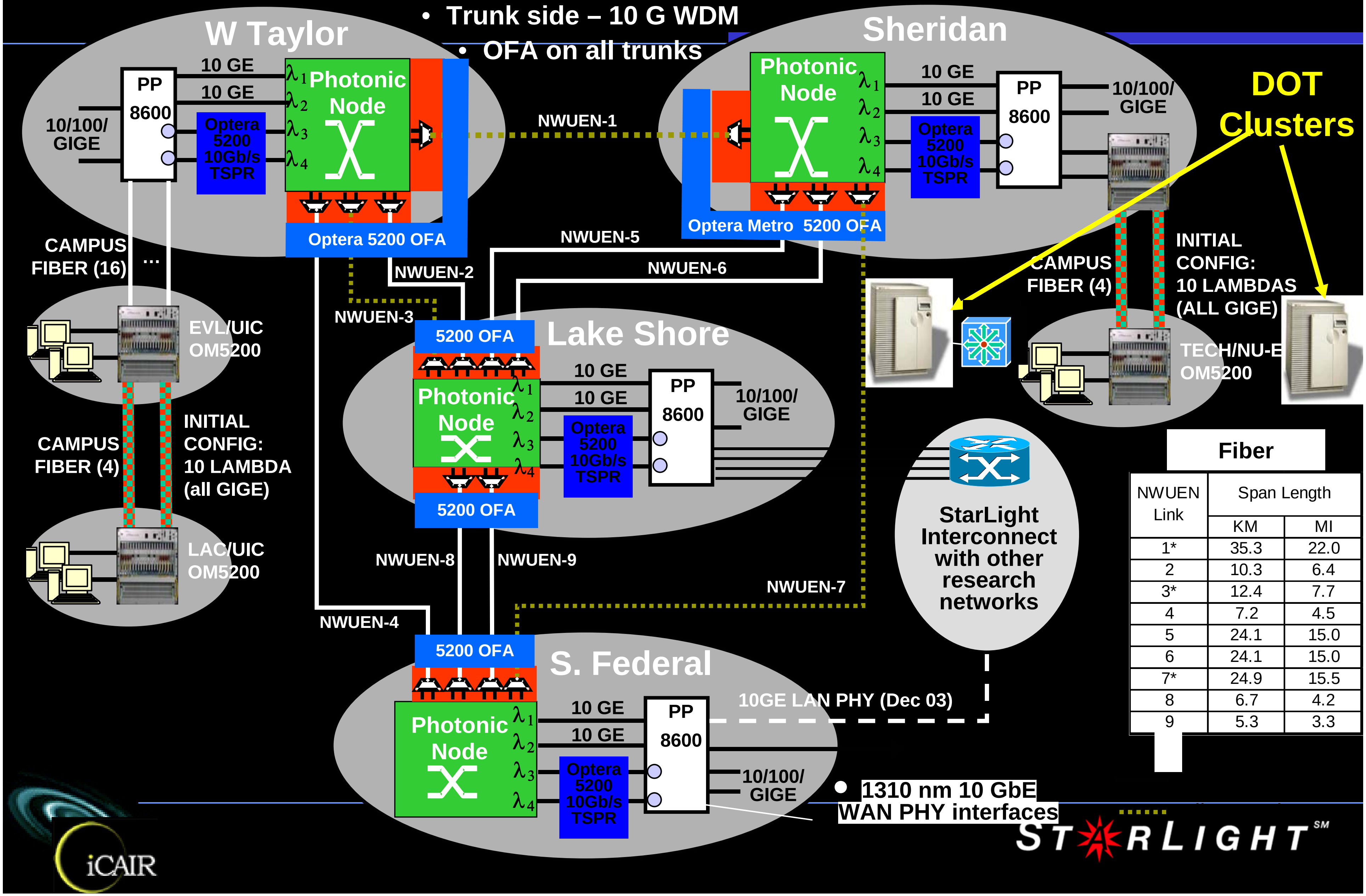
OMNInet Network Configuration

- 8x8x8λ Scalable photonic switch
  - Trunk side – 10 G WDM
    - OFA on all trunks

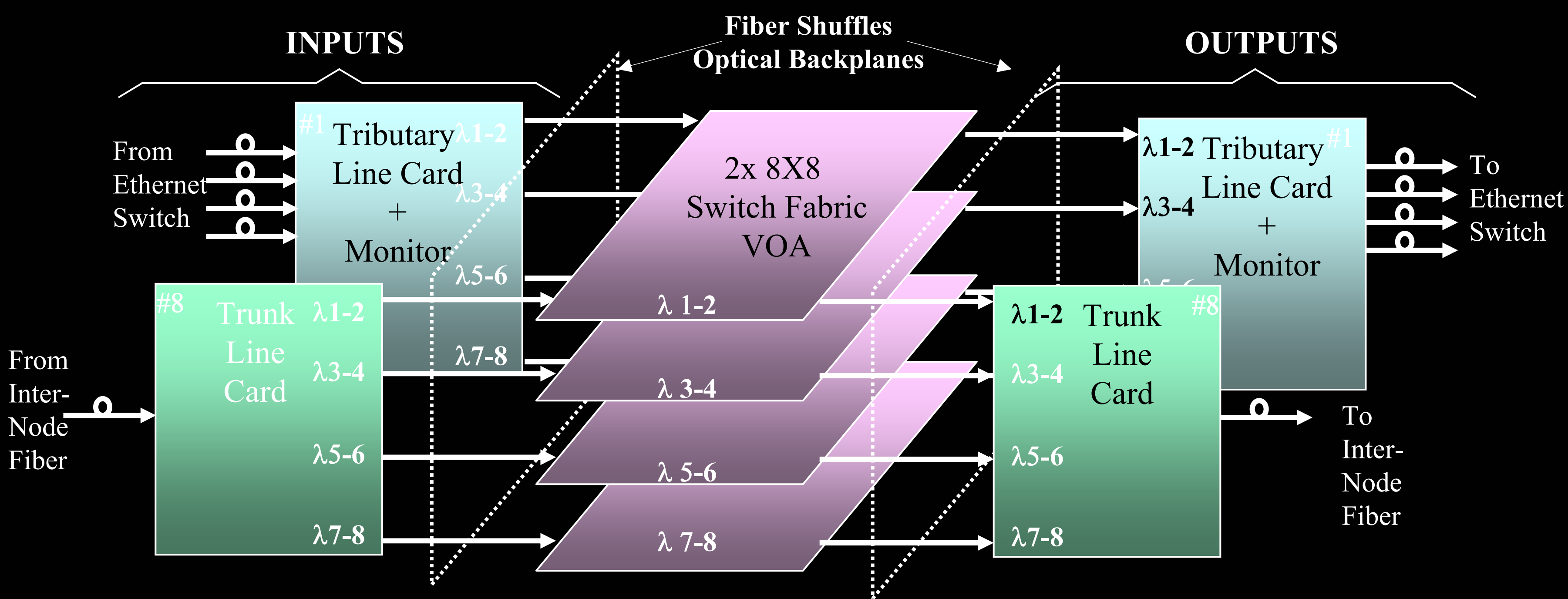


Fiber

NWUEN Link	Span Length	
	KM	MI
1*	35.3	22.0
2	10.3	6.4
3*	12.4	7.7
4	7.2	4.5
5	24.1	15.0
6	24.1	15.0
7*	24.9	15.5
8	6.7	4.2
9	5.3	3.3

Photonic Switch Architecture

• Wavelength plane architecture can connect any input signal of a specific wavelength to any output without wavelength translation.
• Could switch 8 instances of 8 wavelengths.
• Scalable Architecture - Larger Photonic Switch Node 640 x 640 wavelengths using the same architecture was developed.



Source: Kent Felski, Nortel

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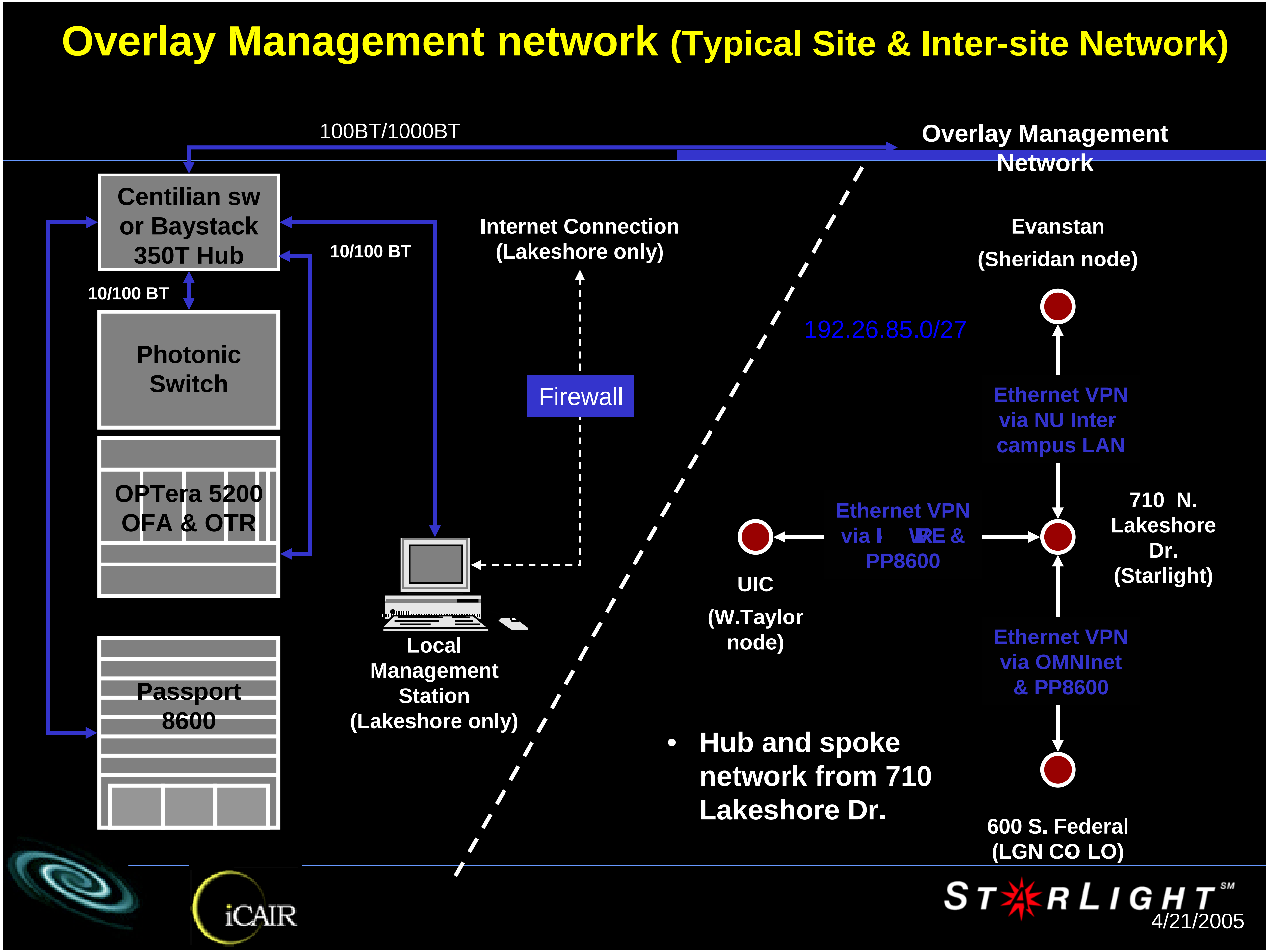
Overlay Management network (Typical Site & Inter-site Network)
100BT/1000BT
Overlay Management Network
Centilian sw or Baystack 350T Hub
10/100 BT
10/100 BT
Photonic Switch
OPTera 5200 OFA & OTR
Passport 8600
Internet Connection (Lakeshore only)
Firewall
Local Management Station (Lakeshore only)
192.26.85.0/27
Evanstan
(Sheridan node)
Ethernet VPN via NU Inter campus LAN
Ethernet VPN via I WIRE & PP8600
UIC (W.Taylor node)
710 N. Lakeshore Dr. (Starlight)
Ethernet VPN via OMNInet & PP8600
600 S. Federal (LGN CO LO)
• Hub and spoke network from 710 Lakeshore Dr.
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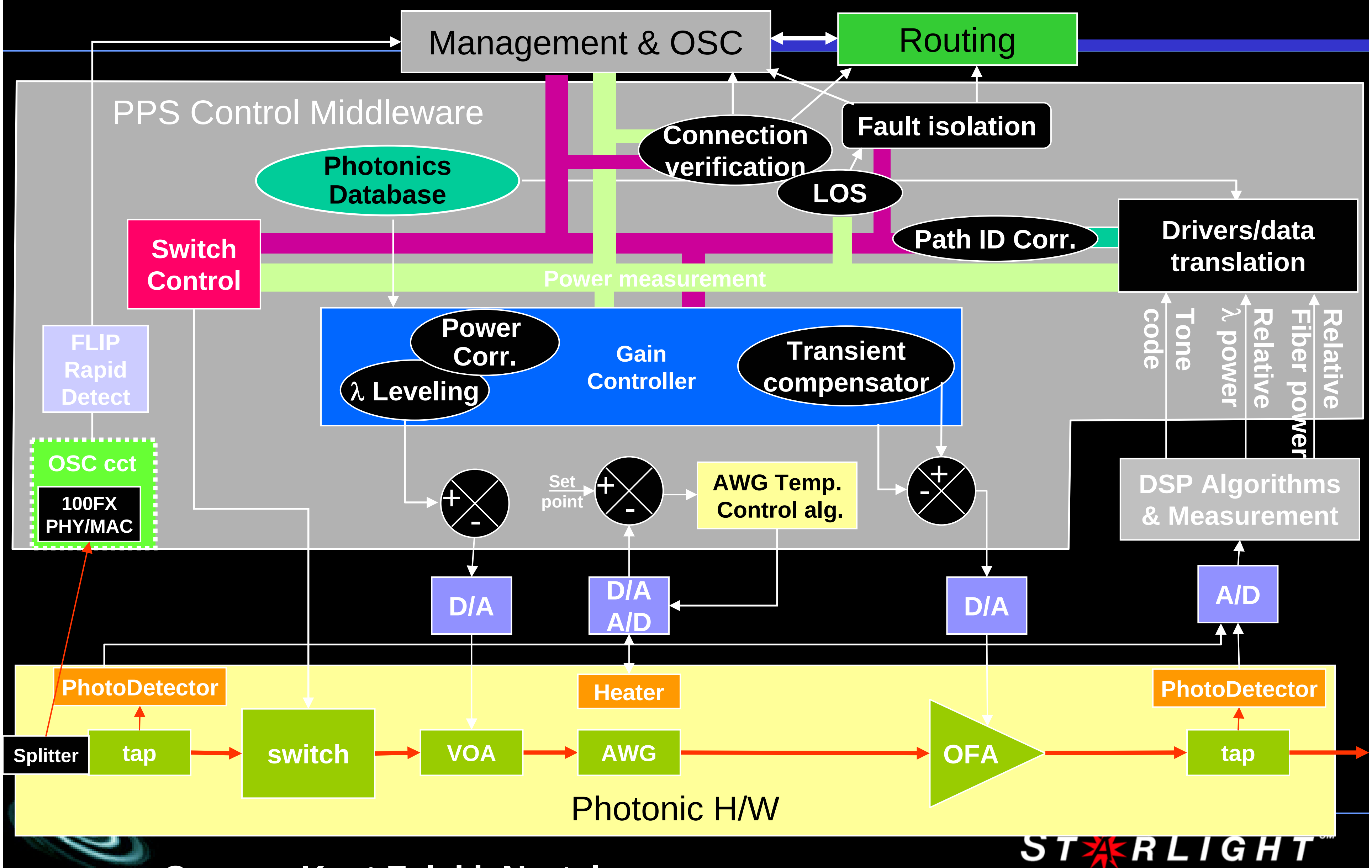
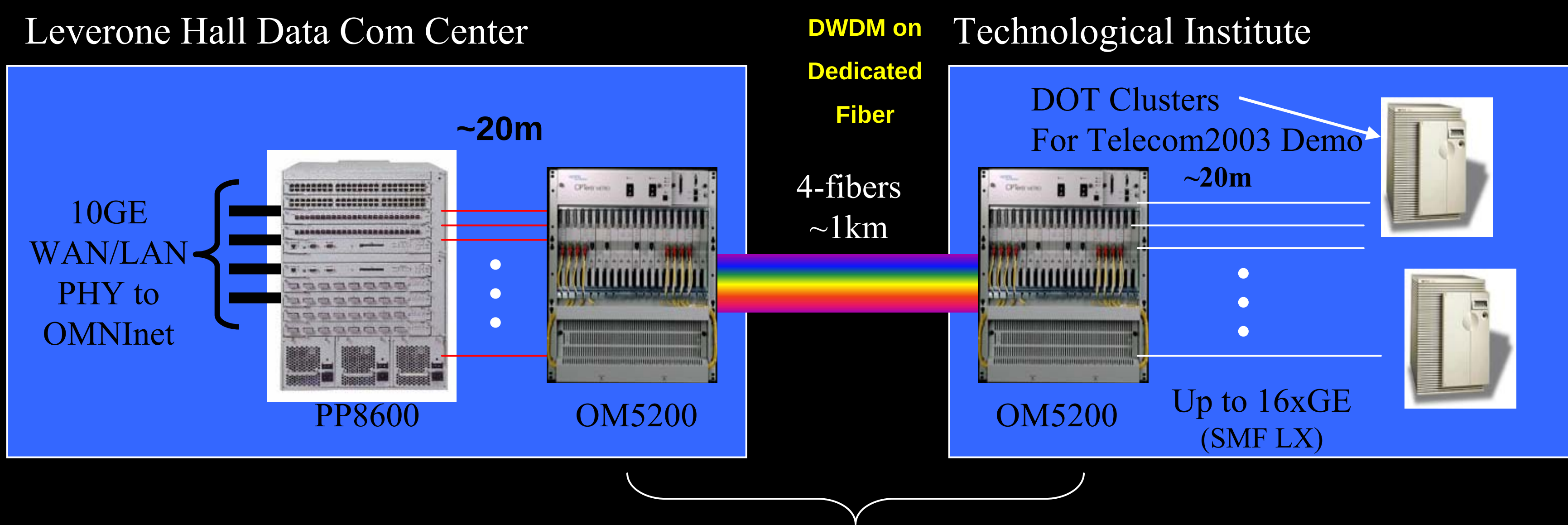
4/21/2005

Photonic Performance Subsystem



Source: Kent Felski, Nortel

Integrating Applications and Lightpaths
iCAIR Grid Clusters and OM5200 DWDM System



DWDM Between Cluster Site and OMNInet Core Node in Evanston

- The implementation is lambdas (unprotected).
- Installed shelf capacity and common equipment permits expansion of up to 16 lambdas through deployment of additional OCLD, and OCI modules.
- A fully expanded OM5200 system is capable of supporting 64 lambdas (unprotected) over the same 4-fiber span.

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GRID Distributed Optical Testbed Components

Cluster

Advanced Photonics

Enviromental Conditioning, Power

Cluster

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Some Results

- Most Lightpaths Had Less Than 10 packets Lost Per Million
- For Stressed Lightpaths, 50 Packets Lost Per Million (~10^{-10} BER)
- Note, However, That Some Measurements Were Limited
- In a Number of Tests, Large Scale Data Streams Were Transported For Many Hours With No Packet Losses (Measured).
- More Than 1000 Successful Lightpath Setup/Teardown Operations
- No Optical Component Failures - Several Electronic Component Failures
- Successful Demonstration of Two New Provider Services
- Successful Demonstration of Two New Internal Optical Transport Capabilities
- SONET/Routers Not Required (Would Have Been a Performance Barrier)
- Great Grid Application Results – Extremely High Performance
- Created and Successfully Demonstrated, Multiple Times (at Metro level, Nationally and Internationally), a Basic Control/Management Plane Architectural Model, & Prototype Implementation
- Demonstrated the Utility of Dynamic Lightpath Switching to High Performance Applications
- Demonstrated the Potential of "Photonic Data Services"

Optical Dynamic Intelligent Network Services (ODIN)

- International Center for Advanced Internet Research
- Electronic Visualization Laboratory
- Laboratory for Advanced Computing, UIC

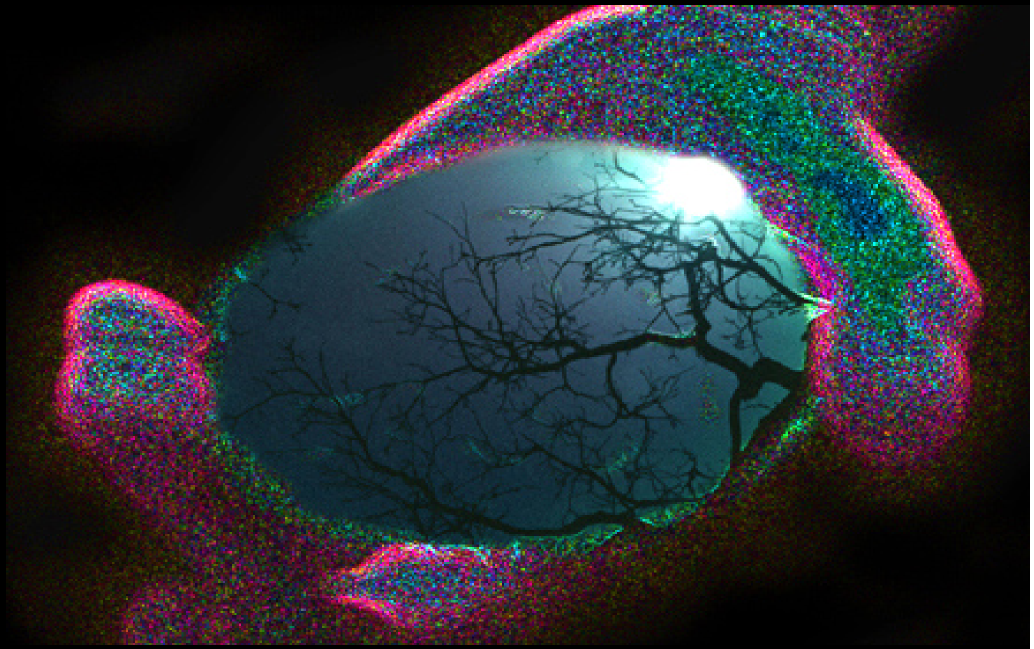
ODIN is mechanism that allows global applications to use intelligent signaling to provision their own international lightpaths to optimize network based resource discovery and performance.
First public demonstration was at iGRID2002 - interdomain application signaling for dynamically provisioned lightpaths

iGrid 2002

United States – Set New World Record for Data Transport

Photonic Data Services

- Laboratory for Advanced Computing, UIC
- National Center for Data Mining, UIC
- International Center for Advanced Internet Research
- SURFnet, NetherLight



At iGRID2002 the LAC, NCDM and iCAIR demonstrated Photonic Data Services (PDS) and set a new data transit record, based on several new protocols designed for high performance optical networks

www.lac.uic.edu, www.icair.org

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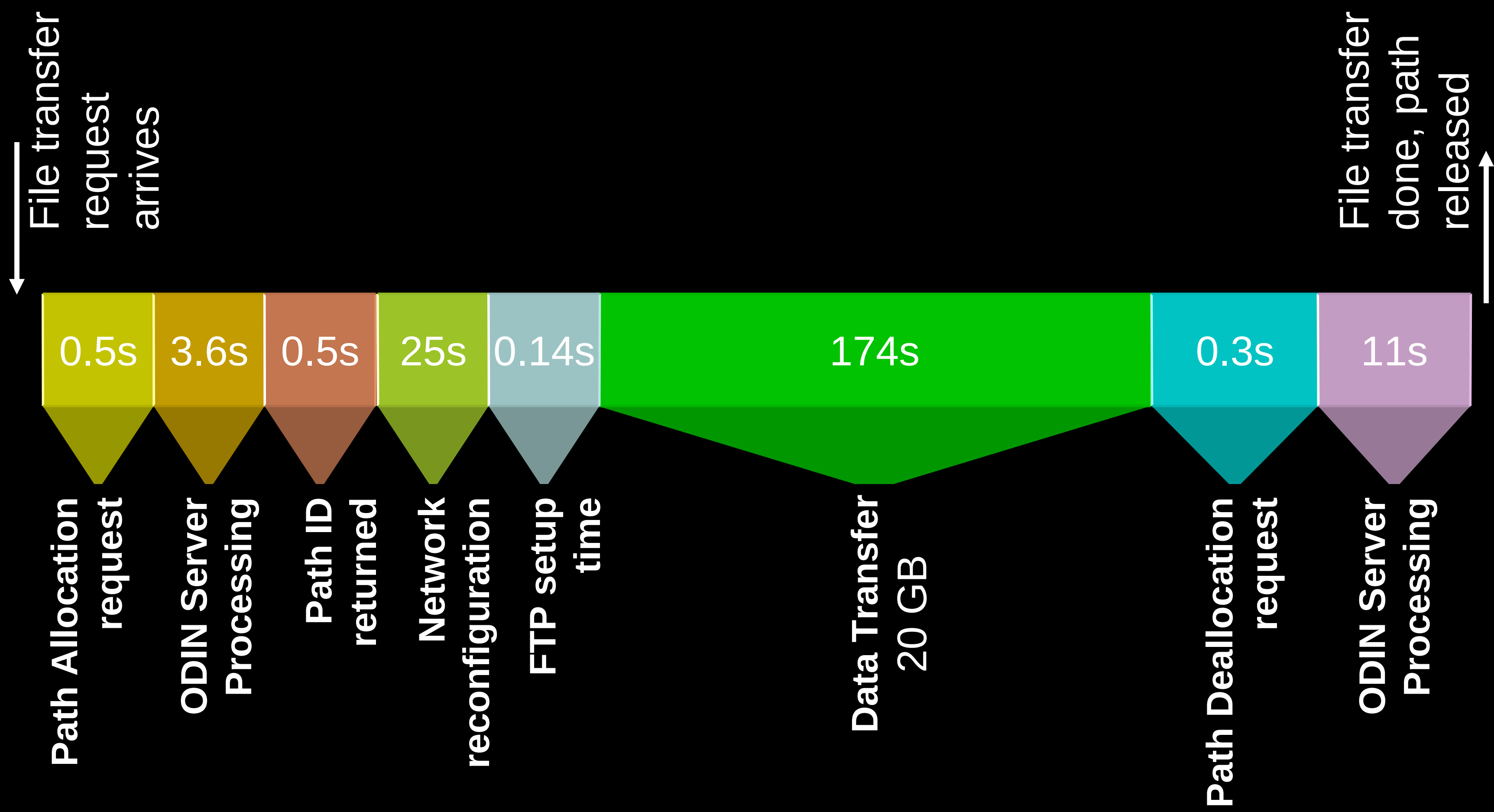
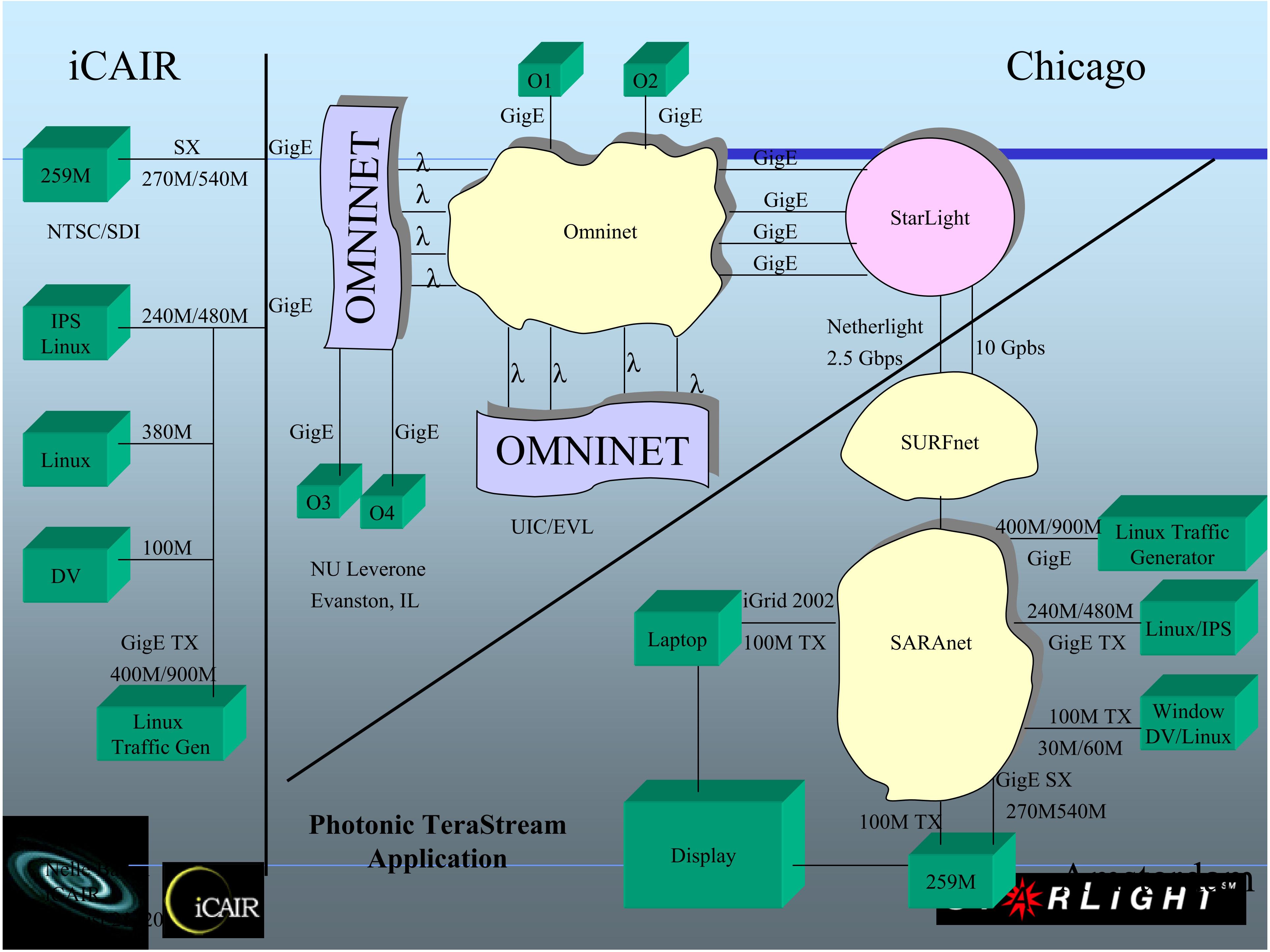
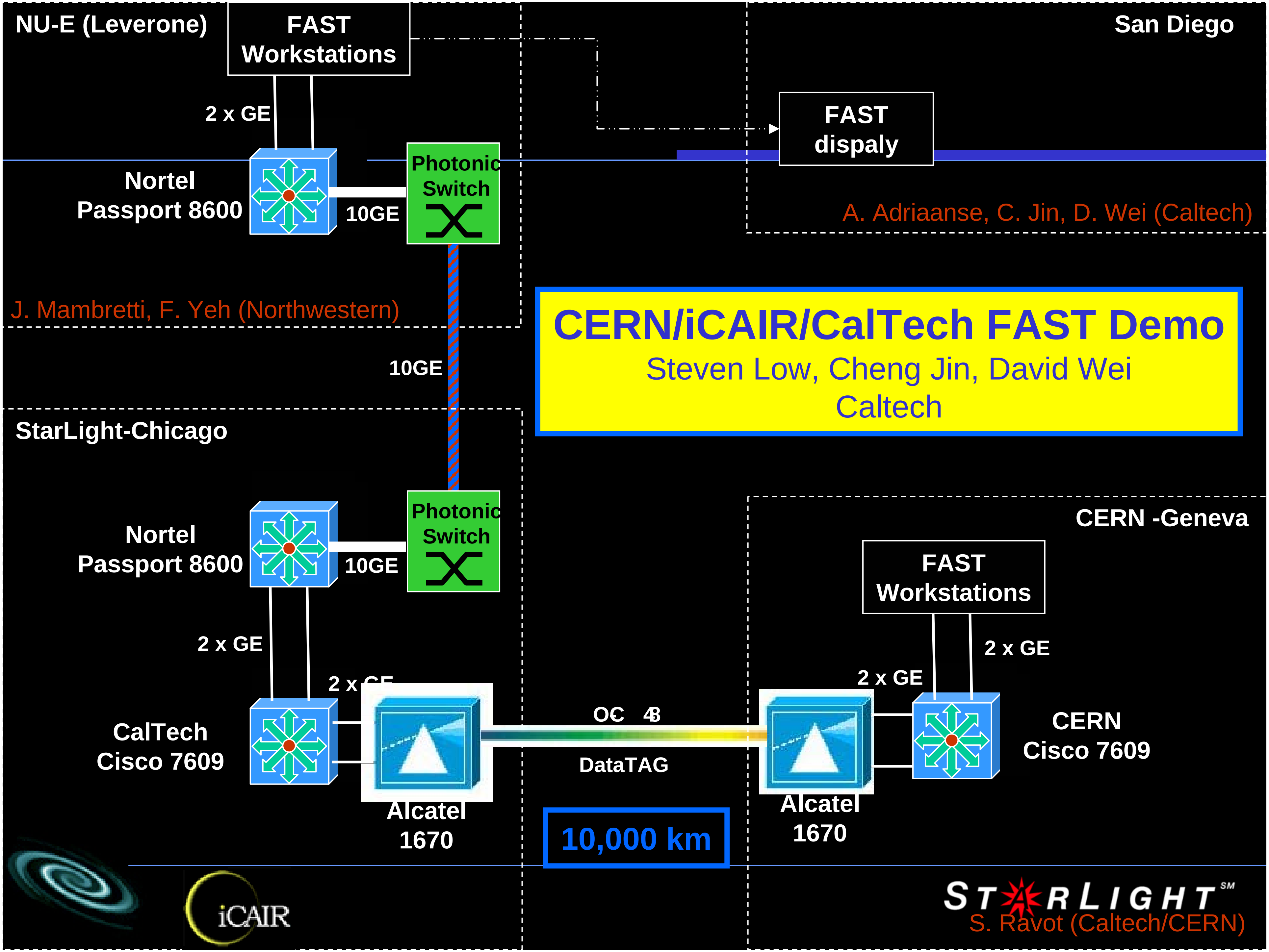
End-to-End Transfer Time



Source: Tal Lavian, Fei Yeh



iCAIR
Chicago
259M
SX
270M/540M
GigE
NTSC/SDI
IPS Linux
240M/480M
Linux
380M
DV
100M
GigE TX
400M/900M
Linux Traffic Gen
OMNINET
O1
O2
GigE
λ
Omninet
StarLight
Netherlight 2.5 Gbps
10 Gpbs
SURFnet
GigE
O3
O4
NU Leverone Evanston, IL
UIC/EVL
Linux Traffic Generator
400M/900M
SARAnet
Linux/IPS
240M/480M
GigE TX
Laptop
iGrid 2002
100M TX
Window DV/Linux
100M TX
30M/60M
GigE SX
270M540M
Display
259M
Photonic TeraStream Application



NU-E (Leverone)
FAST Workstations
2 x GE
Nortel Passport 8600
10GE
Photonic Switch
J. Mambretti, F. Yeh (Northwestern)
San Diego
FAST dispaly
A. Adriaanse, C. Jin, D. Wei (Caltech)
CERN/iCAIR/CalTech FAST Demo
Steven Low, Cheng Jin, David Wei
Caltech
10GE
StarLight-Chicago
Nortel Passport 8600
10GE
Photonic Switch
2 x GE
2 x
CalTech Cisco 7609
Alcatel 1670
OC 48
DataTAG
10,000 km
CERN -Geneva
FAST Workstations
2 x GE
2 x GE
CERN Cisco 7609
Alcatel 1670
iCAIR
STARLIGHT SM
S. Ravot (Caltech/CERN)

DARPA DWDM-RAM Large Scale Data+Dynamic Lambdas – Demonstrated at GGF9 & SC2003

DWDM RAM

HP-PPFS | Data Intensive App2 | Data Intensive App3 | Data Intensive App4

Grid Data Management Services

Data Web Services

Data Grid Services

Grid L3-L7 OGSA Compliant

Dynamic Path Services (ODIN, THOR, etc),OGSA Compliant, Soon WSRF

Dynamic vLANs

Dynamic Lightpaths

Physical Processing Monitoring and Adjustment

New Control Plane And Management Plane Processes

DARPA iCAIR NTONC NORTEL NETWORKS NSF STARLIGHT

SC2004 Demonstration: Control Challenge

Source: Tal Lavian, Thanks to Kees Neggers, Bill St. Arnaud

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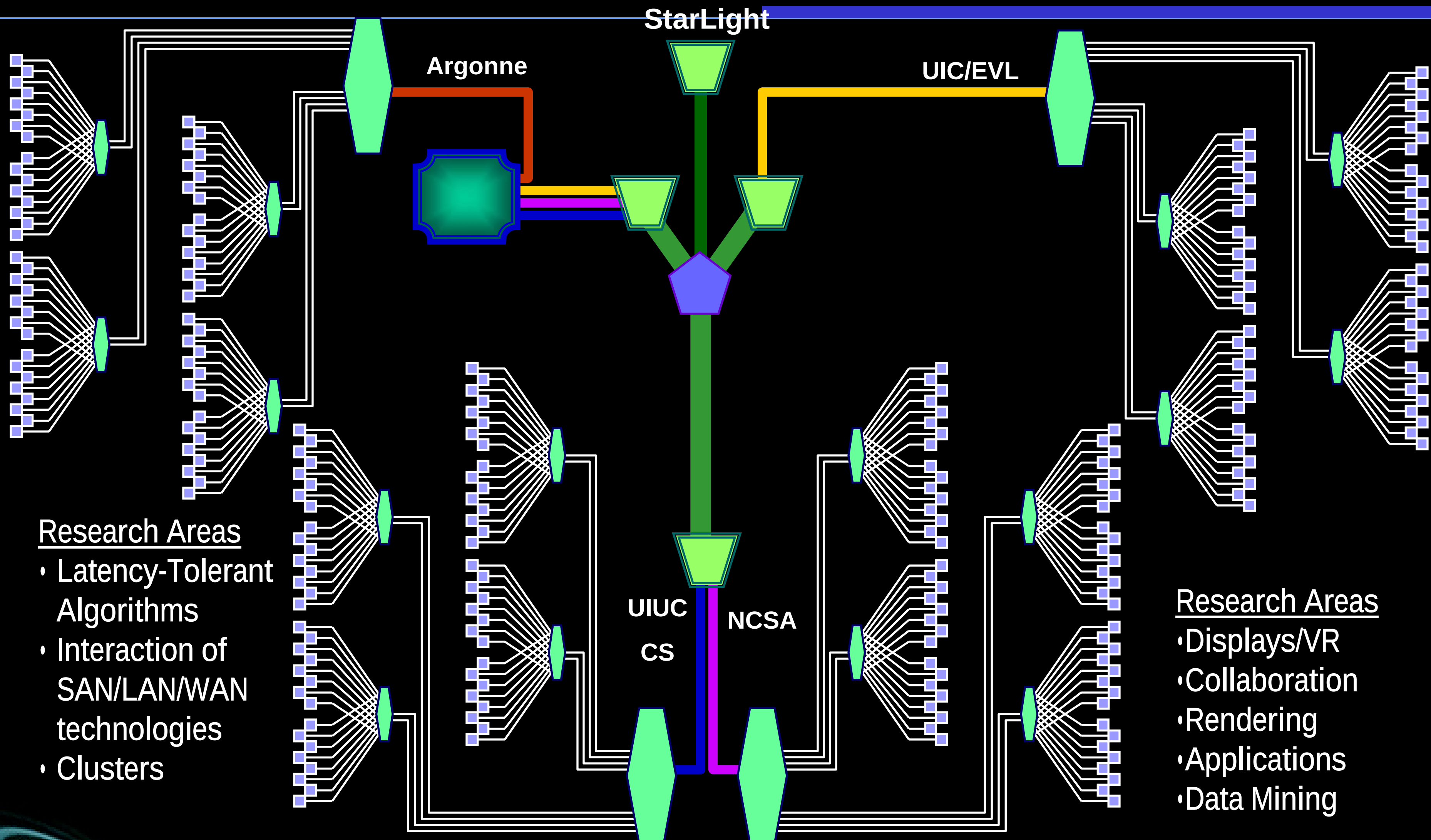
DOT and Illinois' I-WIRE: Distributed Cluster Computing



Research Areas
- Latency-Tolerant Algorithms
- Interaction of SAN/LAN/WAN technologies
- Clusters

Research Areas
- Displays/VR
- Collaboration
- Rendering
- Applications
- Data Mining

Source: Charlie Catlett

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OptIPuter

Dr. Larry Smarr (PI)

Director, California Institute for Telecommunications and Information Technologies

Harry E. Gruber Professor,

Dept. of Computer Science and Engineering

Jacobs School of Engineering, UCSD

Tom DeFanti, (PI)

Director, Electronic Visualization Laboratory, University of Illinois at Chicago,

Professor, University of Illinois at Chicago,

Maxine Brown (Co-PI and Program Manager)

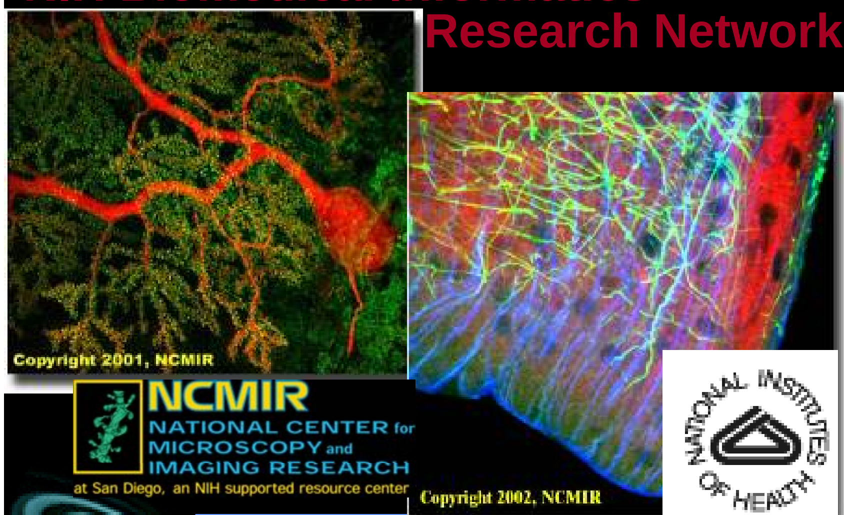
Associate Director, Electronic Visualization Laboratory, University of Illinois at Chicago,

Associate Professor, University of Illinois at Chicago,

The OptIPuter Project –
Creating a LambdaGrid "Web" for Gigabyte Data Objects

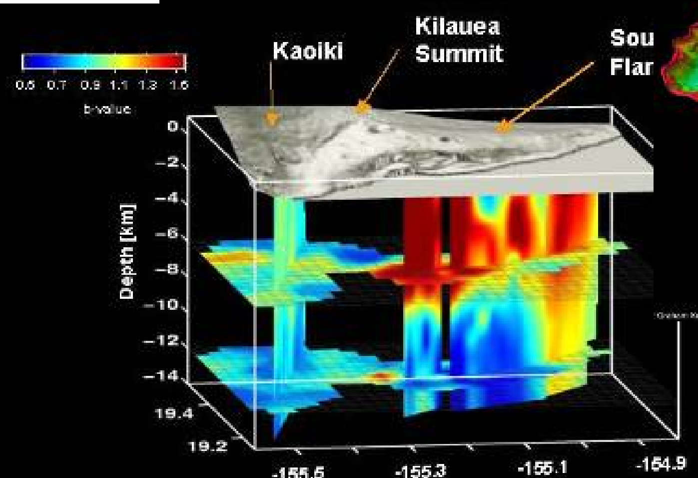
- NSF Large Information Technology Research Proposal
  - Calit2 (UCSD and UCI) and UIC Lead Campuses—Larry Smarr PI
  - USC, SDSU, NW, Texas A&M, UvA, SARA Partnering Campuses
- Industrial Partners
  - IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent
- $13.5 Million Over Five Years
- Optical IP Streams From Lab Clusters to Large Data Objects

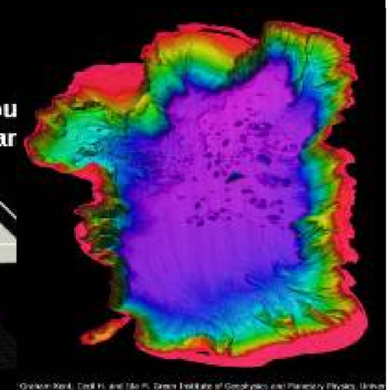
NIH Biomedical Informatics Research Network



http://ncmir.ucsd.edu/gallery.html

NSF EarthScope and ORION





SDSC

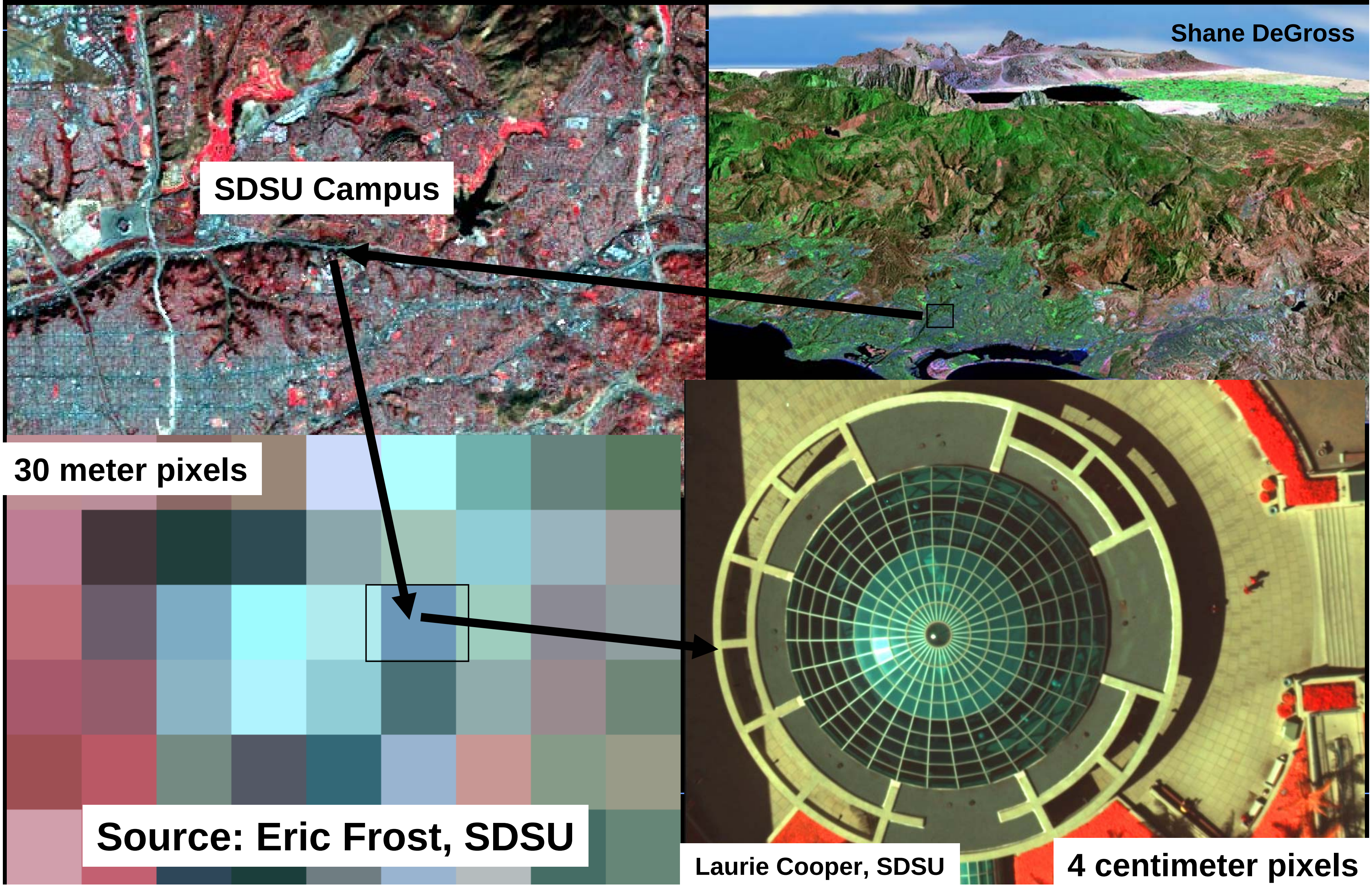
siovizcenter.ucsd.edu/library/gallery/shoot1/index.shtml

What is the OptIPuter?

- **Optical networking, Internet Protocol, Computer Storage, Processing and Visualization Technologies**
  - Dedicated Light-pipe (One or More 1-10 Gbps WAN Lambdas)
  - Links Linux Cluster End Points With 1-10 Gbps per Node
  - Clusters Optimized for Storage, Visualization, and Computing
  - Does NOT Require TCP Transport Layer Protocol
  - Exploring Both Intelligent Routers and Passive Switches
- **Applications Drivers:**
  - Interactive Collaborative Visualization of Large Remote Data Objects
    - Earth and Ocean Sciences
    - Biomedical Imaging
- **The OptIPuter Exploits a New World in Which the Central Architectural Element is Optical Networking, NOT Computers - Creating "SuperNetworks"**

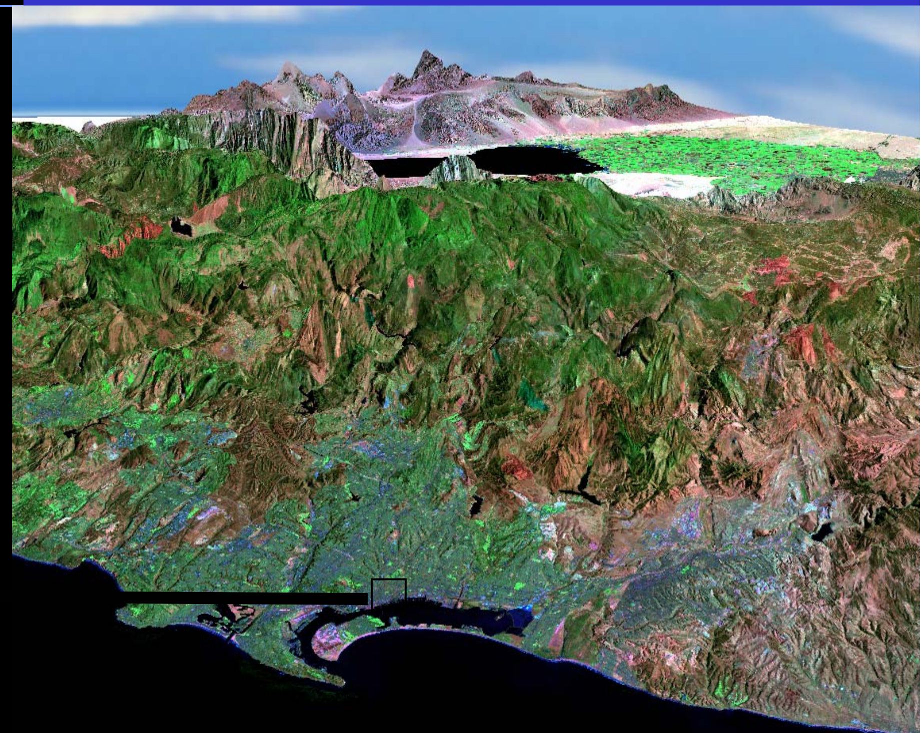
Source: Larry Smarr

Today's Aerial Imaging is >500,000 Times More Detailed than Landsat7



USGS Images 10,000 Times More Data than Landsat7

Landsat7 Imagery
100 Foot Resolution
Draped on elevation data



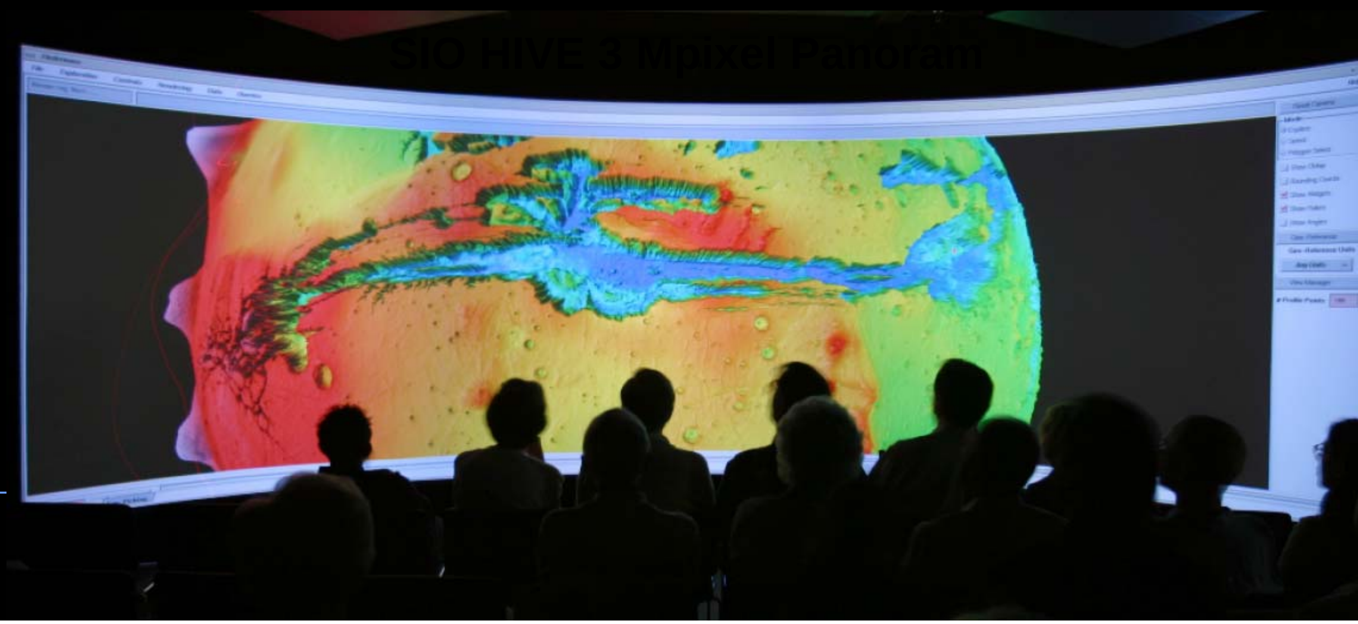
New USGS Aerial Imagery
At 1-Foot Resolution

Source: Electronic Visualization Lab, UIC

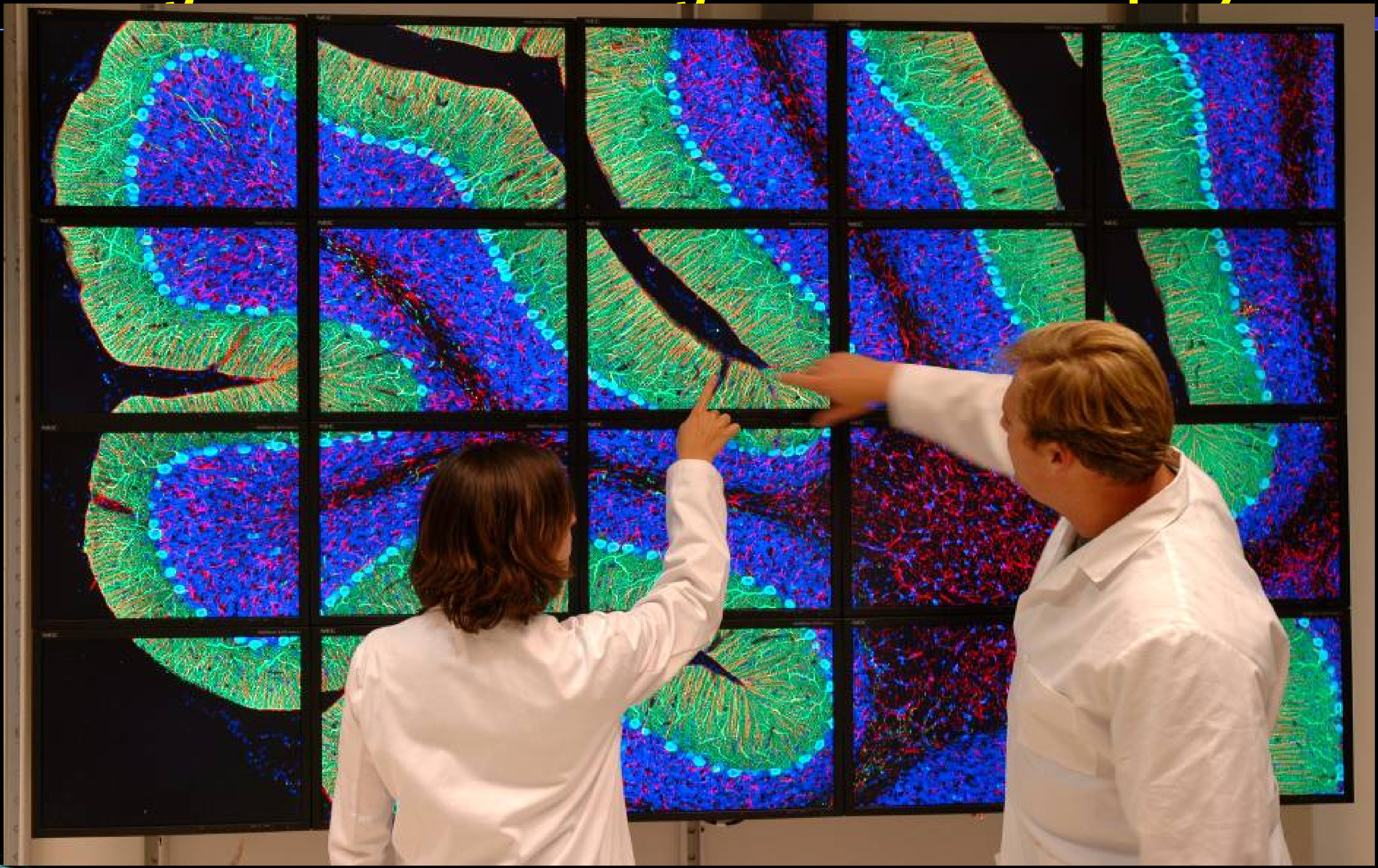
Earth and Planetary Sciences are an OptIPuter Large Data Object Visualization


EVL Varrier Autostereo 3D Image


SIO 18 Mpixel IBM OptIPuter Viz Cluster


SIO HIVE 3 Mpixel Panoram

OptIPuter JuxtaView Software for Viewing High Resolution Images on Tiled Displays



30 Million Pixel Display
NCMIR Lab UCSD

Source: David Lee, Jason Leigh, EVL, UIC

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The Crisis Response Room of the Future

SHD Streaming TV -- Immersive Virtual Reality – 100 Megapixel Displays

Source: Electronic Visualization Lab, UIC

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Increasing Accuracy in Hurricane Forecasts
Ensemble Runs With Increased Resolution

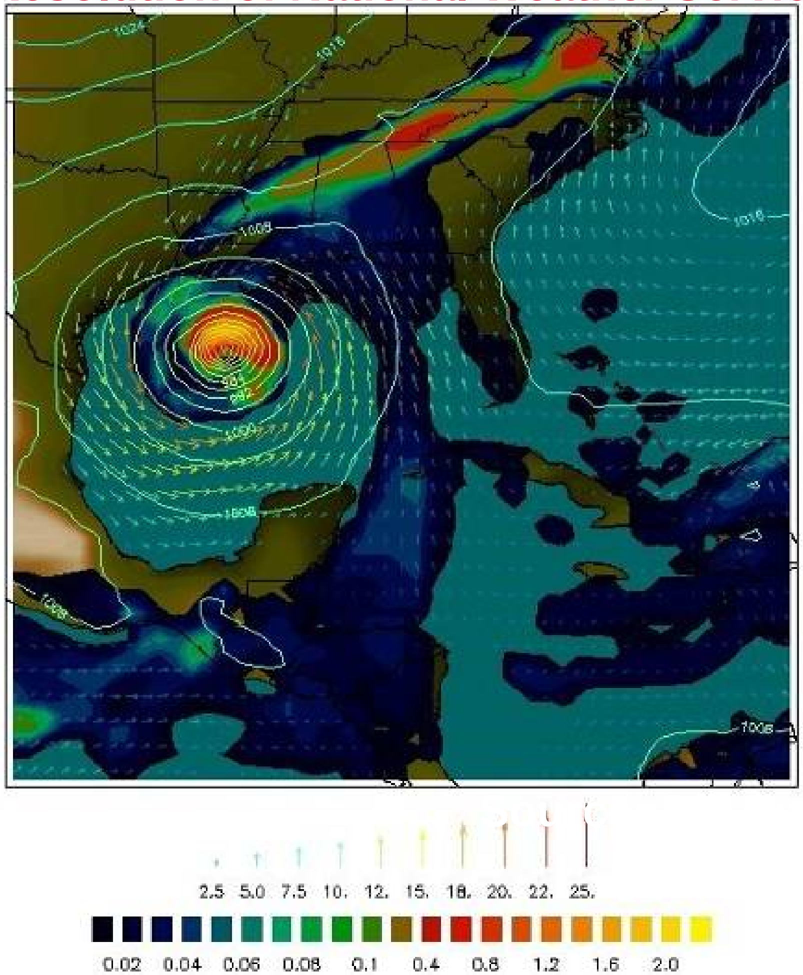
5.75 Day Forecast of Hurricane Isidore

NASA fvGCM – 0.625x0.5 degrees

Precip [inches/hr] : Sea Level Pressure [mb] : 1000 MB Winds [m/s]

2002 SEP 26 18:00Z

Operational Forecast
Resolution of National Weather Service

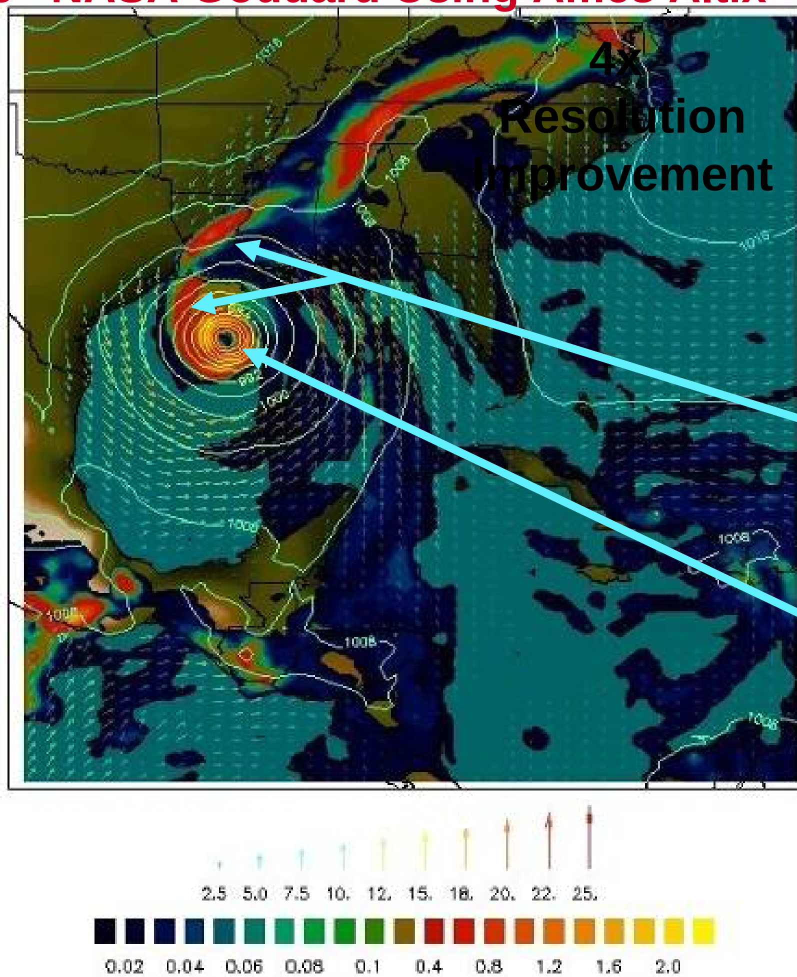


NASA fvGCM – 0.36x0.25 degrees

Precip [inches/hr] : Sea Level Pressure [mb] : 1000 MB Winds [m/s]

2002 SEP 26 18:00Z

Higher Resolution Research Forecast
NASA Goddard Using Ames Altix



Source: Smarr, UCSD

InterCenter Networking is Bottleneck

Intense Rain-Bands

Resolved Eye Wall

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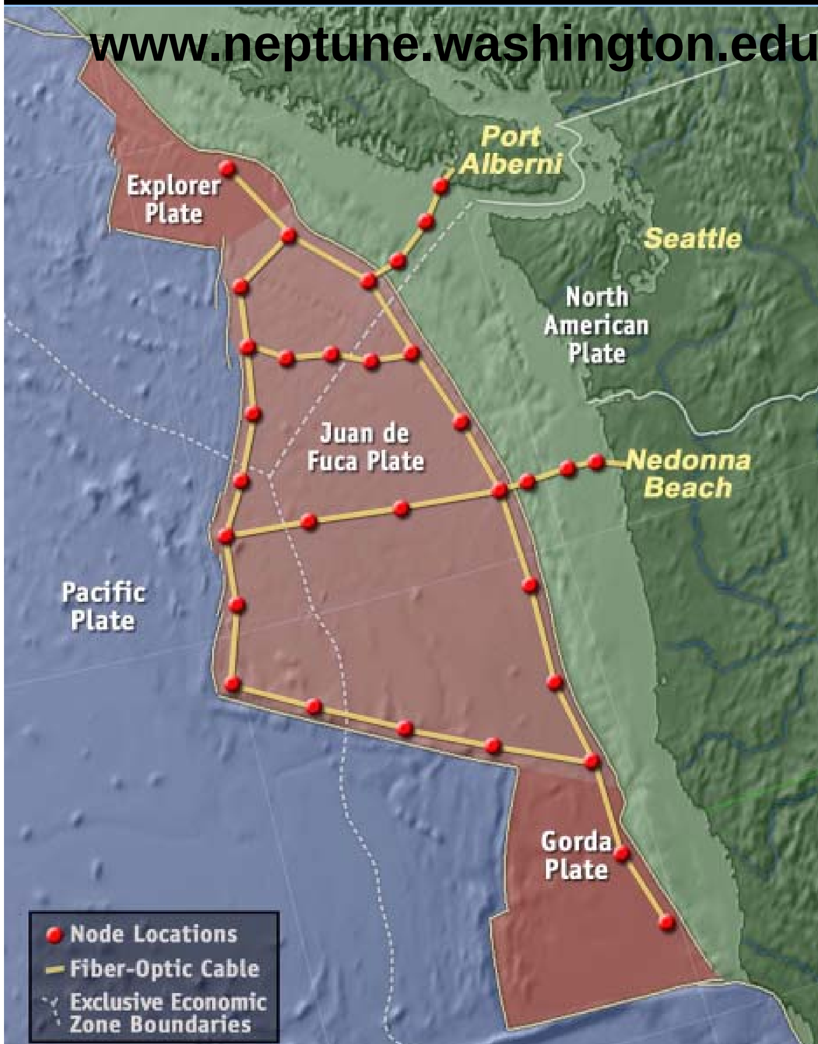
New OptIPuter Driver: Gigabit Fibers on the Ocean Floor
A Working Prototype Cyberinfrastructure for NSF's ORION



- **NSF ITR with Principal Investigators**
  - **John Orcutt & Larry Smarr - UCSD**
  - **John Delaney & Ed Lazowska –UW**
  - **Mark Abbott – OSU**
- **Collaborators at:**
  - **MBARI, WHOI, NCSA, UIC, CalPoly, UVic, CANARIE, Microsoft,**

LOOKING (Laboratory for the Ocean Observatory Knowledge Integration Grid) –
Adding Web Services to LambdaGrids

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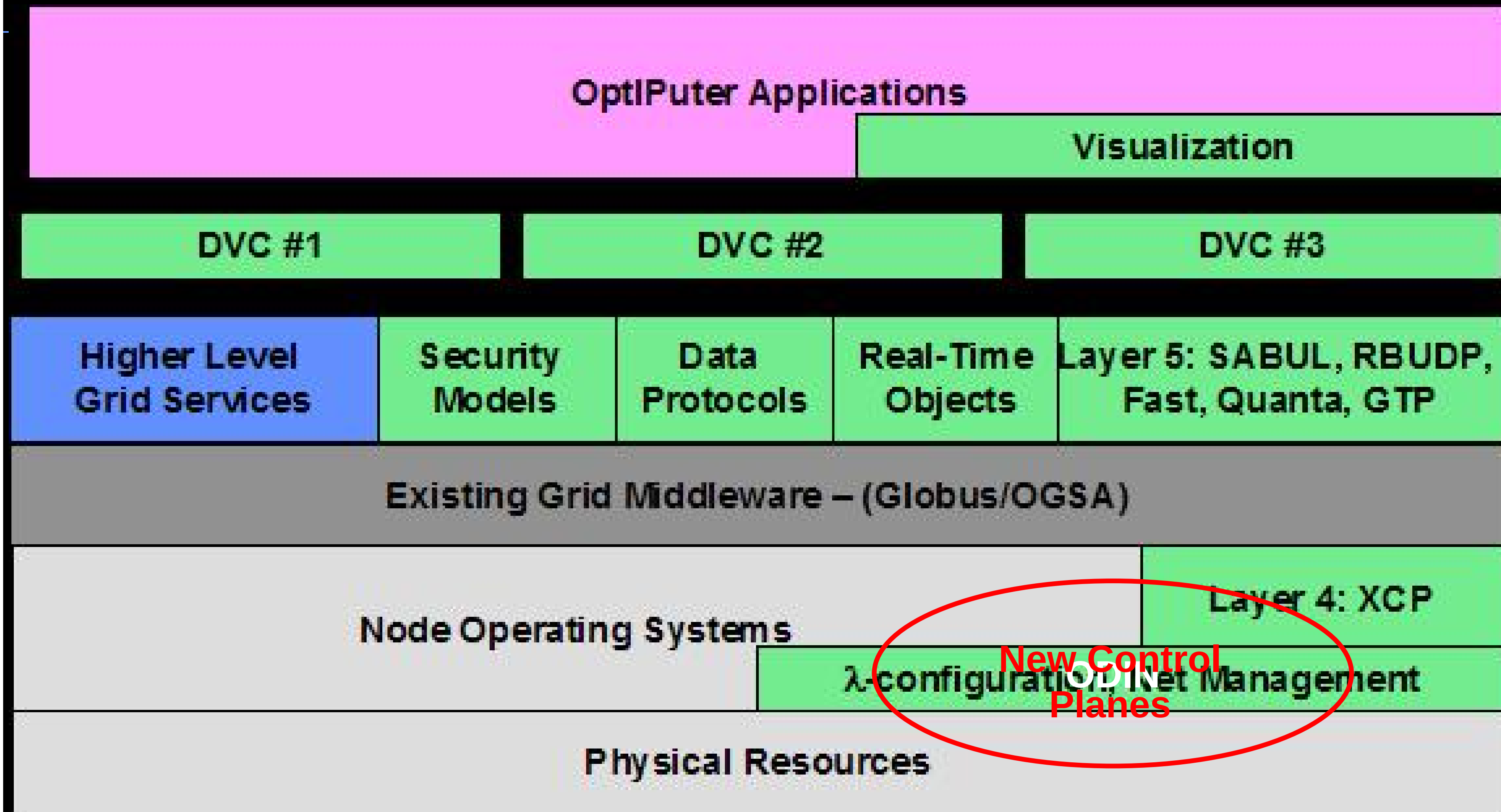
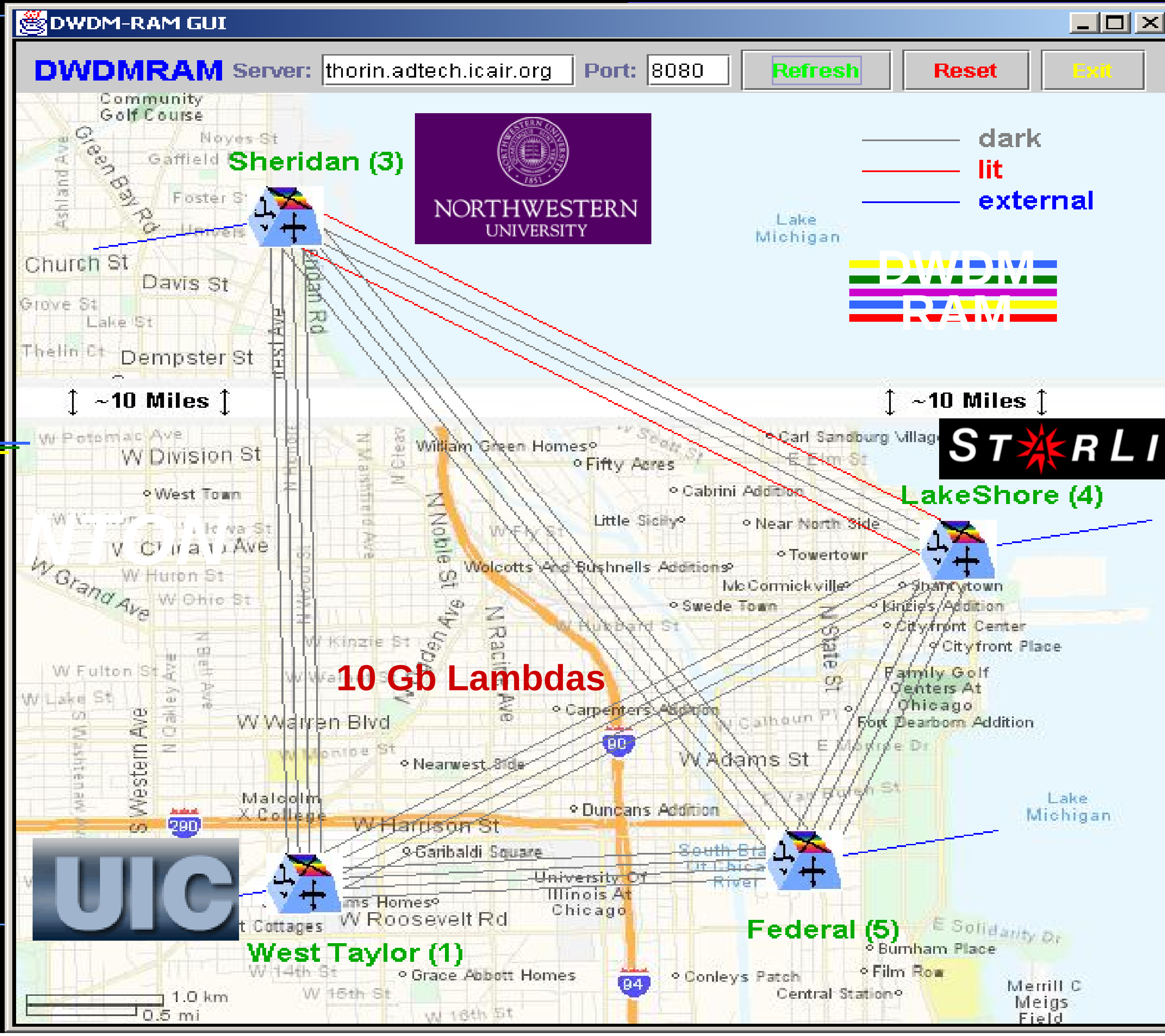
OptIPuter Architecture

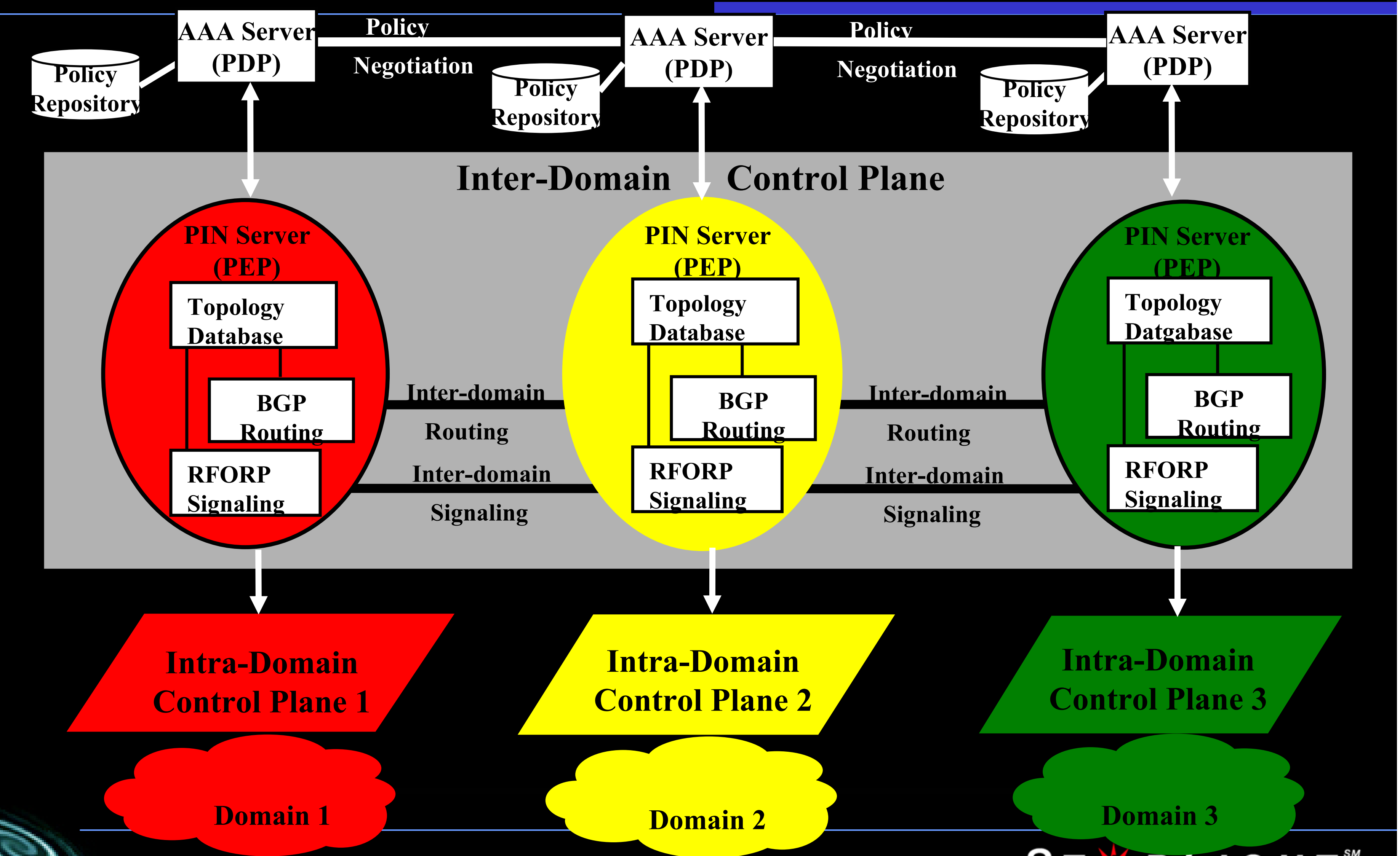


Source: Andrew Chien, UCSD
OptIPuter Software Architect

OMNInet
The Metro Area OOO Tesbed



PIN Architecture



Source: Oliver Yu, Eric He

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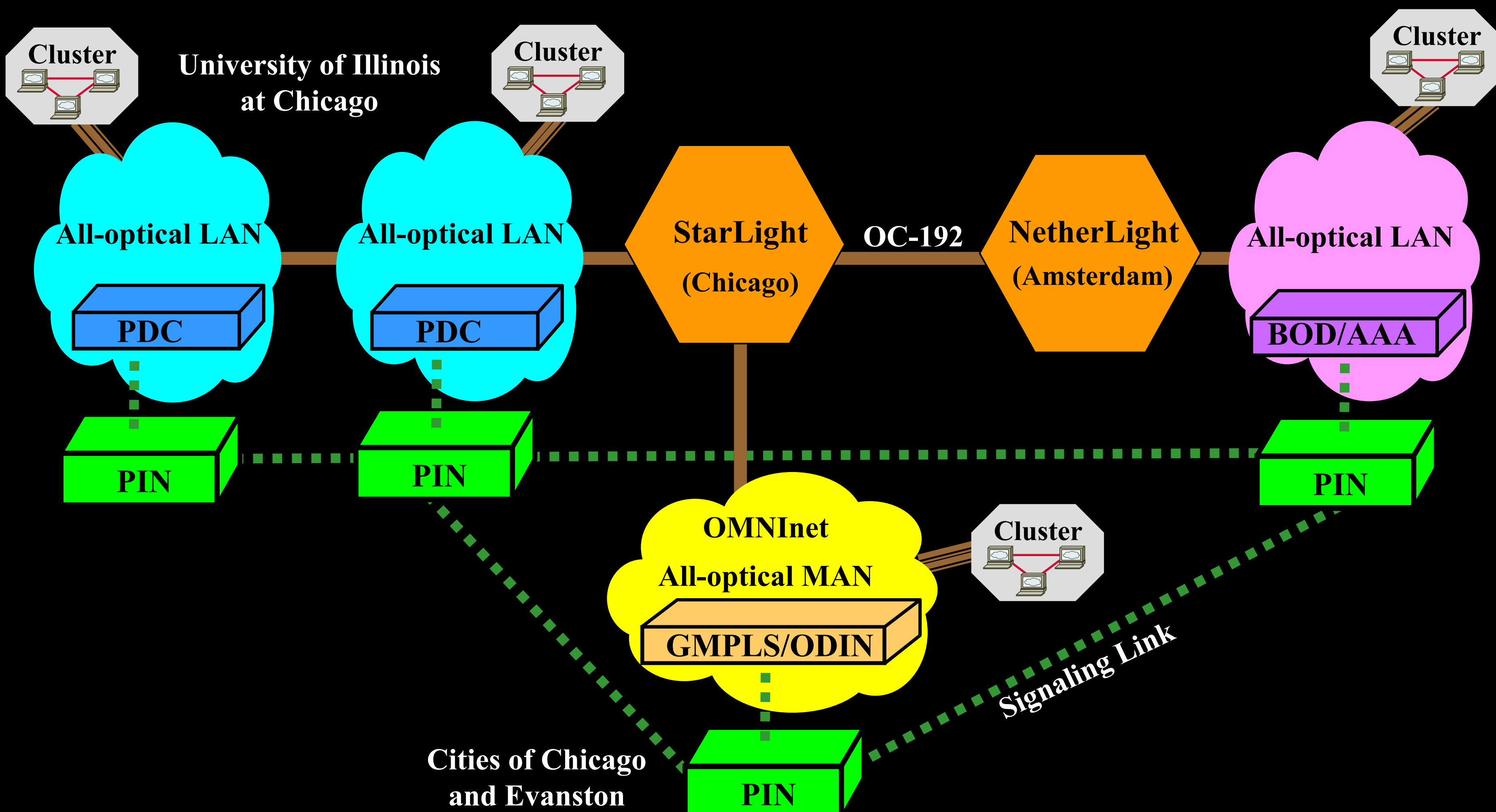
Demo of Multi-Domain OptIPuter



Source: Oliver Yu, Eric He

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OptIPuter End Nodes Are Smart Bit Buckets

i.e. Scalable Standards-Based Linux Clusters with Rocks & Globus

Building RockStar at SC2003

Complete SW Install and HW Build

- **From Piles of Parts to Running Cluster in Under 2 Hours**
- **Computational Chemistry & Brain Image Segmentation Ran**
- **Included the NSF Middleware (NMI) R3 Release of Software**

Rocks is the 2004 Most Important Software Innovation
HPCwire Reader's Choice and Editor's Choice Awards

Source: Phil Papadopoulos, SDSC

GAMESS

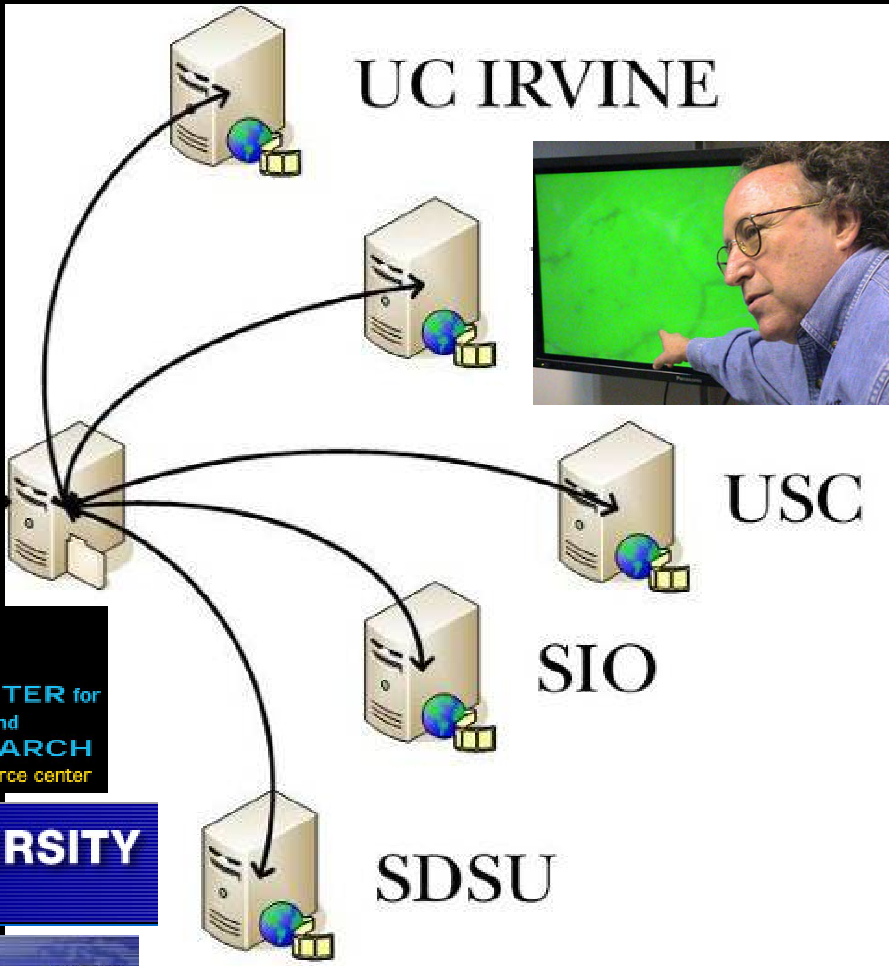
Sun microsystems SDSC ROCKS BIRN BIOMEDICAL INFORMATICS RESEARCH NETWO NPACI

Brain Imaging Collaboration -- UCSD & Osaka Univ. Using Real-Time Instrument Steering and HDTV

Most Powerful Electron Microscope in the World -- Osaka, Japan

HDTV

Southern California OptIPuter



NCMIR NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH at San Diego, an NIH supported resource center

OSAKA UNIVERSITY

KDDI Labs USA

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Source: Mark Ellisman, UCSD

UCSD Campus LambdaStore Architecture

SIO Ocean Supercomputer

IBM Storage Cluster

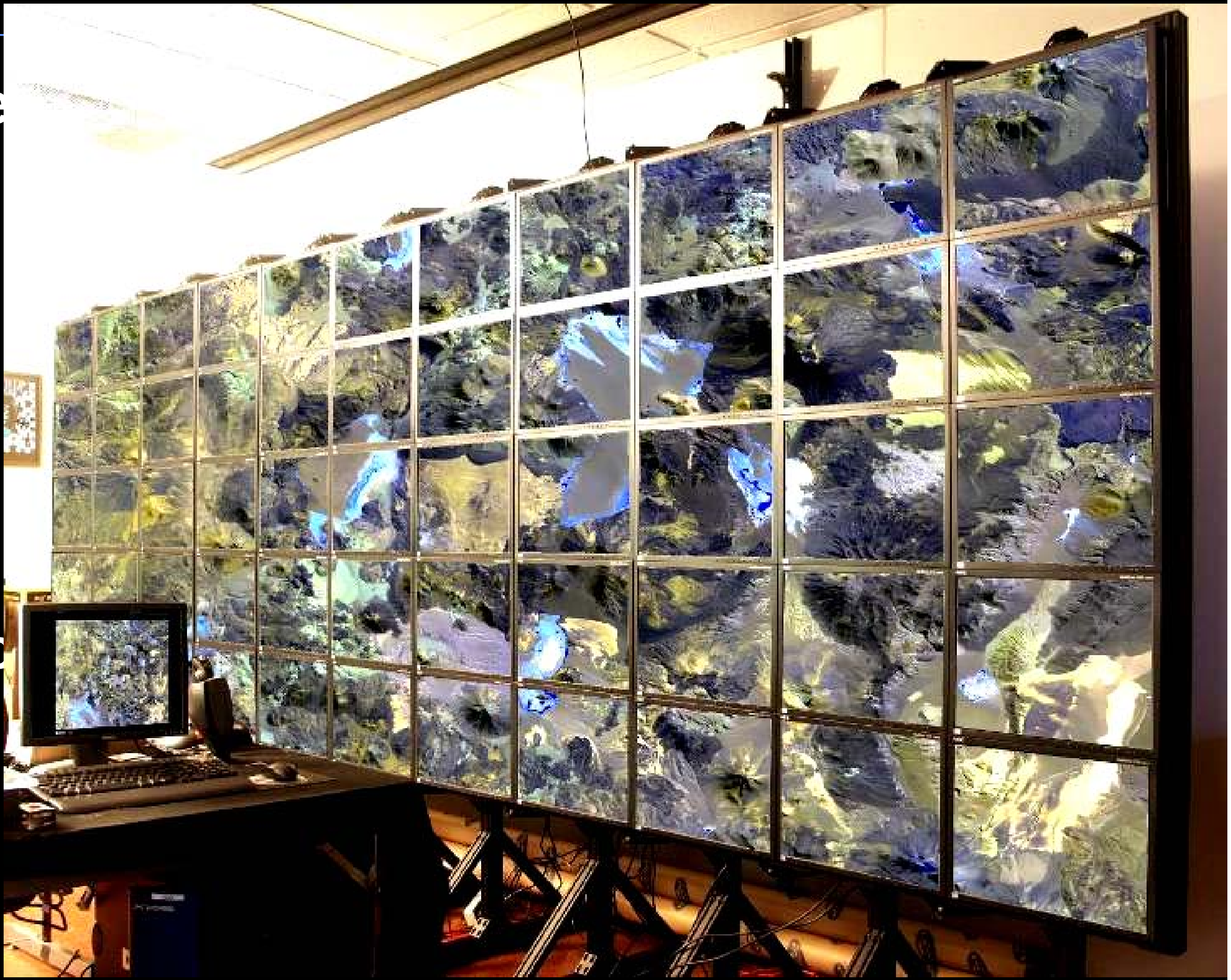
Streaming Microscope

Extreme switch with 2 ten gigabit uplinks

OptIPuter Scalable Display Systems

OptIPuter is Prototyping The PC of 2010

- **Terabits to the Desktop…**
- **100 Megapixels Display**
  - **55-Panel**
- **1/3 Terabit/sec I/O**
  - **30 x 10GE interfaces**
  - **Linked to OptIPuter**
- **1/4 TeraFLOP**



Source: Jason Leigh, Tom DeFanti, EVL@UIC
OptIPuter Co-PIs

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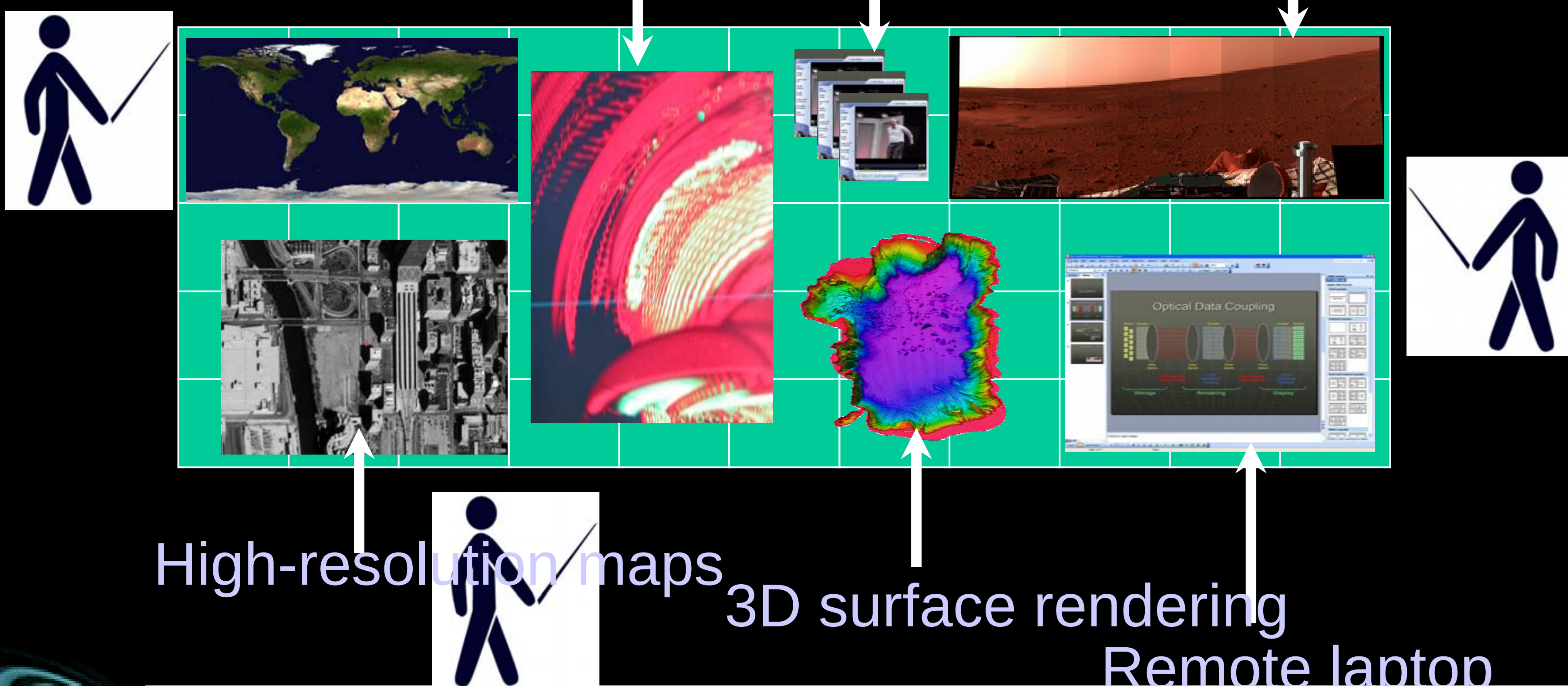
Scalable Adaptive Graphics Environment (SAGE) Required for Working in Display-Rich Environments

Information Must Be Able To Flexibly Move Around The Wall



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Source: Jason Leigh, UIC

OptIPuter is Expanding the Reach of its Education and Outreach Programs

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NLR Will Provide an Experimental Network Infrastructure for U.S. Scientists & Researchers

"National LambdaRail" Partnership

Serves Very High-End Experimental and Research Applications

4 x 10Gb Wavelengths Initially

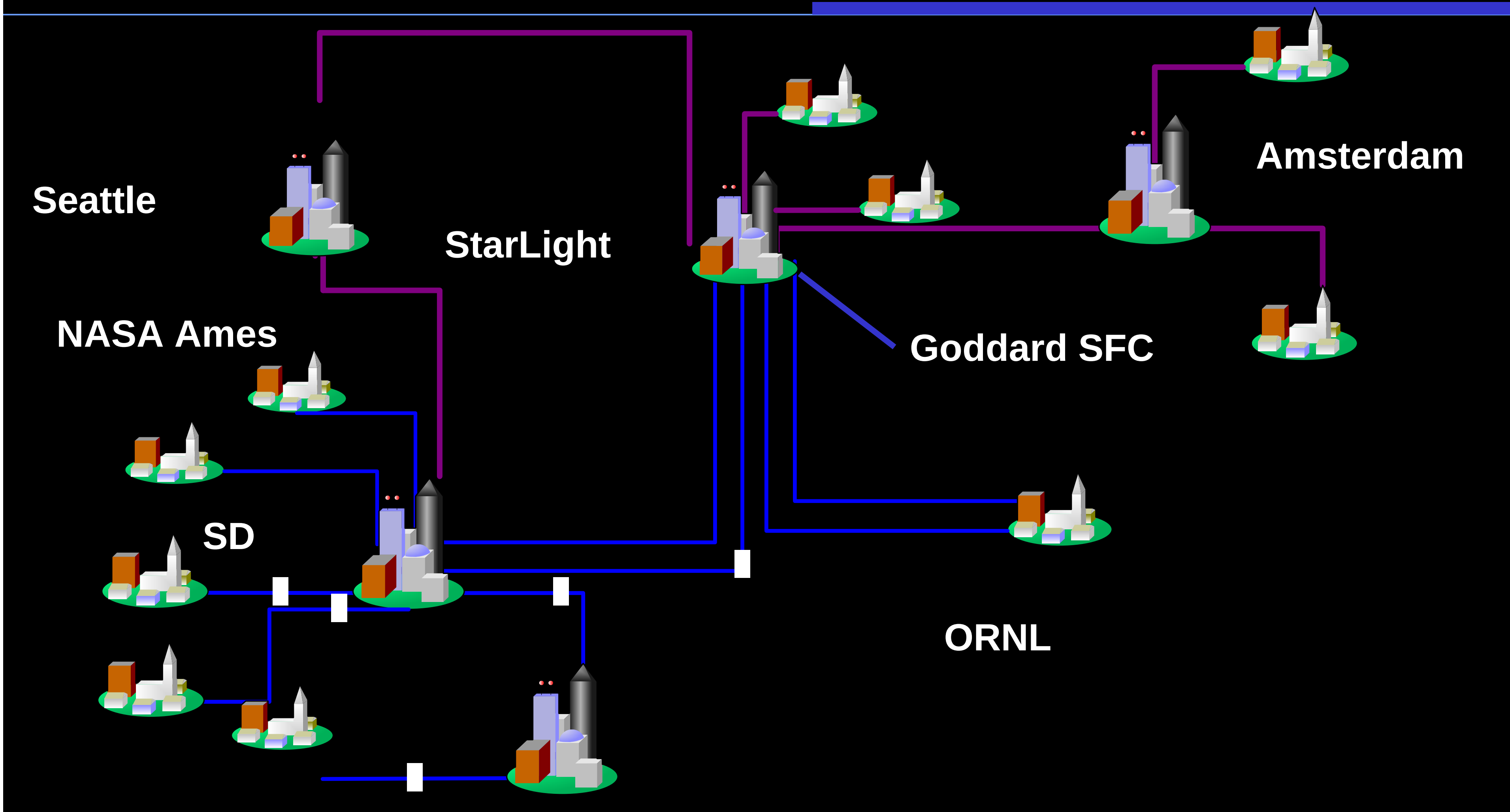
Capable of 40 x 10Gb wavelengths at Buildout

Links Two Dozen State and Regional Optical Networks

First Light September 2004

For more information regarding NLR see http://www.nlr.net or contact info@nlr.net

Expanding the OptIPuter LambdaGrid



10GE OptIPuter CAVEWAVE Helped Launch the National LambdaRail

Next Step: Coupling NASA Centers to NSF OptIPuter

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Source: Tom DeFanti, OptIPuter co-PI

The OptIPuter Is Being Supported By StarLight – a Facility "By Researchers For Researchers"

StarLight is an experimental optical infrastructure and proving ground for network services optimized for high-performance applications

GE+2.5+10GE Exchange

Soon: Multiple 10GEs Over Optics – World's "Largest" 10GE Exchange!

View from StarLight

Abbott Hall, Northwestern University's Chicago downtown campus

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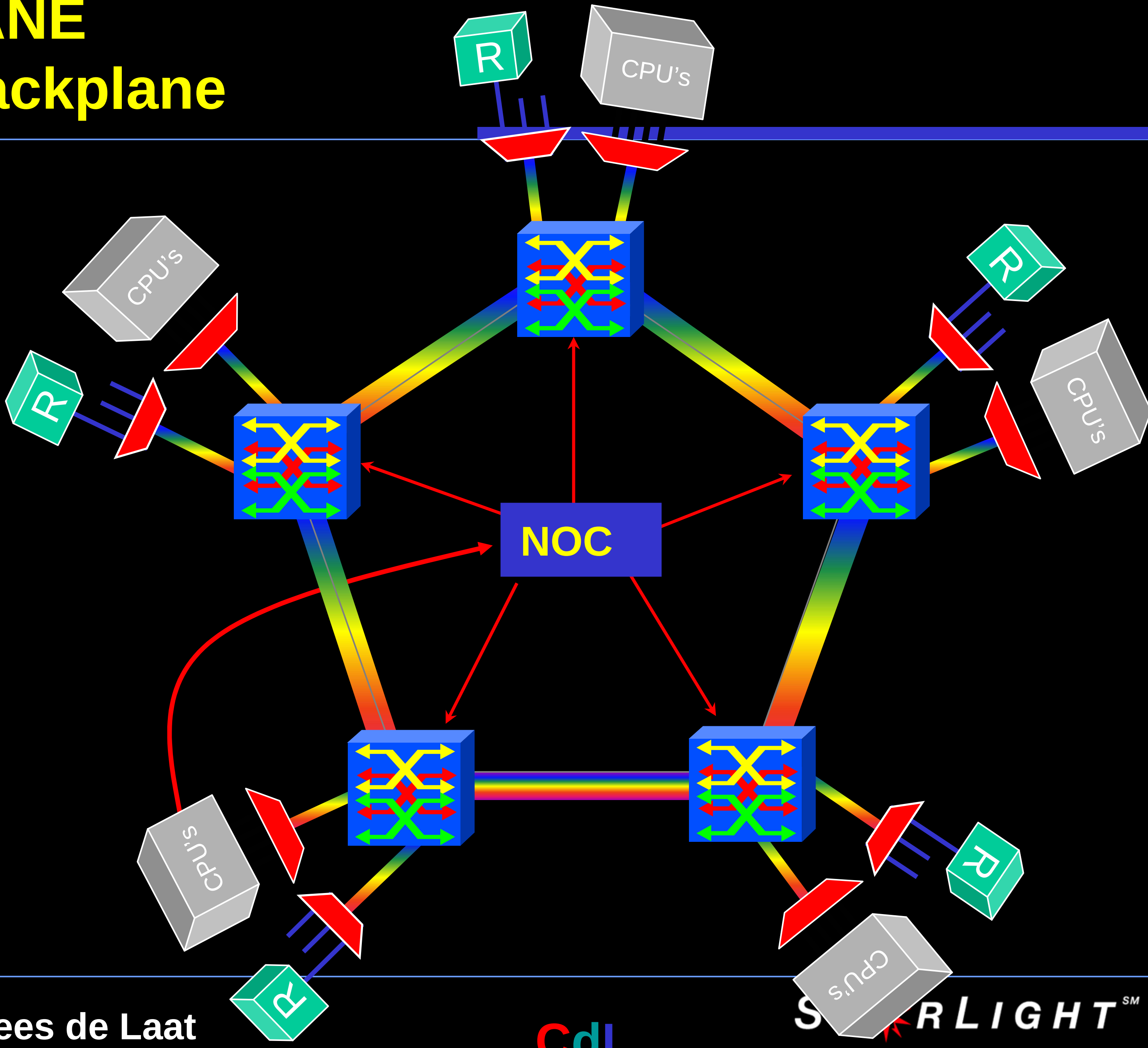
STARPLANE
DWDM Backplane



UvA-VLE
UvA-MM
VU
ULeiden
TUDelft

Source: Cees de Laat

CdL

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Timeframes

- 1999 - 2000 Initial Design Concepts
- 2001 Initial Dynamic Lightpath Testbed
- 2002 DL Lightpath Initial Control, Management Plane Design and Development, Various Demonstrations, Including at at iGRID 2002, GGF, SC2002 Including International Interdomain, Provisioning of Lightpaths With Direct Application Signaling to
- 2003 Enhancements at Various Levels, Demonstrations at GGF, SC2003
- 2004 SuperComm 2004, SC2004 Demonstrations, Optical Multicast
- 2005 Designs for GLIF Persistent Infrastructure, Plans for Demonstrations at iGRID 2005, SC2005
- 2006 Integration With Other Communication Modalities, Enhanced Management Modules
- 2007 Multi-Mode Integration

World of Tomorrow - 1939

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World Of Tomorrow 2005

iGrid 2005

THE GLOBAL LAMBDA INTEGRATED FACILITY

September 26-30, 2005
University of California, San Diego
California Institute for Telecommunications and Information Technology [Cal-(IT)^2]
United States

Co-Organizers: Tom DeFanti, Maxine Brown

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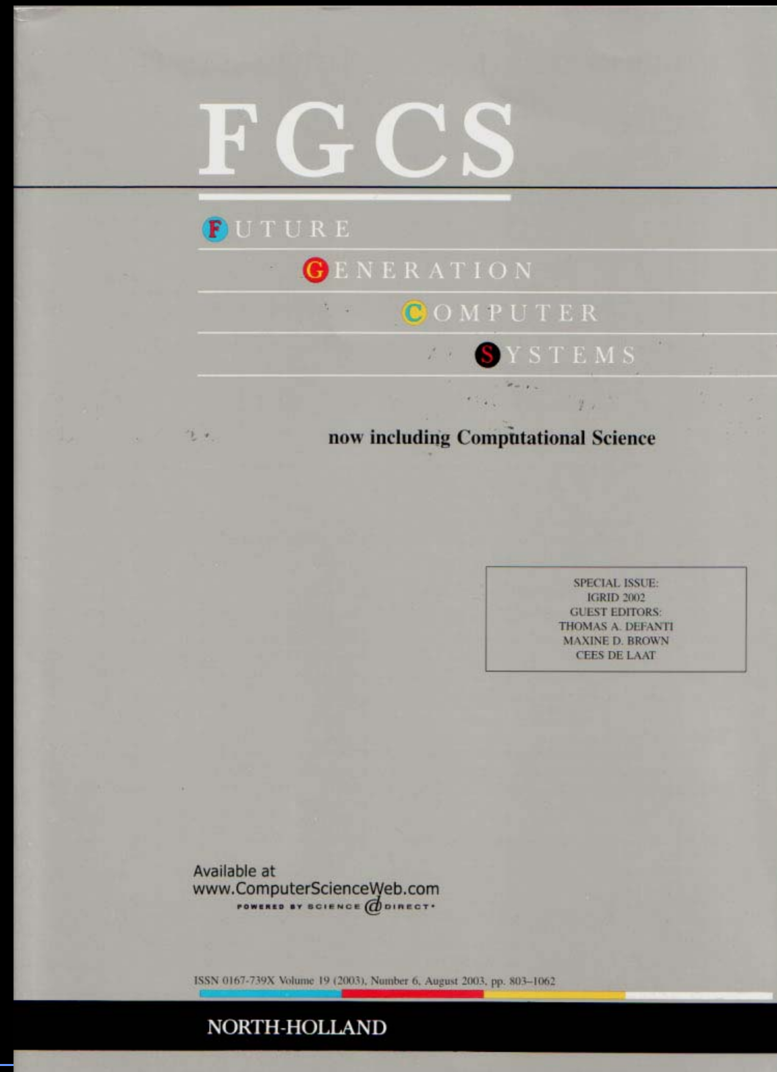
Future Generation Computer Systems (FGCS)

Volume 19, Number 6
August 2003

Special Issue on iGrid 2002
September 24-26, 2002
Amsterdam, The Netherlands

22 Refereed Application Papers!

Guest Editors Tom DeFanti, Maxine Brown and Cees de Laat



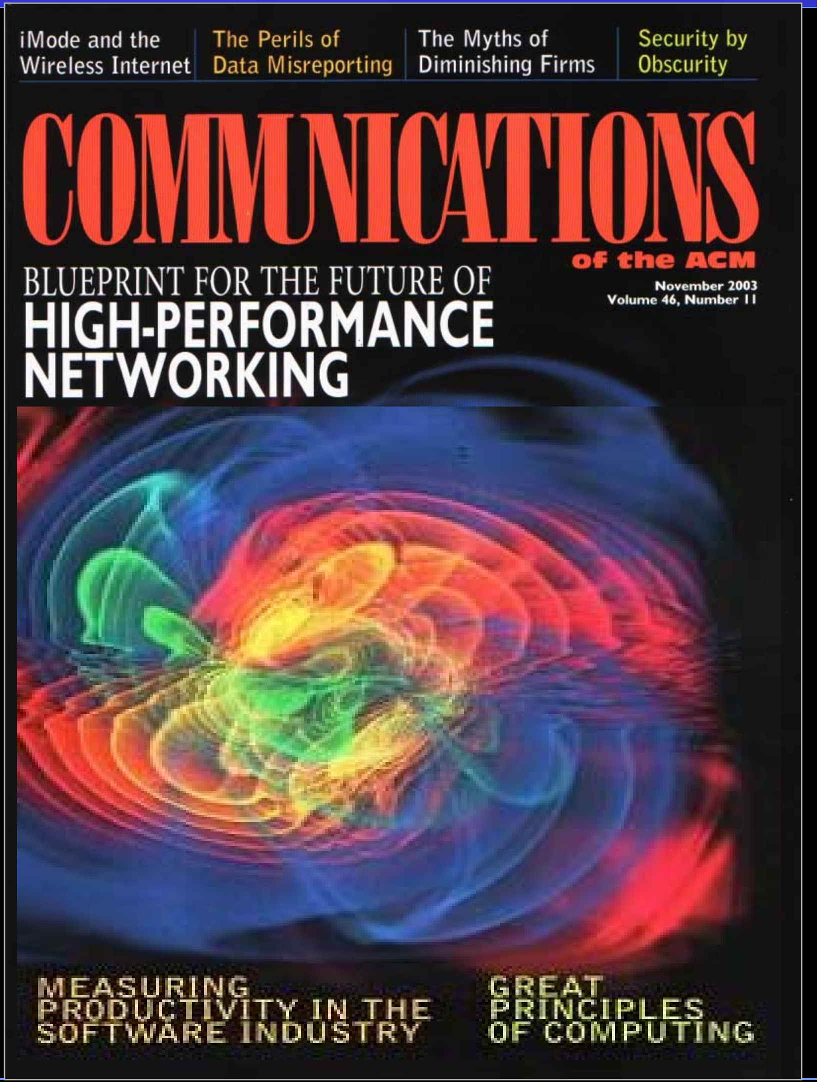
http://www.igrid2002.org
http://www.elsevier.com/locate/future

Communications of the ACM (CACM)

Volume 46, Number 11
November 2003

Special issue: Blueprint for the Future of High-Performance Networking

- ***Introduction,*** **Maxine Brown (guest editor)**
- ***TransLight: a global-scale LambdaGrid for e-science,*** **Tom DeFanti, Cees de Laat, Joe Mambretti, Kees Neggers, Bill St. Arnaud**
- ***Transport protocols for high performance,*** **Aaron Falk, Ted Faber, Joseph Bannister, Andrew Chien, Bob Grossman, Jason Leigh**
- ***Data integration in a bandwidth-rich world,*** **Ian Foster, Robert Grossman**
- ***The OptIPuter,*** **Larry Smarr, Andrew Chien, Tom DeFanti, Jason Leigh, Philip Papadopoulos**
- ***Data-intensive e-science frontier research,*** **Harvey Newman, Mark Ellisman, John Orcutt**



www.acm.org/cacm

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www.startap.net/starlight

Thanks to All Participants, NSF,and National and International Supporters!