"The OptIPuter, Quartzite, and Starlight Projects: A Campus to Global-Scale Testbed for Optical Technologies Enabling LambdaGrid Computing"

Invited Talk

Optical Fiber Communication Conference (OFC2005)

Anaheim, CA

March 9, 2005

Dr. Larry Smarr

Director, California Institute for Telecommunications and Information Technology

Harry E. Gruber Professor,

Dept. of Computer Science and Engineering

Jacobs School of Engineering, UCSD

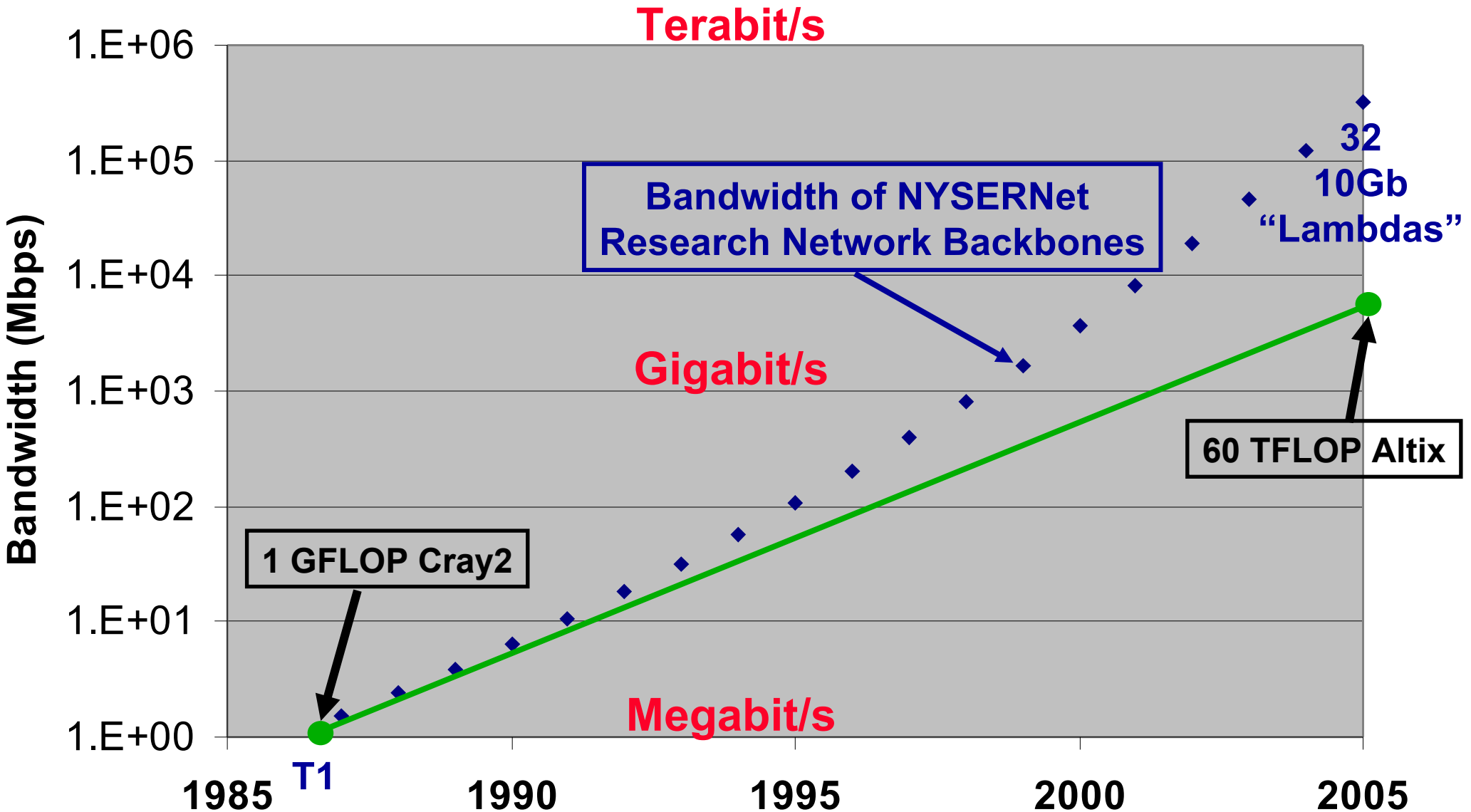




Abstract and OFC Invited Paper

- **Abstract**
  - Dedicated optical connections have significant advantages over shared internet connections. The OptIPuter project (www.optiputer.net) uses medical and earth sciences imaging as application drivers. Quartzite (UCSD) and Starlight (Chicago) create unique combinations of OEO routers and OOO and wavelength-selective optical switches.
- **Invited Paper for OFC 2005**
  - The OptIPuter, Quartzite, and Starlight Projects:
  - A Campus to Global-Scale Testbed for Optical Technologies Enabling LambdaGrid Computing
- **By Larry Smarr,**
  - Harry E. Gruber Professor, Department of Computer Science and Engineering, UCSD
  - Director, California Institute of Telecommunications and Information Technology
- **With Shaya Fainman, Joseph Ford, Phil Papadopoulos**
  - University of California, San Diego
- **and Tom DeFanti, Maxine Brown, and Jason Leigh**
  - Electronic Visualization Laboratory
  - University of Illinois at Chicago

The Evolution from Supercomputer-Centric to a Net-Centric Architecture



Source: Timothy Lance, President, NYSERNet

Calit2 -- Research and Living Laboratories on the Future of the Internet

University of California San Diego & Irvine Campuses
Faculty & Staff
Working in Multidisciplinary Teams
With Students, Industry, and the Community



One Focus Area is
Net-Centric Optical Architectures

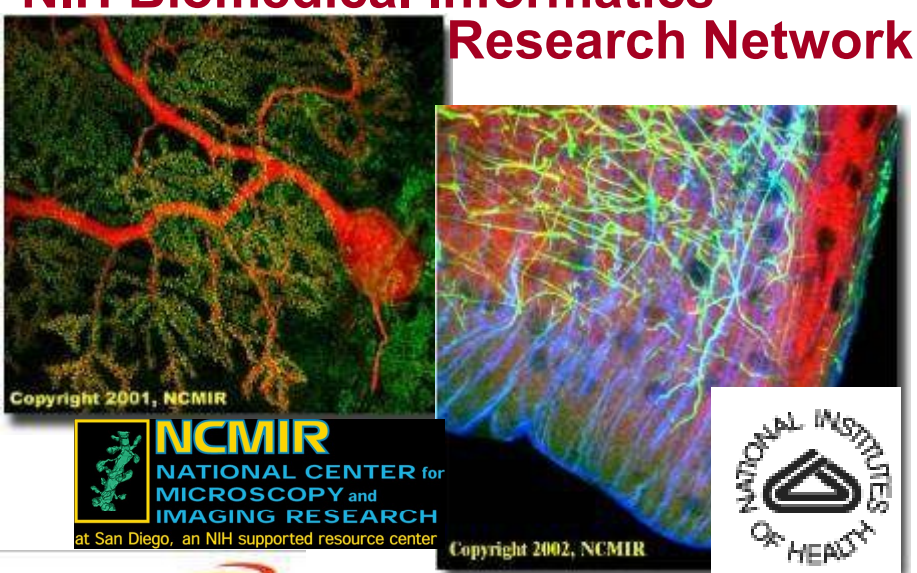
OptIPuter

www.calit2.net

The OptIPuter Project – Bringing the Power of Lambdas to End Users

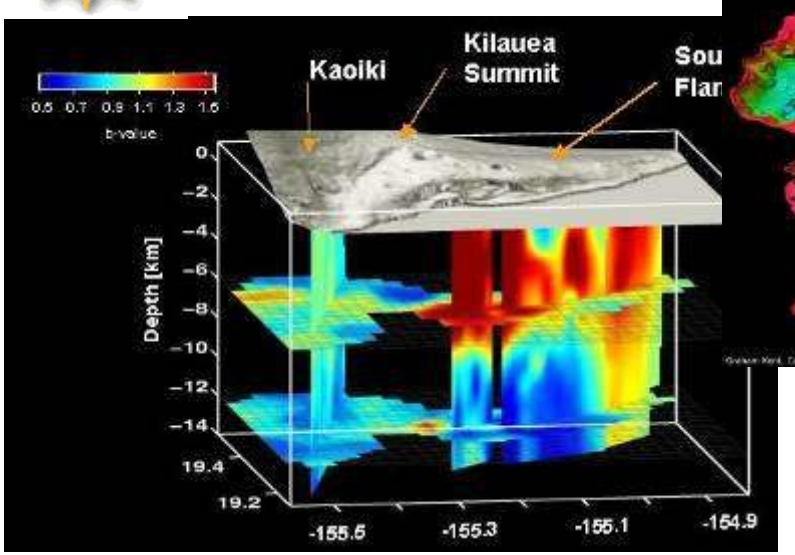
- **NSF Large Information Technology Research Proposal**
  - Calit2 (UCSD, UCI) and UIC Lead Campuses—Larry Smarr PI
  - Partnering Campuses: USC, SDSU, NW, TA&M, UvA, SARA, NASA
- **Industrial Partners**
  - IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent
- **$13.5 Million Over Five Years**
- **Linking Global Scale Science Projects to User's Linux Clusters**

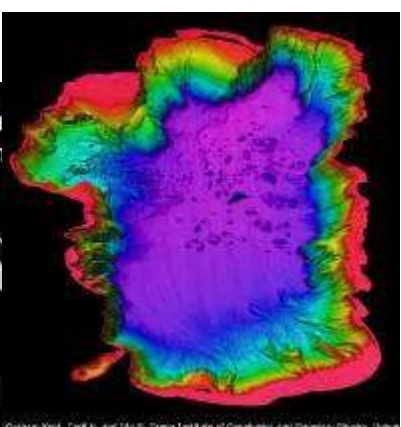
NIH Biomedical Informatics Research Network



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

NSF EarthScope and ORION





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

OptIPuter SDSC it2

Optical Networking, Internet Protocol, Computer
Bringing the Power of Lambdas to Users

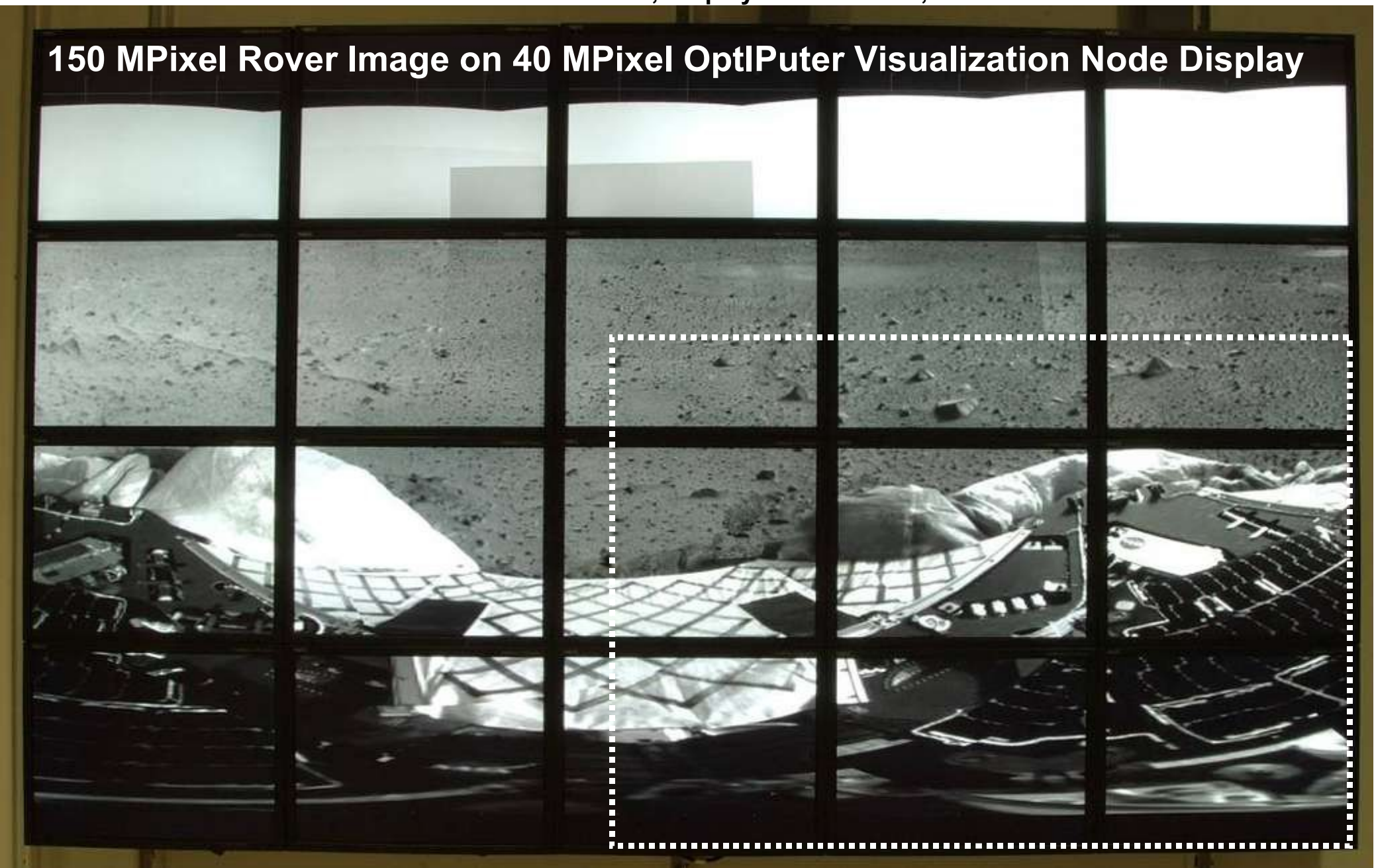
- **Extending Grid Middleware to Control:**
  - Cluster Enpoints- Storage, Visualization, & Computing
    - Linux Clusters With 1 or 10 Gbps I/O per Node
    - Scalable Visualization Displays with OptIPuter Clusters
  - Jitter-Free, Fixed Latency, Predictable Optical Circuits
    - One or Parallel Dedicated Light-Pipes
      - 1 or 10 Gbps WAN Lambdas
    - Uses Internet Protocol, But Does NOT Require TCP
    - Exploring Both Intelligent Routers and Passive Switches
- **Applications Drivers:**
  - Earth and Ocean Sciences
  - Biomedical Imaging

OptIPuter

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Tiled LCD Displays Driven by Linux Graphics Clusters Allow for Both Global Context and High Levels of Detail

"Source: Data from JPL/Mica; Display UCSD NCMIR, David Lee"



Interactively Zooming In Using EVL's JuxtaView on NCMIR's Sun Microsystems Visualization Node

"Source: Data from JPL/Mica; Display UCSD NCMIR, David Lee"



Highest Resolution Zoom on NCMIR 40 MPixel OptIPuter Display Node

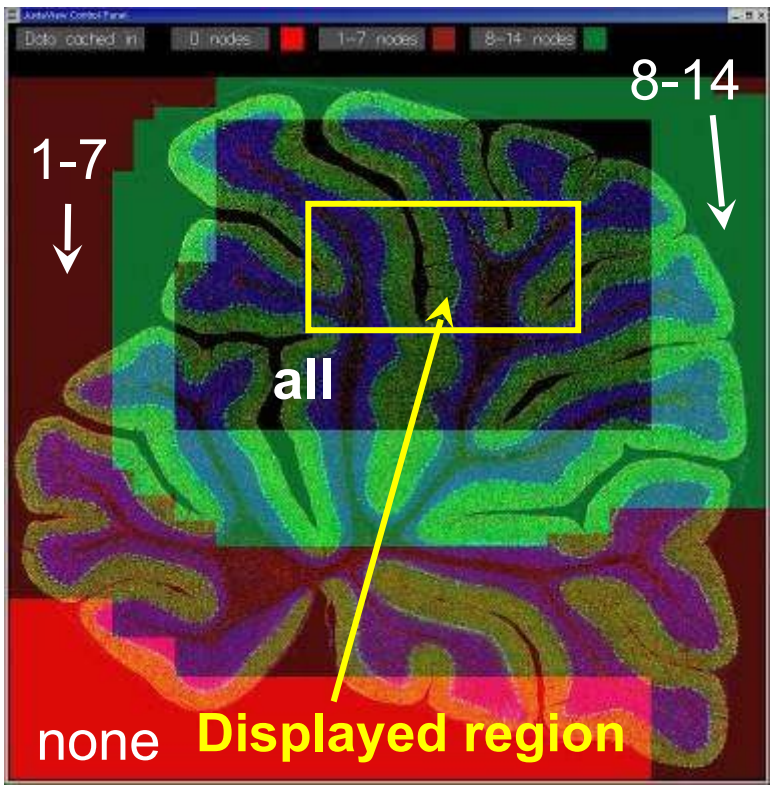
"Source: Data from JPL/Mica; Display UCSD NCMIR, David Lee"



LambdaRAM: Clustered Memory To Provide Low Latency Access To Large Remote Data Sets

- Giant Pool of Cluster Memory Provides Low-Latency Access to Large Remote Data Sets
  - Data Is Prefetched Dynamically
  - LambdaStream Protocol Integrated into JuxtaView Montage Viewer
- 3 Gbps Experiments from Chicago to Amsterdam to UIC
  - LambdaRAM Accessed Data From Amsterdam Faster Than From Local Disk

Visualization of the Pre-Fetch Algorithm





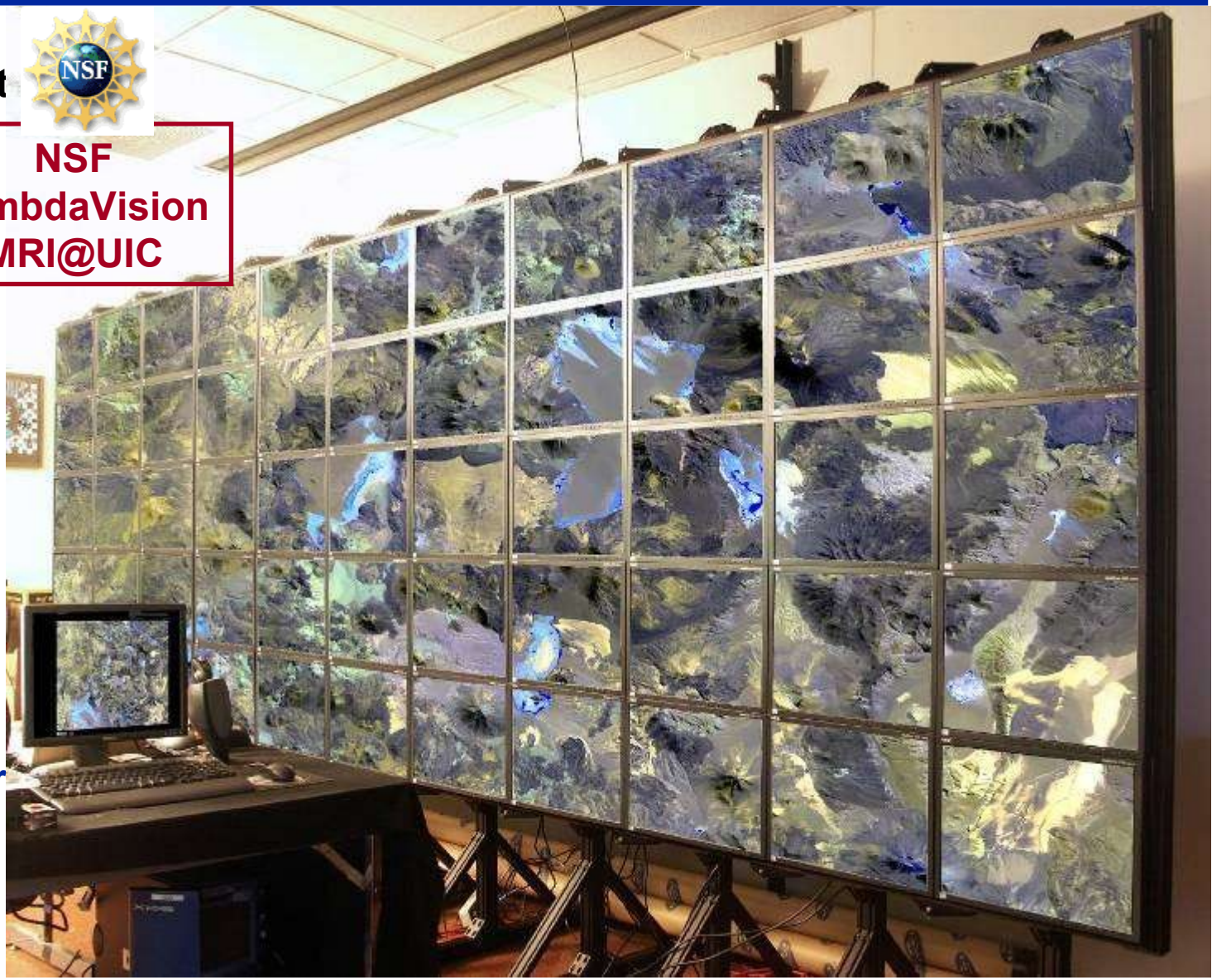
Data on Disk in Amsterdam

Source: David Lee, Jason Leigh

OptIPuter Challenge is to Couple Cluster Endpoints to WAN DWDM Dedicated Photonic Channels

- Scalable Adaptive Graphics Environment (SAGE) Controls:
- 100 Megapixels Display
  - 55-Panel
- 1/4 TeraFLOP
  - Driven by 30 Node Cluster of 64 bit Dual Opterons
- 1/3 Terabit/sec I/O
  - 30 x 10GE interfaces
  - Linked to OptIPuter
- 1/8 TB RAM
- 60 TB Disk

NSF LambdaVision MRI@UIC



OptIPuter

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

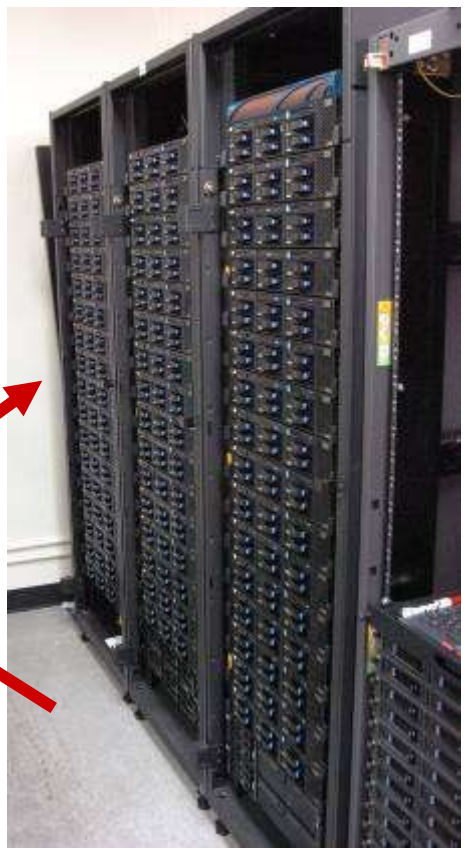
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UCSD Campus LambdaStore Architecture
Dedicated Lambdas to Labs Creates Campus LambdaGrid

SIO Ocean Supercomputer

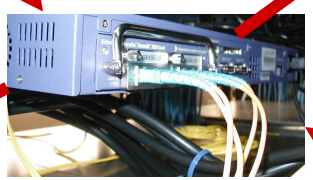


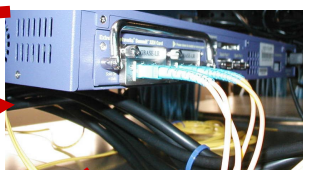
IBM Storage Cluster



Streaming Microscope









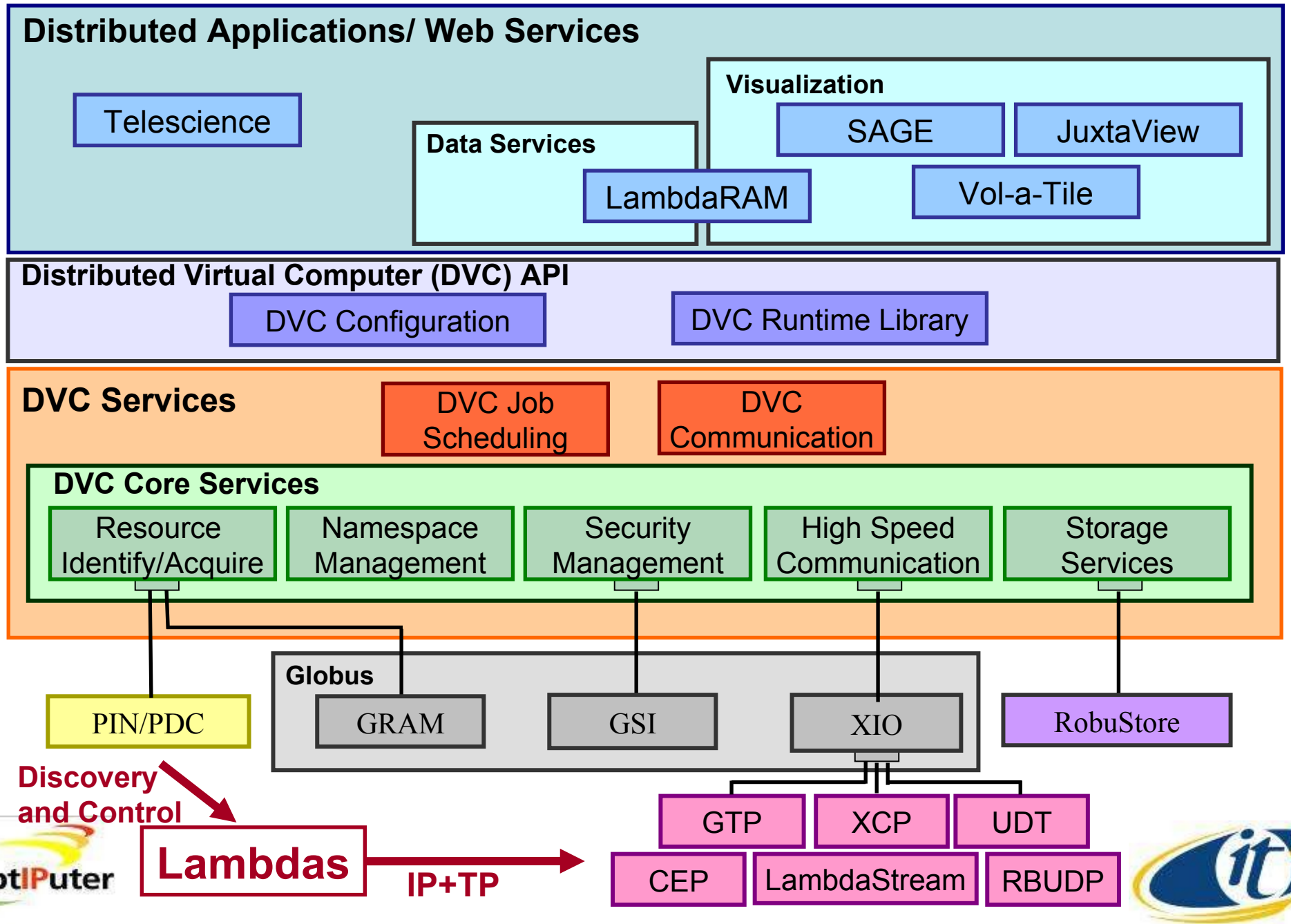
Extreme Switch with
2 Ten Gbps Uplinks



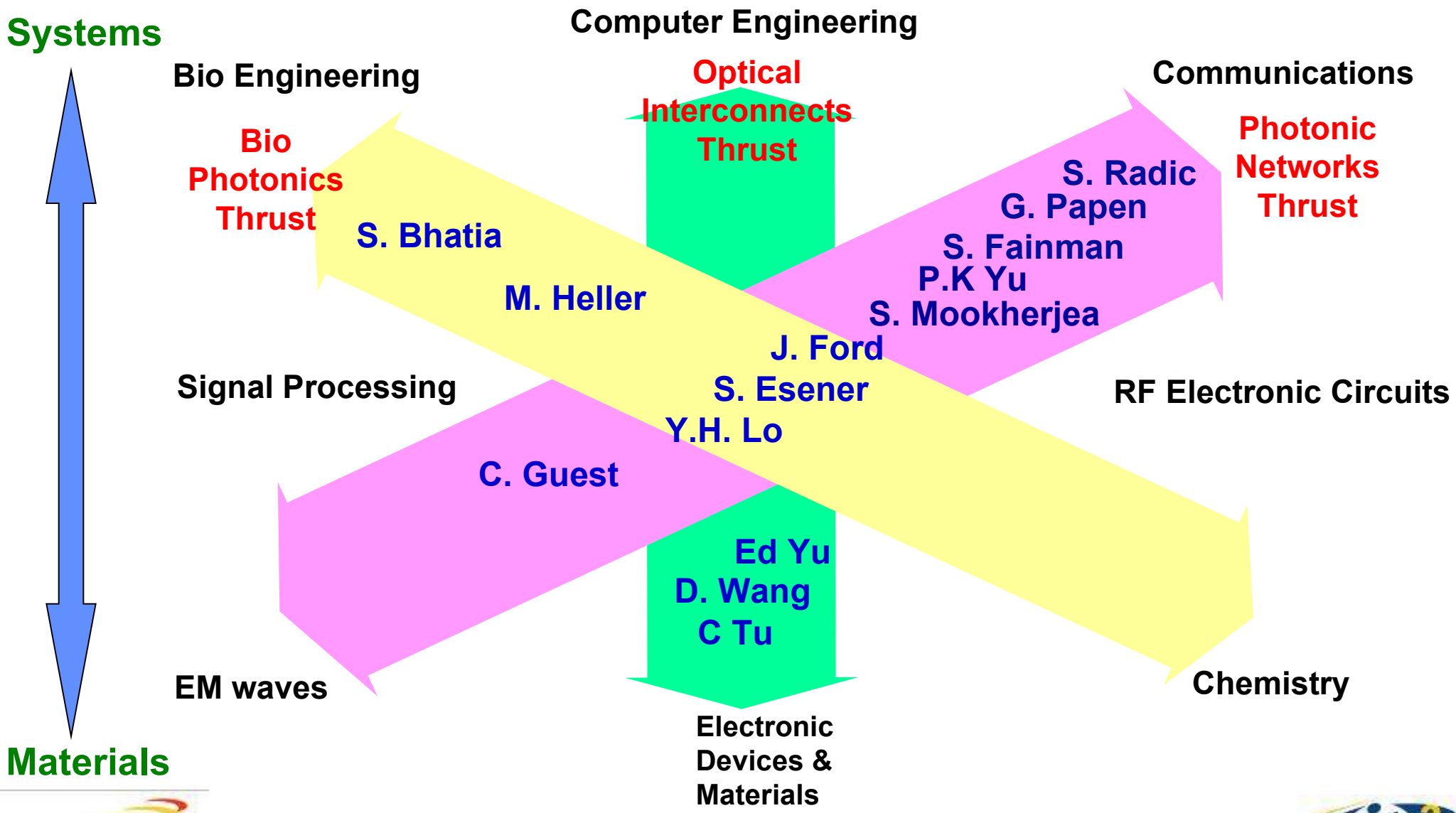


Source: Phil Papadopoulos,
SDSC, Calit2

OptIPuter Software Architecture--a Service-Oriented Architecture Integrating Lambdas Into the Grid



A Photonics-Centric View of UCSD's ECE Department - Many Are Involved with Calit2 Photonics Program



Most Are Involved with Calit2 Photonics Program

UCSD ECE, Jacobs School, and Calit2 Set Photonics as a High Priority for Faculty Recruiting



George Papen, Professor, Electrical and Computer Engineering
Expertise: Advanced Photonic Systems Including Optical Communication Systems, Optical Networking, and Environmental And Atmospheric Remote Sensing
***Ph.D.*:** Electrical and Computer Engineering from the University of Wisconsin, 1989
Background: University of Illinois at Urbana-Champaign

UCSD Photonics



Joseph Ford, Assoc. Professor, Electrical and Computer Engineering
Expertise: Optoelectronic Subsystems Integration (MEMS, Diffractive Optics, VLSI); Fiber Optic and Free-Space Communications
***Ph.D.*:** Applied Physics, UCSD, 1992
Background: Bell Labs Adv. Photonics Dept., Chief Scientist, Optical Micro-Machines.



Stojan Radic, Assoc. Professor, Electrical and Computer Engineering
Expertise: Optical Communication Networks; All-Optical Processing; Parametric Processes in High-confinement Fiber and Semiconductor Devices
***Ph.D.*:** Institute of Optics, University of Rochester, 1995
Background: Corning research, Bell Labs Trans. Dept., Nortel Chair Assoc. Prof., Duke



Deli Wang, Asst. Professor, Electrical and Computer Engineering
Expertise: Nanoscale Science and Technology; Semiconductor Nanomaterials and Devices for Electronic, Optoelectronic and Biological Applications
***Ph.D.*:** Materials, UC Santa Barbara, 2001
Background: Postdoctoral Fellow, Harvard University

All Joined UCSD in Last 2.5 Years



Shayan Mookherjea, Asst. Professor, Electrical and Computer Engineering
Expertise: Optical Devices and Optical Communication Networks, Including Photonics, Lightwave Systems and Nano-Scale Optics
***Ph.D.*:** Electrical Engineering, Caltech, 2003
Background: 2003 Wilts Prize for Best Thesis in Caltech Electrical Engineering

it²

NSF Quartzite Research Instrumentation Award ECE Faculty Augment OptIPuter Testbed

- Hybrid System of Packet-Based and Circuit-Based Devices
- Match the Network to the Number of Existing Endpoints
- Greatly Increase the Number of 10Gb Optical Paths
  - Evaluating DWDM and CWDM Technologies for Campus Scale
- Hybrid Network "Switch Stack" at Campus Collocation Point
  - Packet Switch—Chiaro Networks
  - Transparent Optical Switch--Glimmerglass
    - Physically Build New Topologies Without Physical Rewiring
  - Experimental Pre-Commercial Devices
    - Lucent Wavelength-Selective Switch
  - Experimental Academic Devices
    - Radic/Ford Packet-Rate Wavelength Routing and Multicasting

OptIPuter

Source: Phil Papadopoulos, SDSC, Calit2—Quartzite PI

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The Optical Core of the UCSD Campus-Scale Testbed -- Evaluating Packet Routing versus Lambda Switching

Goals by 2007:

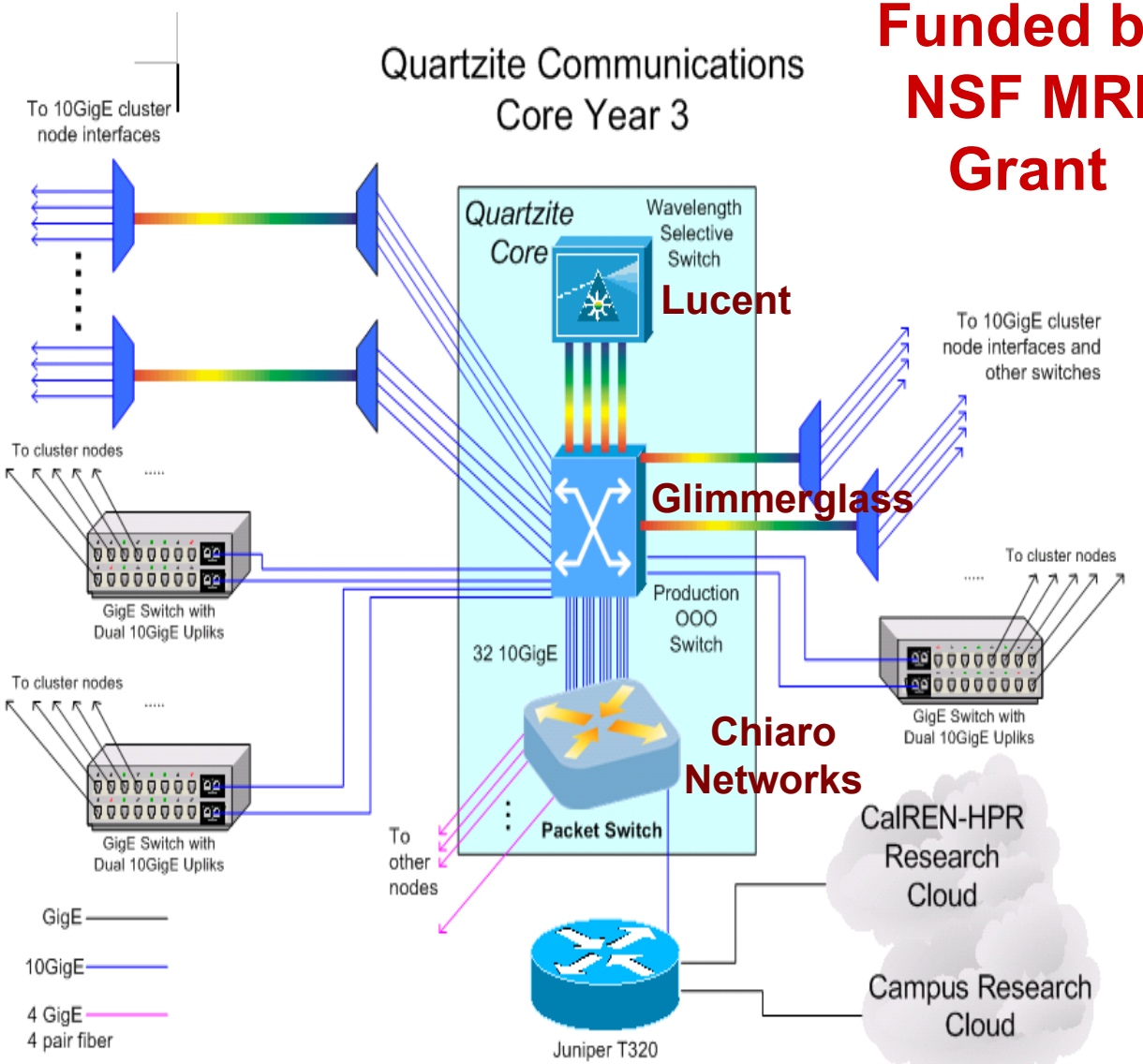
>= 50 endpoints at 10 GigE

>= 32 Packet switched

>= 32 Switched wavelengths

>= 300 Connected endpoints

Approximately 0.5 TBit/s Arrive at the "Optical" Center of Campus
Switching will be a Hybrid Combination of:
Packet, Lambda, Circuit -- OOO and Packet Switches Already in Place



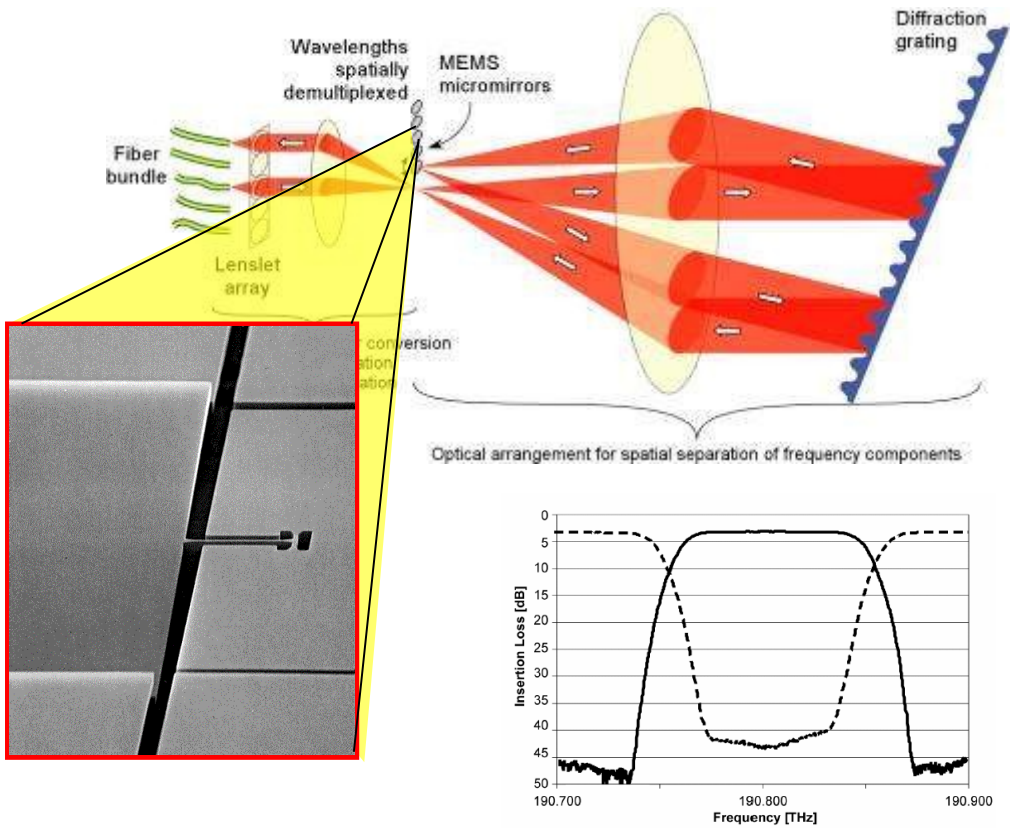
Funded by NSF MRI Grant

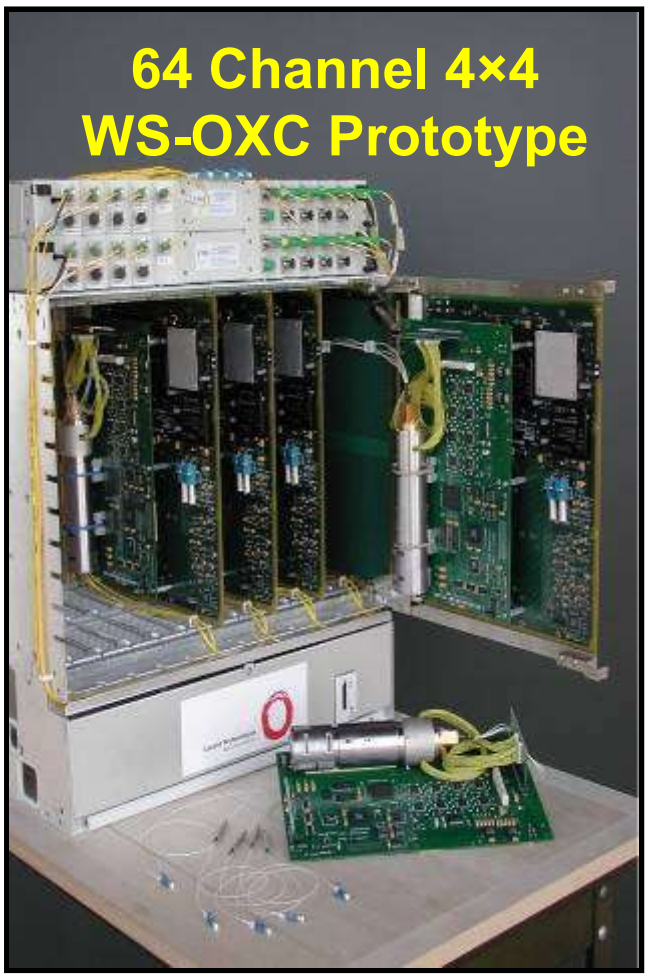
Source: Phil Papadopoulos, SDSC, Calit2

UCSD Quartzite Testbed -- Lucent 1xK Wavelength-Selective Switch

MEMS Wavelength Switching Concept:

Modular Transparent DWDM Network Provisioning





Micro-Electro-Mechanical Switching + Free-Space Optical Wavelength MUX

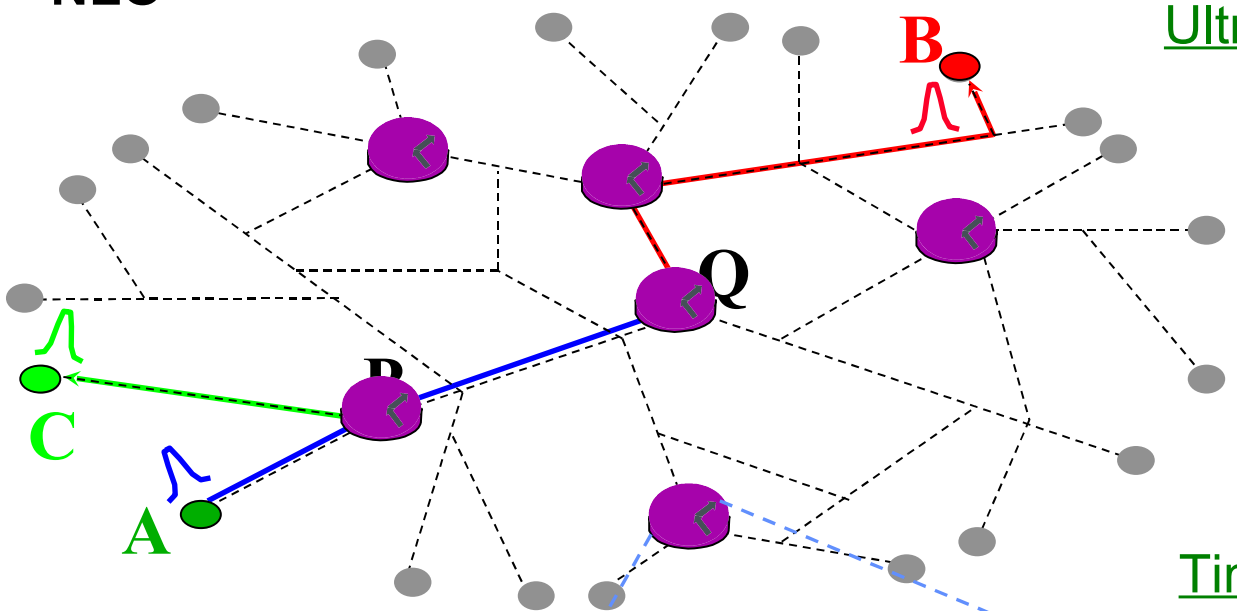
Millisecond-Rate Provisioning for DWDM & CWDM Networks

OptIPuter

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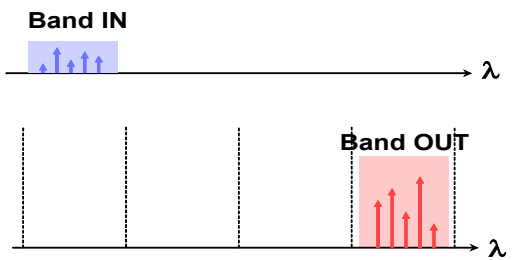
Packet-Rate Wavelength Routing and Multicasting
Parametric λ-Conversion + Passive Waveguide Routing

Conventional 10 GbE Terminals Connected via Transparent Passive Router + NLO



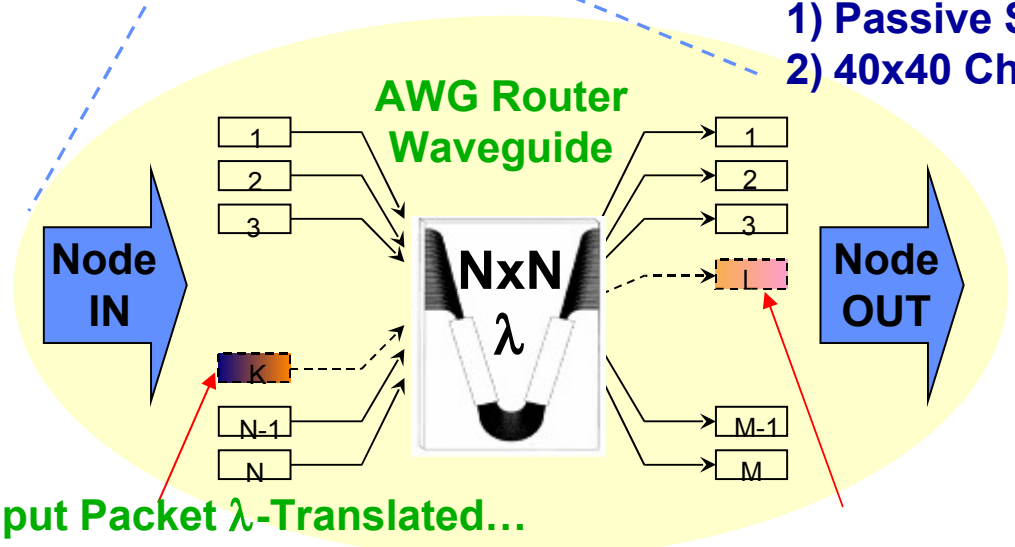
Ultra-fast Parametric λ-Conversion

1) Wavelength Band Translation
2) 1 to 100nm Translation
3) Amplification & 2R Regeneration



Time-of-Flight Transparent Routing

1) Passive Silica Waveguide
2) 40x40 Channels, 50 GHz Passband



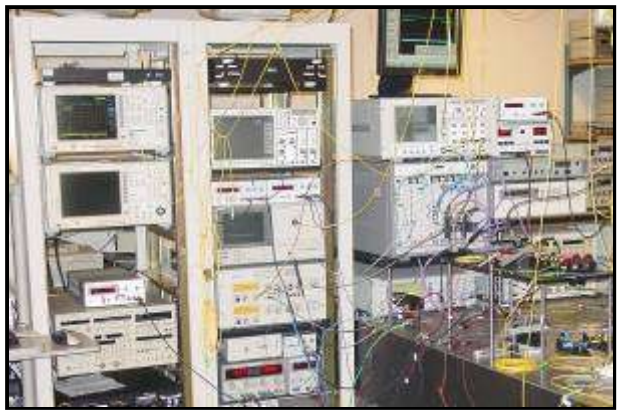
Source:
Joseph Ford,
Stojan Radic,
ECE, UCSD

OptIPuter

UCSD Photonics

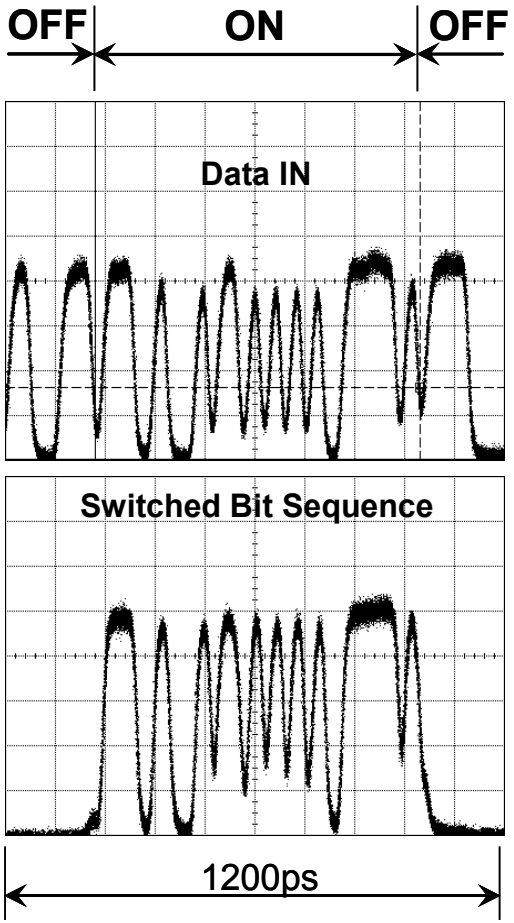
it²

Experimental Demo: λ-Conversion @ 40 Gb/s





UCSD Parametric Processing Laboratory



OC-768 Packet Switched in Primitive Parametric Cell

Parametric Processing

- Nonlinear Processing in High Confinement Fiber / SOA / QD
- Sub-Picosecond Response Time + Time-of-Flight

Advantages over Conventional O-E-O Routing

- Data Rate / Format Independent: Transparent to 1 Tb/s
- Routes Signals by Multichannel Band (Not Single λ)
- Selective Conjugation Supports Long-Haul Transmission

OptIPuter

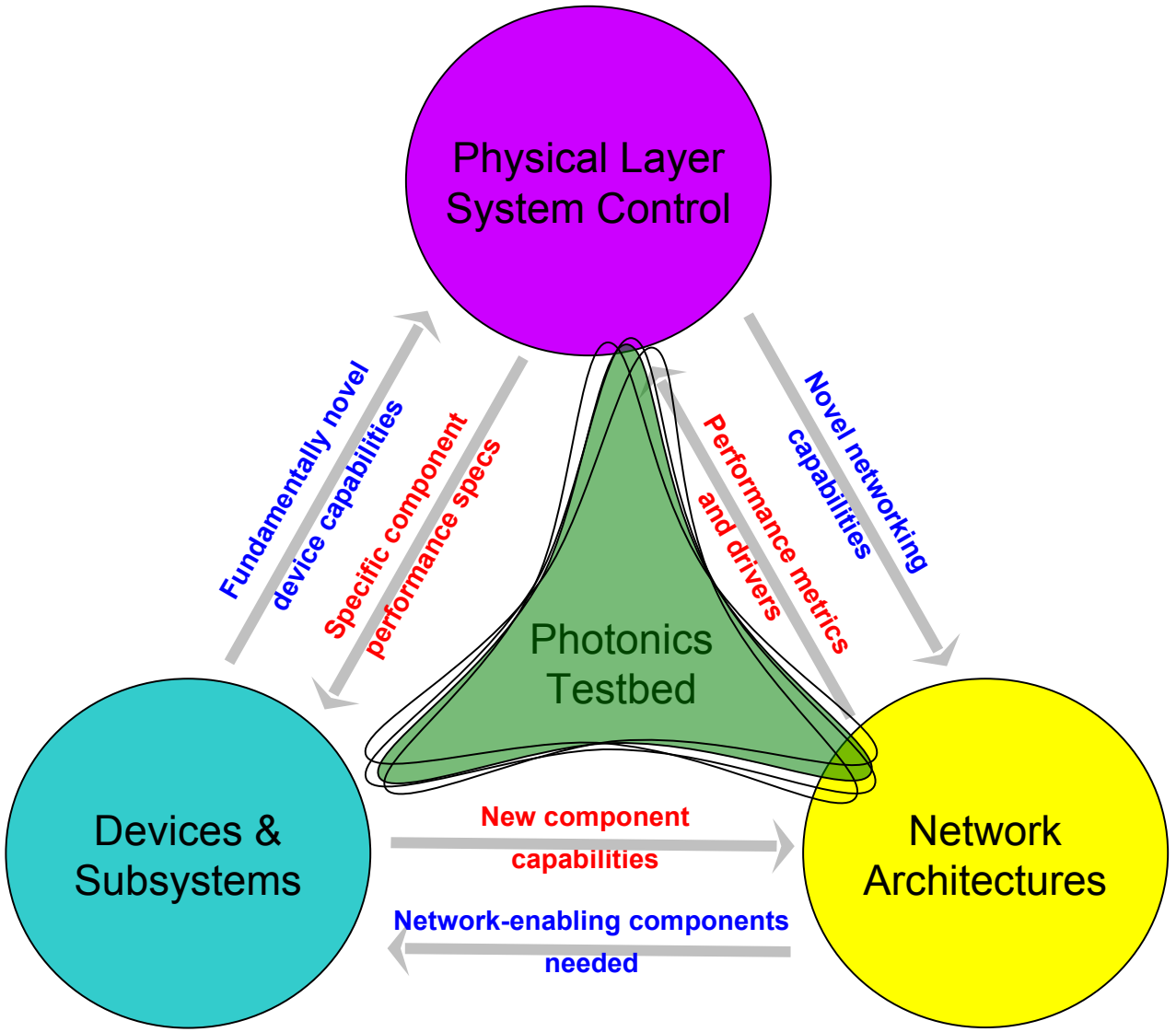
UCSD Photonics

it²

Source: Joseph Ford, Stojan Radic, ECE, UCSD

Scalable Intelligent Optical Networks (SION) Photonics Research Testbed

UCSD Photonics



To Enable Cross-Integrational Photonics Systems Research

OptIPuter

it²

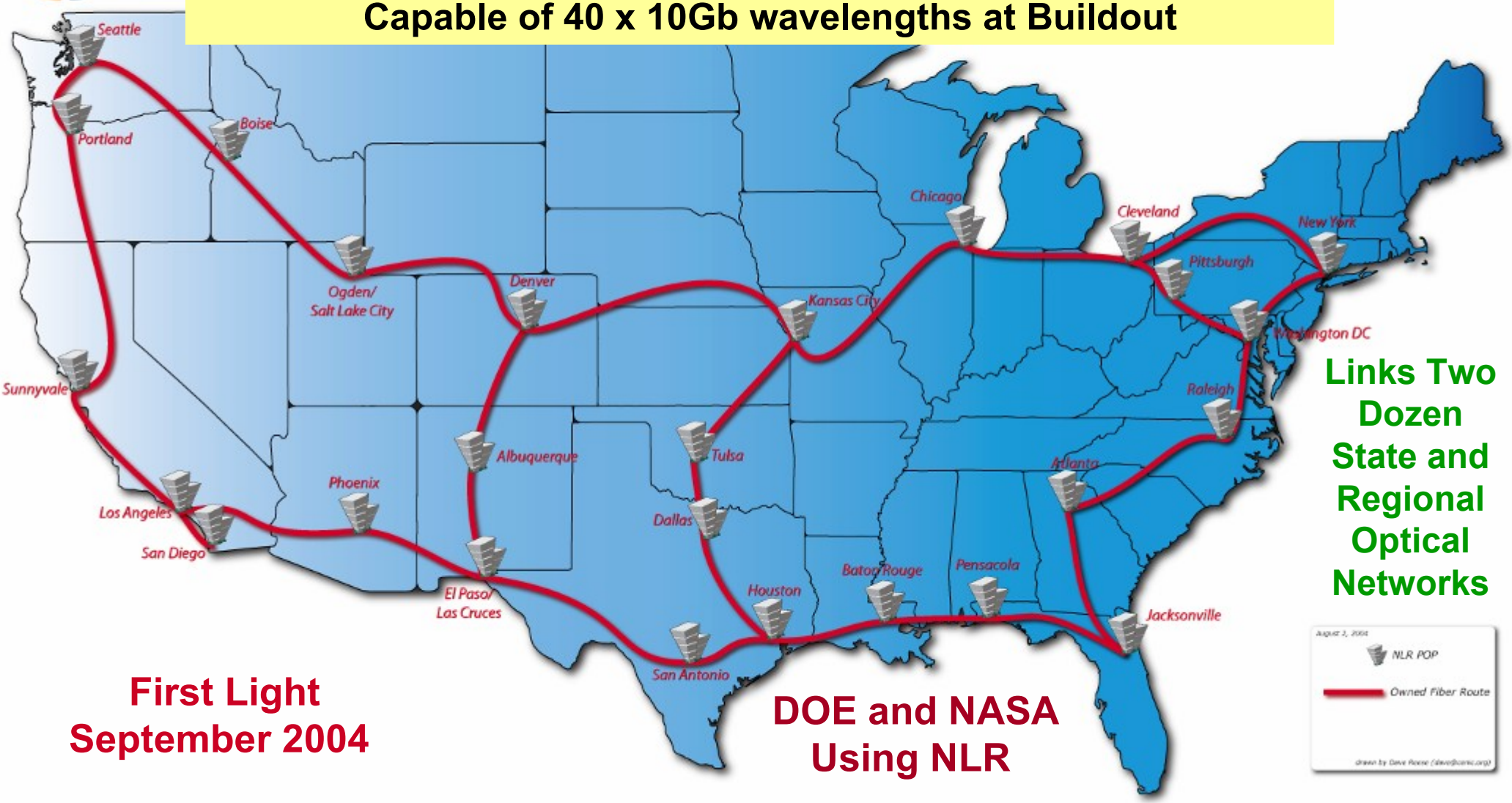
NLR Will Provide an Experimental Network Infrastructure for U.S. Scientists & Researchers

"National LambdaRail" Partnership

Serves Very High-End Experimental and Research Applications

4 x 10Gb Wavelengths Initially

Capable of 40 x 10Gb wavelengths at Buildout



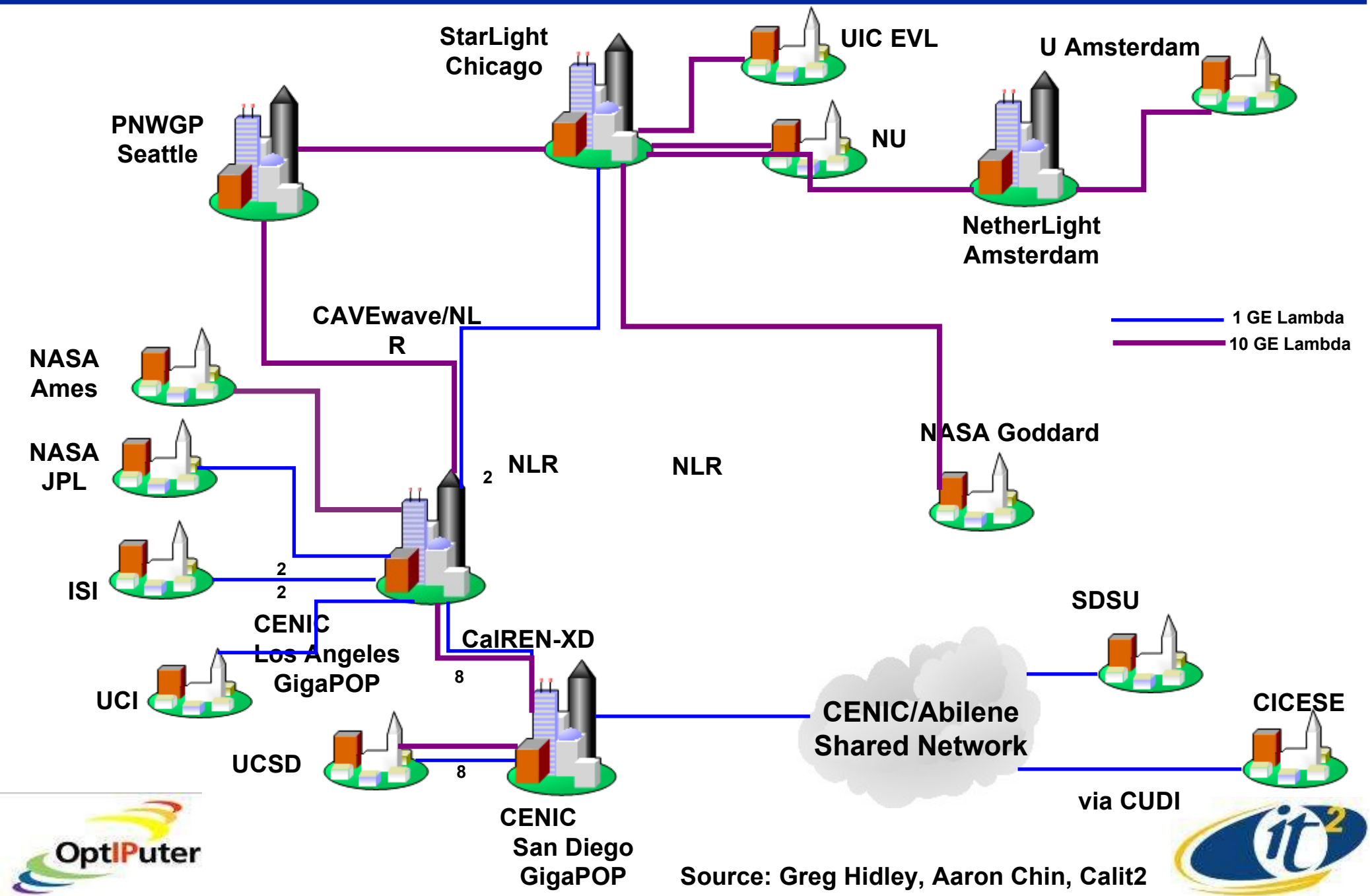
Links Two Dozen State and Regional Optical Networks

First Light September 2004

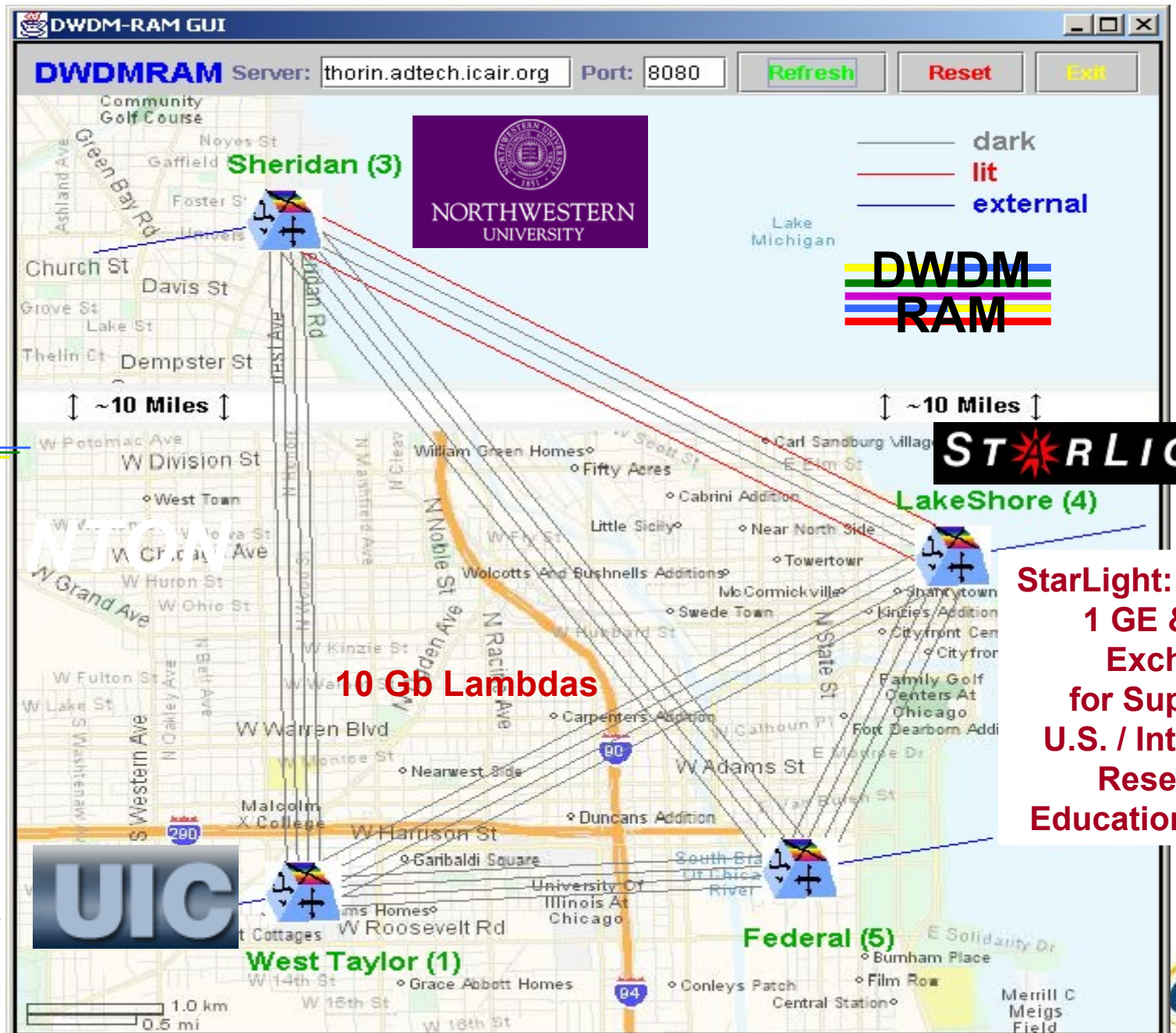
DOE and NASA Using NLR

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

The OptIPuter LambdaGrid is Rapidly Expanding

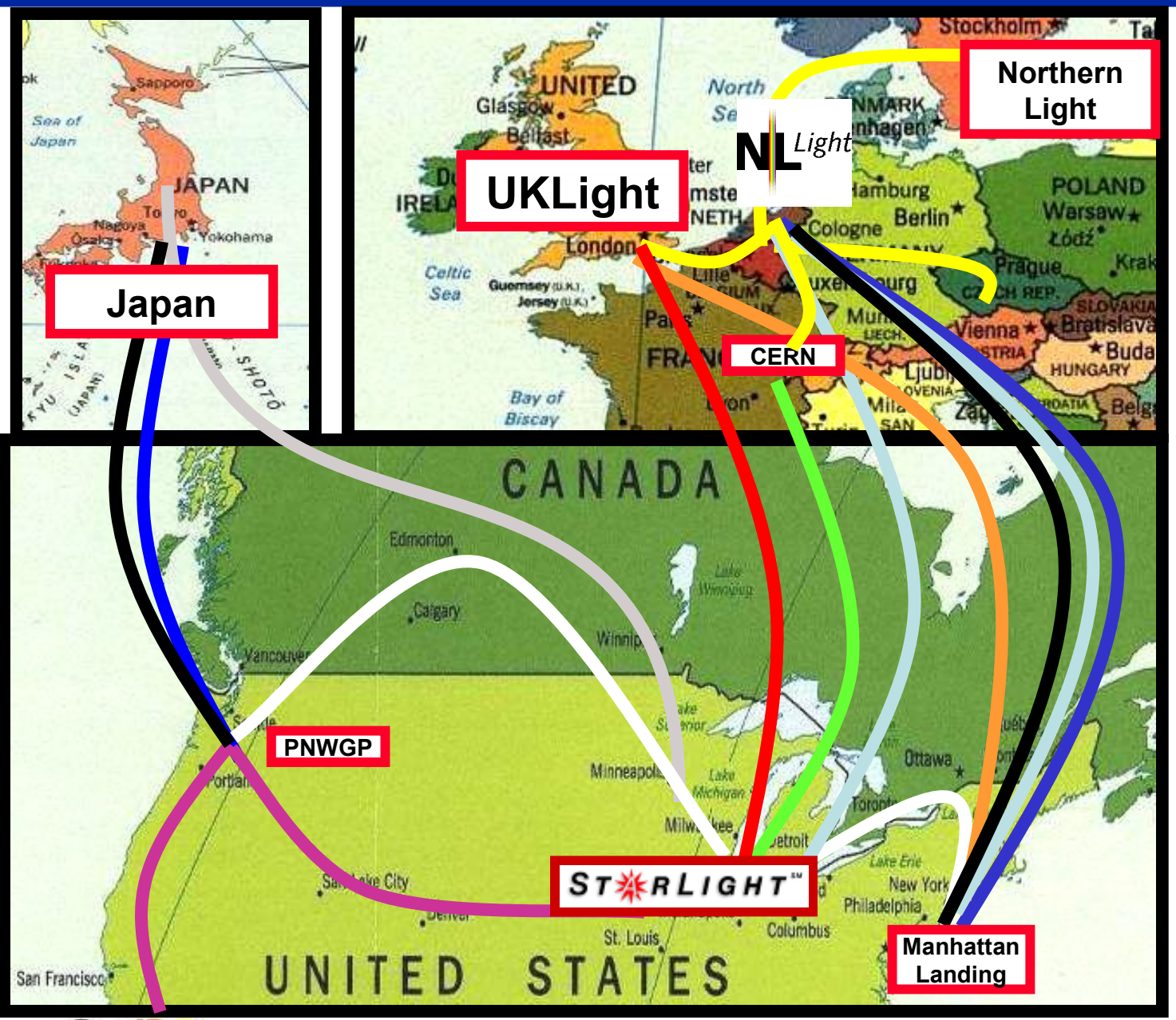


OptIPuter Has Built on the Lessons Learned from the OMNInet Metro Area OOO Testbed



StarLight: the Largest 1 GE & 10 GE Exchange for Supporting U.S. / International Research & Education Networks

Dedicated Research 10Gb Optical Circuits in 2005
North America, Europe and Japan



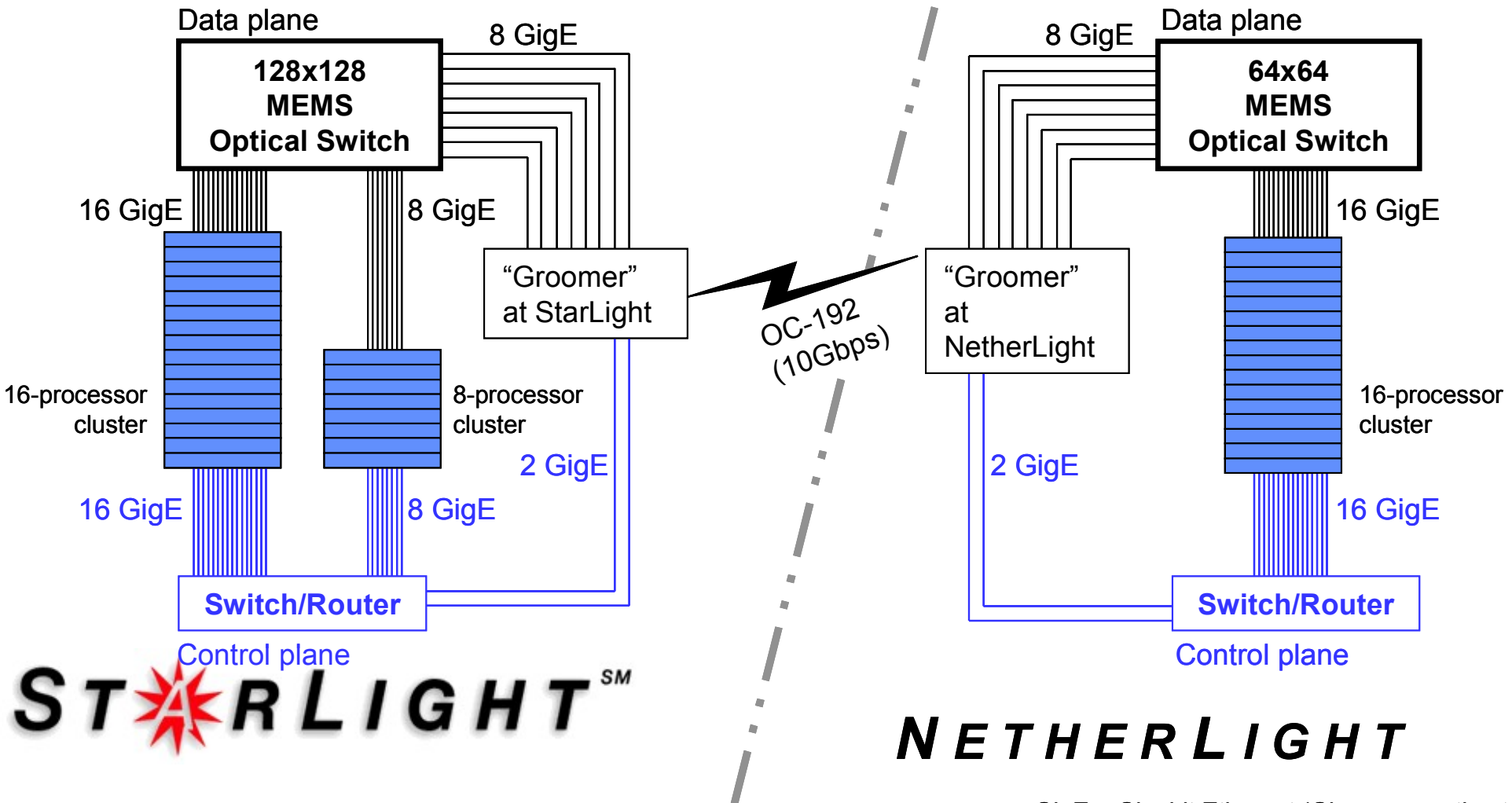
US IRNC (black)
–20Gb NYC—Amsterdam
–10Gb LA—Tokyo
GEANT/I2 (orange)
–30Gb London, etc.—NYC
UK to US (red)
–10Gb London—Chicago
SURFnet to US (light blue)
–10Gb Amsterdam—NYC
–10Gb Amsterdam—Chicago
Canadian CA*net4 to US (white)
–30Gb Chicago-Canada-NYC
–30Gb Chicago-Canada-Seattle
Japan JGN II to US (grey)
–10Gb Chicago—Tokyo
European (not GEANT) (yellow)
–10Gb Amsterdam—CERN
–10Gb Prague—Amsterdam
–2.5Gb Stockholm—Amsterdam
–10Gb London—Amsterdam
IEEAF lambdas (dark blue)
–10Gb NYC—Amsterdam
–10Gb Seattle—Tokyo
CAVEwave/PacificWave (purple)
–10Gb Chicago—Seattle—SD
–10Gb Seattle—LA—SD

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Calient Lambda Switches Now Installed at StarLight and NetherLight

University of Amsterdam is an OptIPuter Partner



GigE = Gigabit Ethernet (Gbps connection type)

Now Supporting 10GE International Lambdas

Source: Maxine Brown, OptIPuter Project Manager

Multiple HD Streams Over Lambdas Will Radically Transform Campus Collaboration





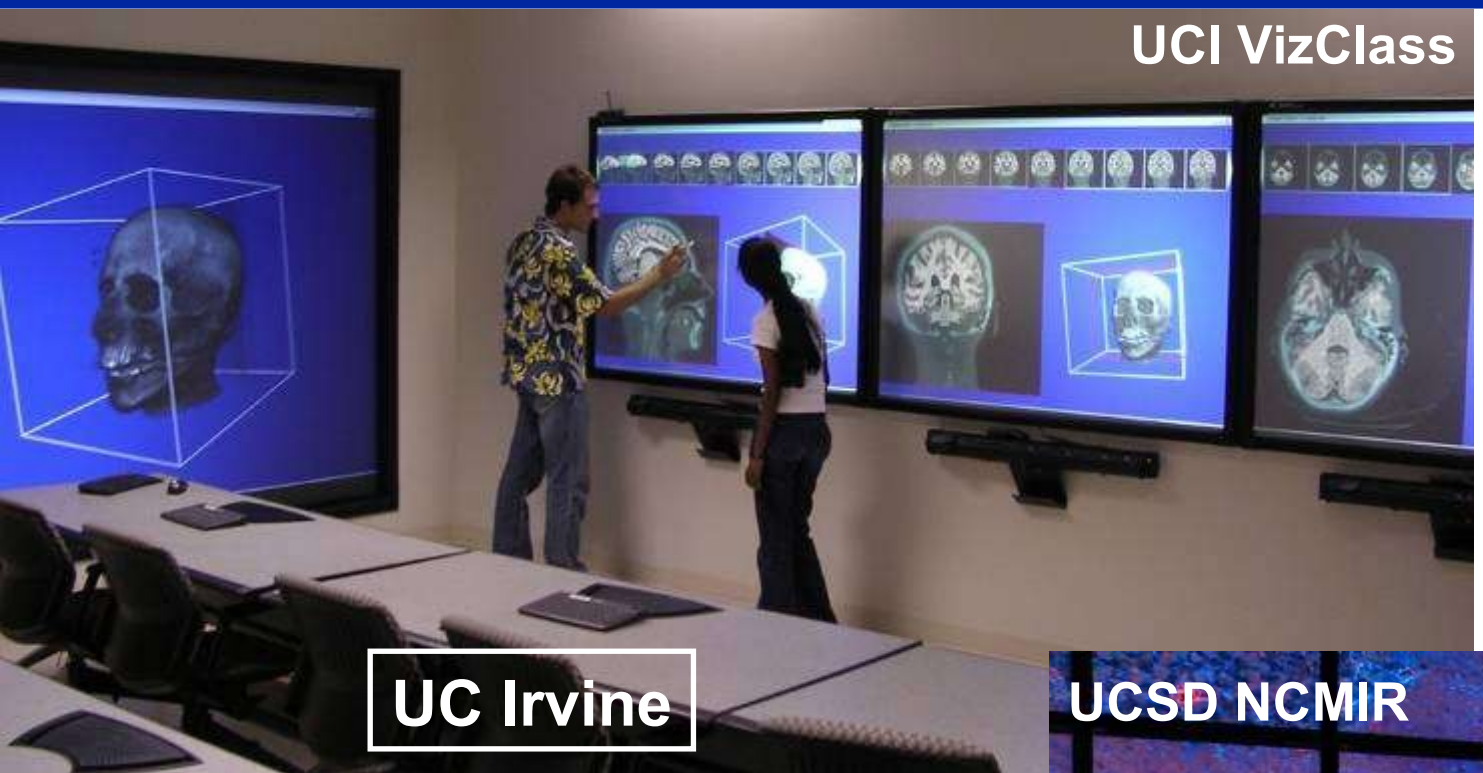


OptIPuter

Source: U Washington Research Channel

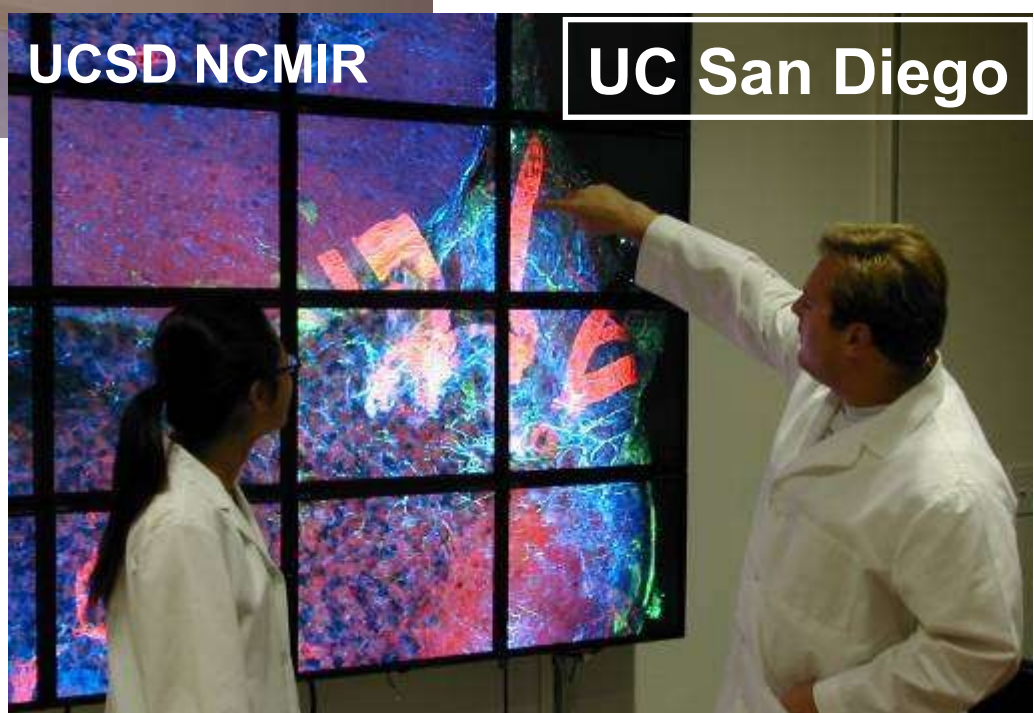
it²

Calit2 Collaboration Rooms Testbed
UCI to UCSD



Source: Falko Kuester, UCI & Mark Ellisman, UCSD

OptIPuter



In 2005 Calit2 will Link Its Two Buildings via CENIC-XD Dedicated Fiber over 75 Miles Using OptIPuter Architecture to Create a Distributed Collaboration Laboratory

OptIPuter

The Networking Double Header of the Century Will Be Driven by LambdaGrid Applications

Maxine Brown, Tom DeFanti, Co-Organizers



iGrid 2005

THE GLOBAL LAMBDA INTEGRATED FACILITY

www.startap.net/igrid2005/

September 26-30, 2005

University of California, San Diego

California Institute for Telecommunications and Information Technology

SC|05 Gateway to Discovery

Washington State Convention and Trade Center Seattle, WA
November 12-18 2005

http://sc05.supercomp.org