Shrinking the Planet—How Dedicated Optical Networks are Transforming Computational Science and Collaboration

Invited Lecture in the
Frontiers in Computational and Information Sciences Lecture Series
Pacific Northwest National Laboratory
August 25, 2008

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

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Abstract

During the last few years, a radical restructuring of global optical networks supporting e-Science projects has caused a paradigm shift in computational science and collaboration technologies. From a scalable tiled display wall in a researcher's campus laboratory, one can experience global Telepresence, augmented by minimized latency to remote global data repositories, scientific instruments, and computational resources. Calit2 is using its two campuses at UCSD and UCI to prototype the “research campus of the future” by deploying campus-scale “Green” research cyberinfrastructure, providing “on-ramps” to the National LambdaRail and the Global Integrated Lambda Facility. I will describe how this user configurable "OptIPuter" global platform opens new frontiers in many disciplines of science, such as interactive environmental observatories, climate change simulations, brain imaging, and marine microbial metagenomics, as well as in collaborative work environments, digital cinema, and visual cultural analytics. Specifically, I will discuss how PNNL and UCSD could set up an OptIPuter collaboratory to support their new joint Aerosol Chemistry and Climate Institute (ACCI).

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Interactive Supercomputing Collaboratory Prototype:
Using Analog Communications to Prototype the Fiber Optic Future

"What we really have to do is eliminate distance between individuals who want to interact with other people and with other computers."
— Larry Smarr, Director, NCSA

SIGGRAPH 1989







**"We're using satellite technology…
to demo what It might be like to have
high-speed fiber-optic links between
advanced computers
in two different geographic locations."**

— Al Gore, Senator
Chair, US Senate Subcommittee on Science, Technology and Space

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Chesapeake Bay Simulation Collaboratory : vBNS Linked CAVE, ImmersaDesk, Power Wall, and Workstation

Alliance Project: Collaborative Video Production via Tele-Immersion and Virtual Director

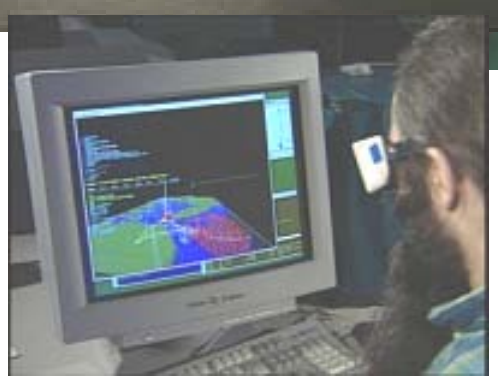
Alliance Application Technologies
Environmental Hydrology Team







Alliance 1997





NCSA™ UIC

sgi

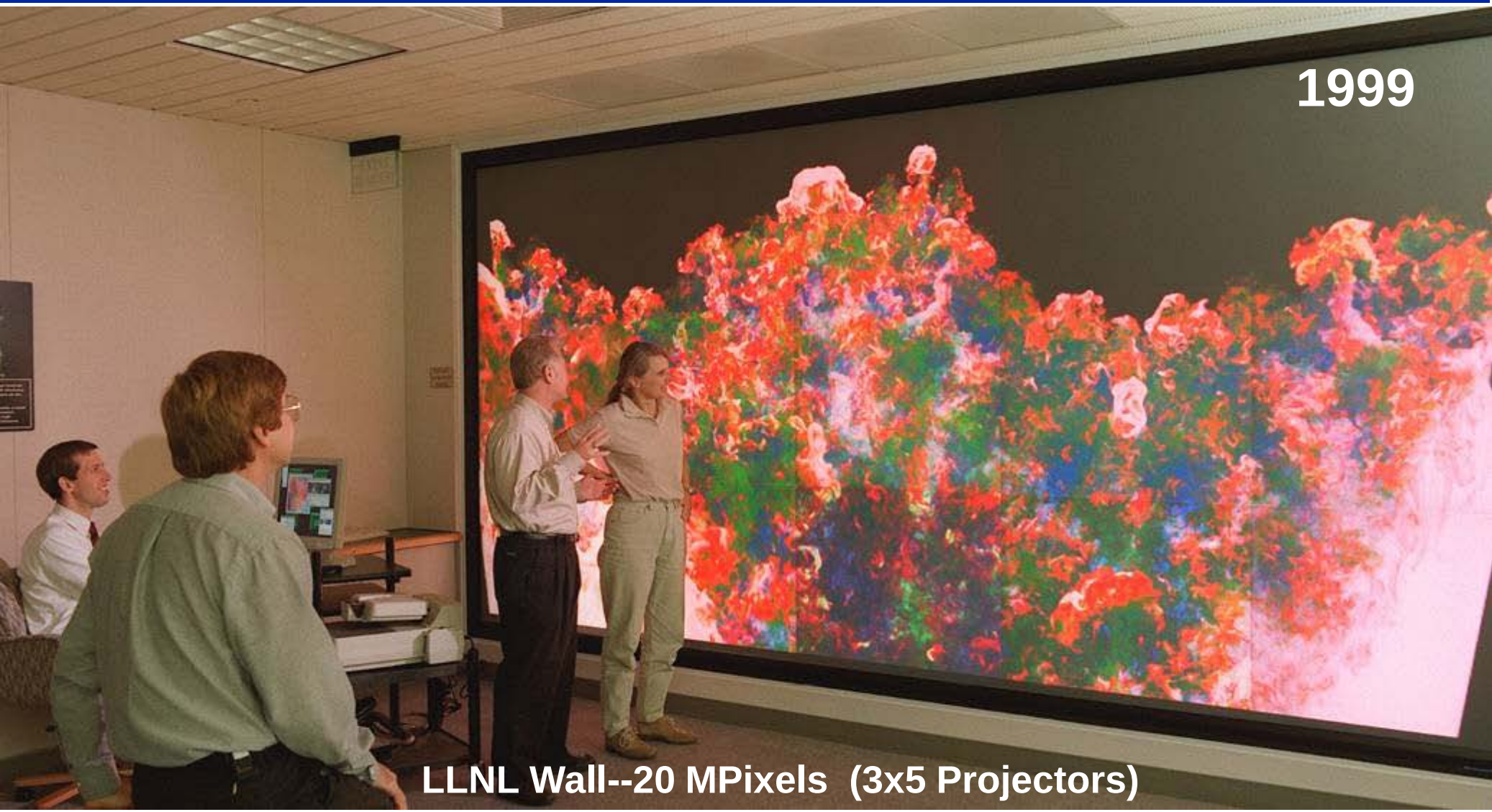
ALLIANCE

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Donna Cox, Robert Patterson, Stuart Levy, NCSA Virtual Director Team
Glenn Wheless, Old Dominion Univ.

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ASCI Brought Scalable Tiled Walls to Support Visual Analysis of Supercomputing Complexity



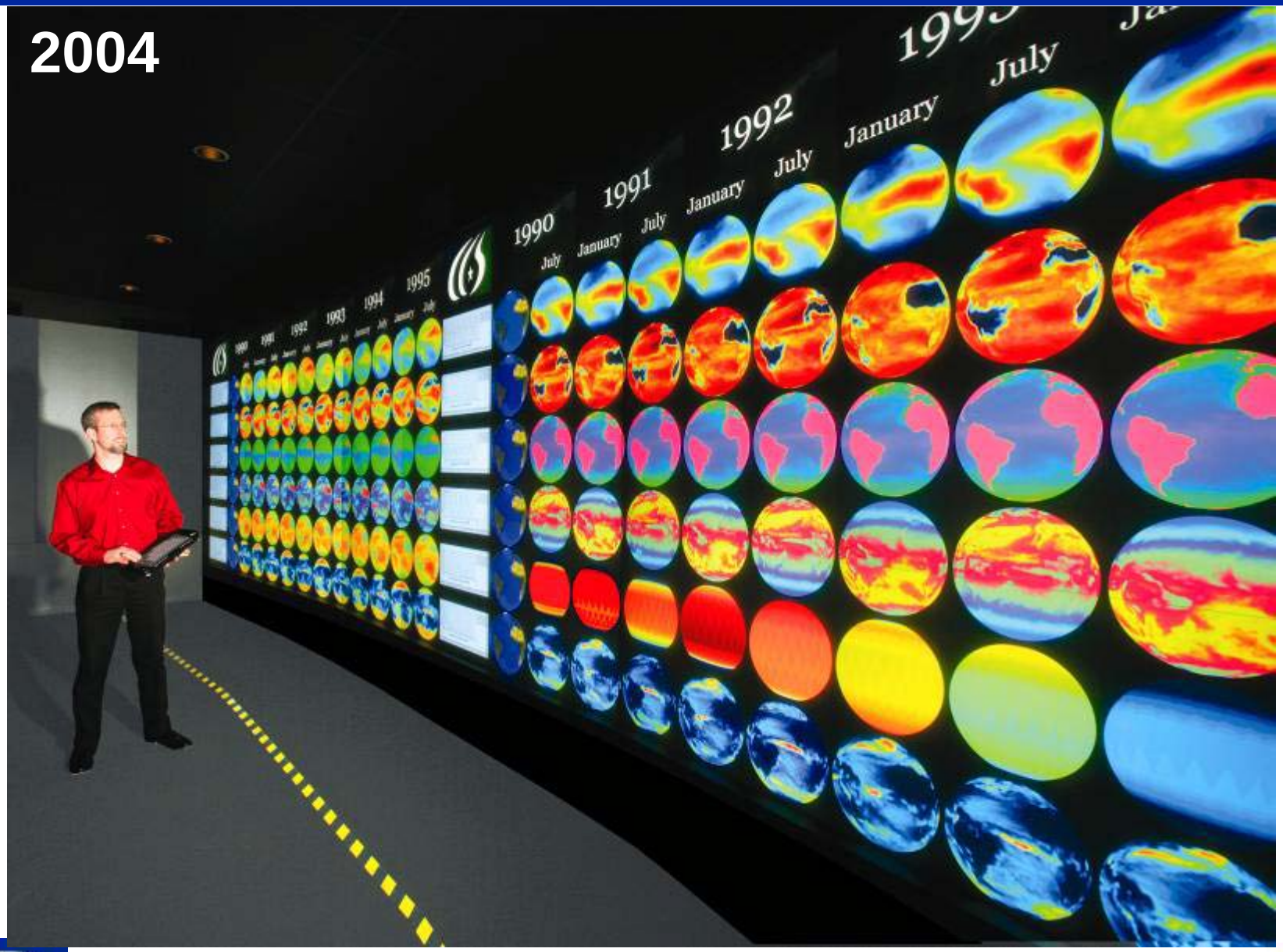
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An Early sPPM Simulation Run
Source: LLNL

ASCI
Accelerated Strategic Computing Initiative
Los Alamos
Sandia
Lawrence Livermore

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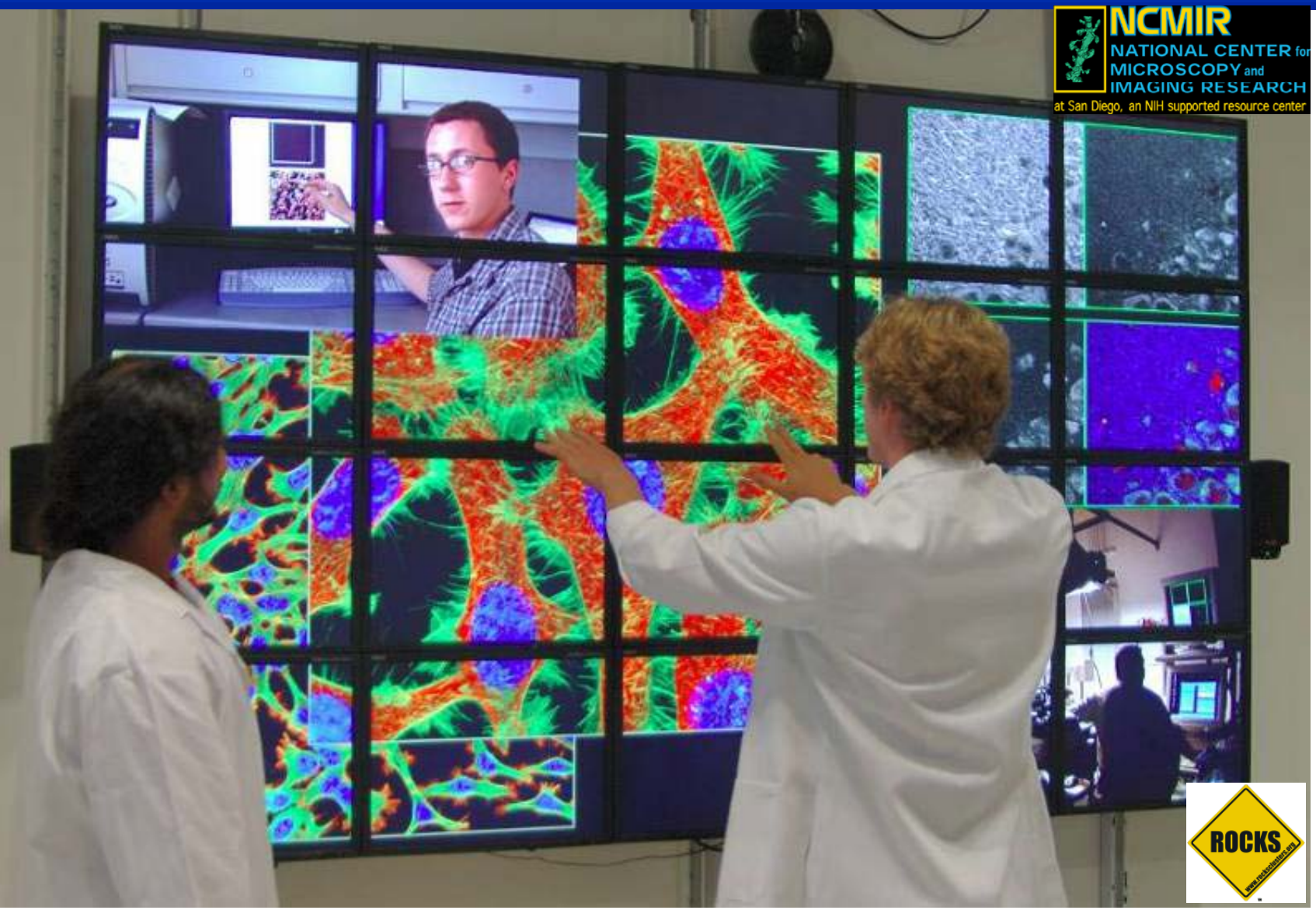
Challenge—How to Bring This Visualization Capability to the Supercomputer End User?



35Mpixel EVEREST Display ORNL

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The OptIPuter Project: Creating High Resolution Portals Over Dedicated Optical Channels to Global Science Data



Scalable Adaptive Graphics Environment (SAGE)

evl electronic visualization laboratory

NSF

Now in Sixth and Final Year

Picture Source: Mark Ellisman, David Lee, Jason Leigh

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Calit2 (UCSD, UCI), SDSC, and UIC Leads—Larry Smarr PI

Univ. Partners: NCSA, USC, SDSU, NW, TA&M, UvA, SARA, KISTI, AIST

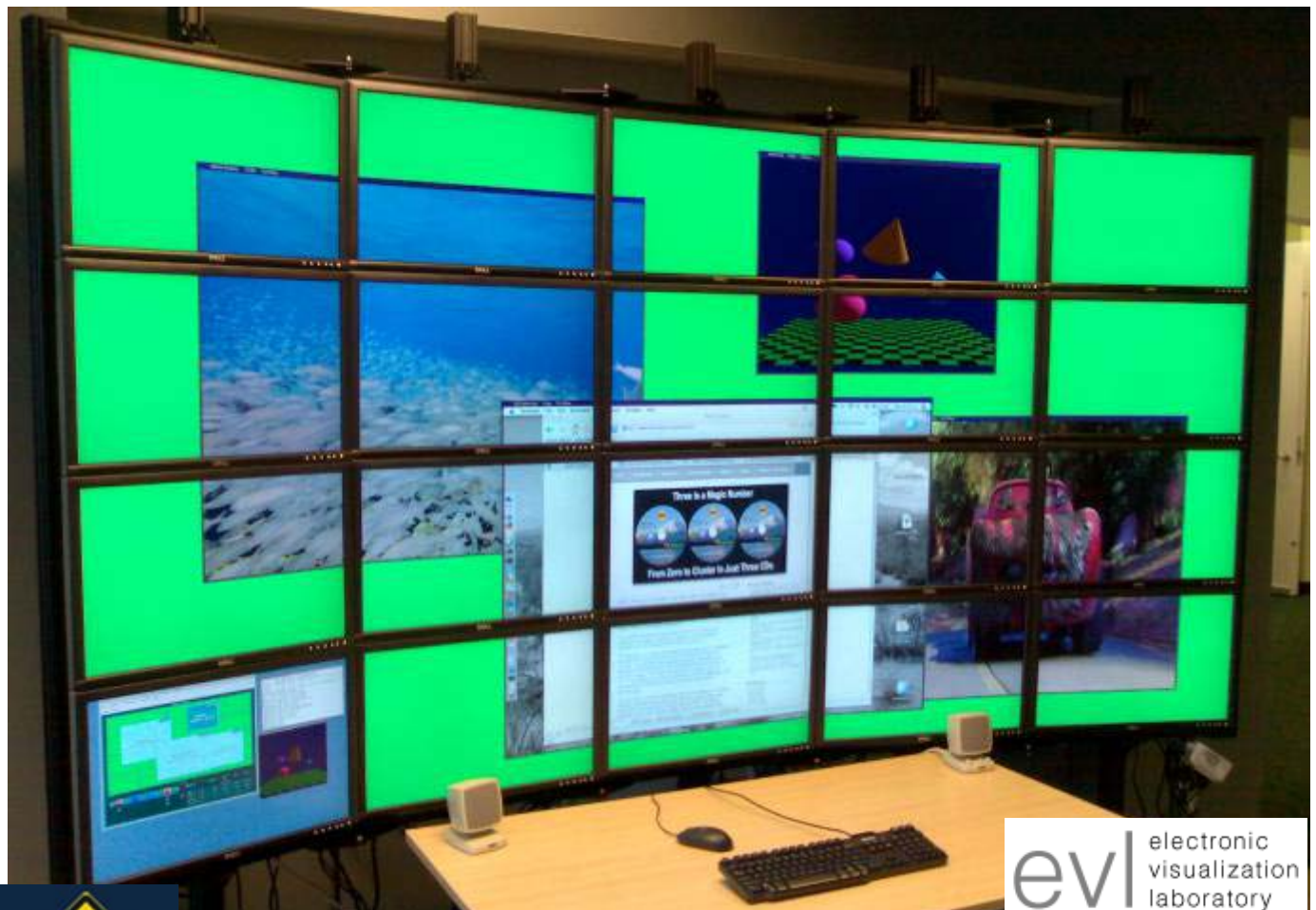
Industry: IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent

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My OptIPortal™ – Affordable Termination Device for the OptIPuter Global Backplane

- 20 Dual CPU Nodes, Twenty 24” Monitors, ~$50,000
- 1/4 Teraflop, 5 Terabyte Storage, 45 Mega Pixels--Nice PC!
- Scalable Adaptive Graphics Environment (SAGE) Jason Leigh, EVL-UIC





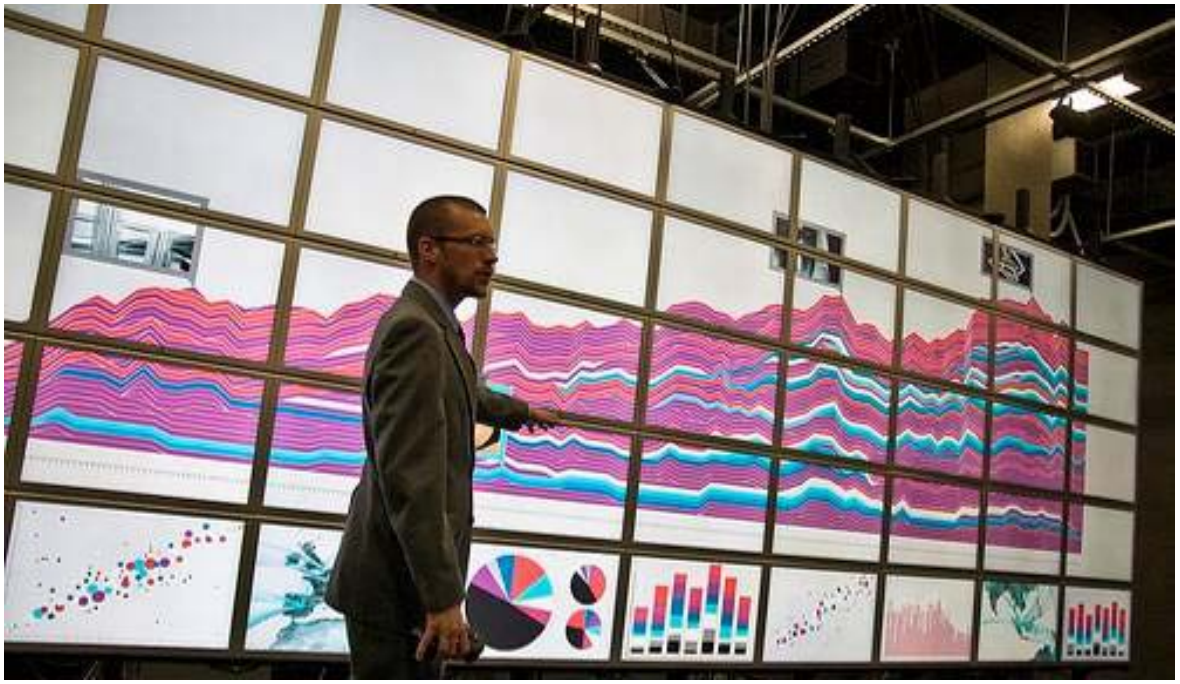
Source: Phil Papadopoulos SDSC, Calit2

World's Largest OptIPortal – 1/3 Billion Pixels



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Cultural Analytics: Analysis and Visualization of Global Cultural Flows and Dynamics



Calit2@UCI
200 Mpixel
HIPerWall



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UCIrvine

Software Studies Initiative, Calti2@UCSD

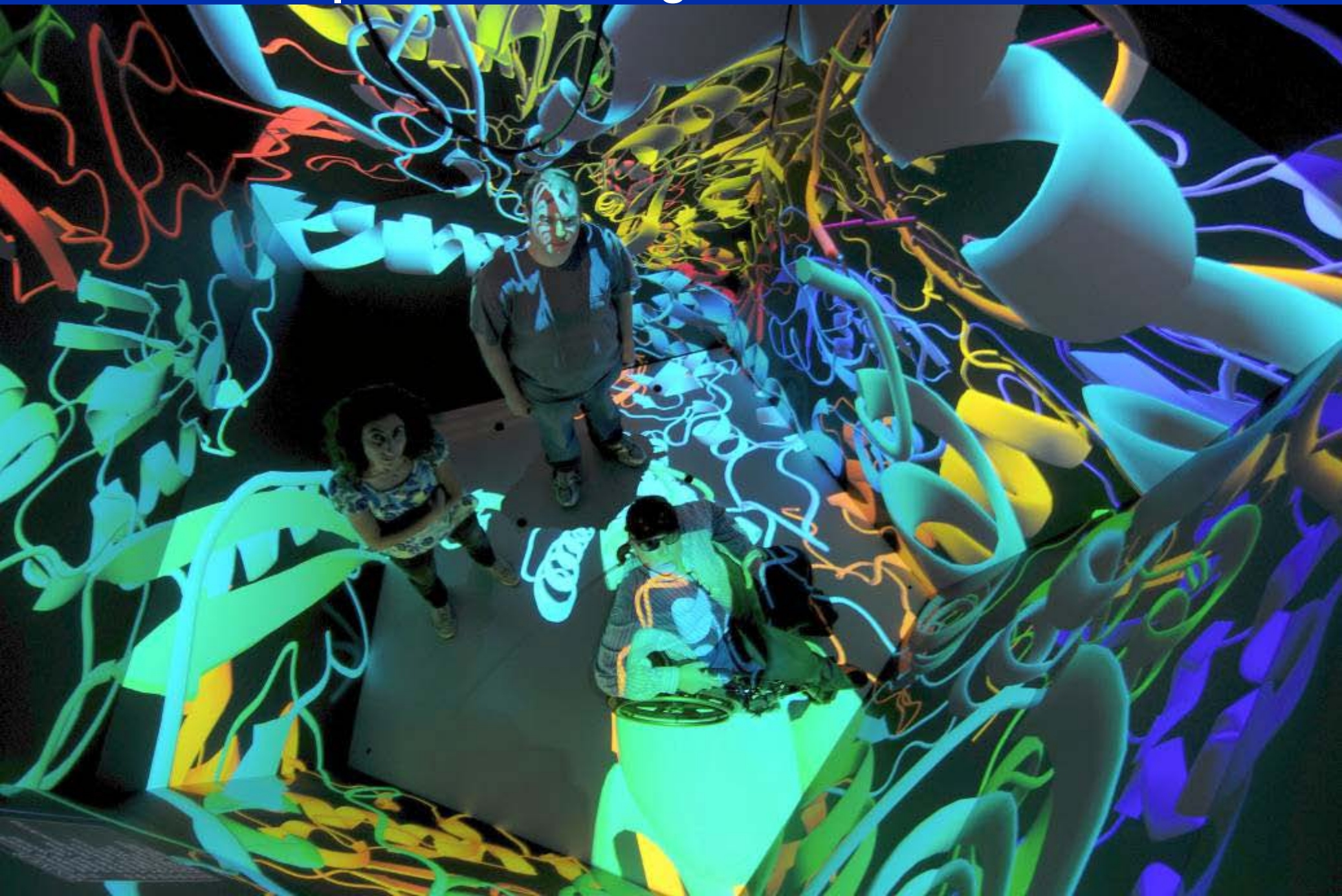
Interface Designs for Cultural Analytics Research Environment

Jeremy Douglass (top) & Lev Manovich (bottom)

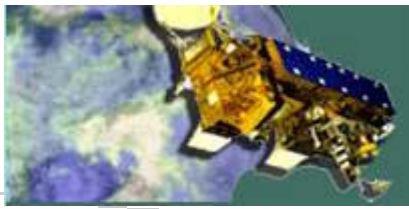
Second Annual Meeting of the Humanities, Arts, Science, and Technology Advanced Collaboratory (HASTAC II) UC Irvine May 23, 2008

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Calit2 3D Immersive StarCAVE OptIPortal: Enables Exploration of High Resolution Simulations



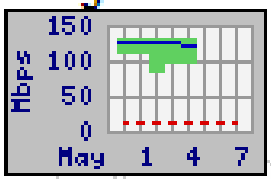
Challenge: Average Throughput of NASA Data Products to End User is ~ 50 Mbps



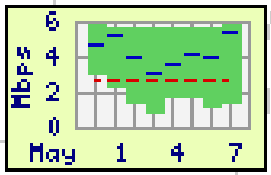
EOS Active Network Testing

AQUA Mission Destinations

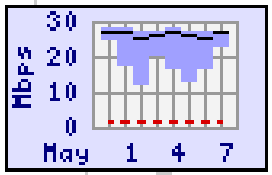
Oregon St.



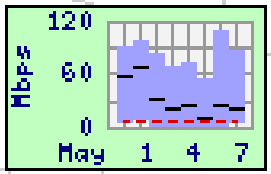
RSS



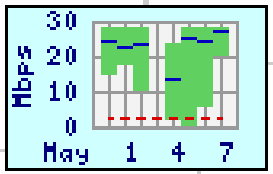
Montana



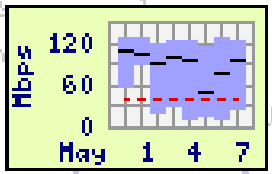
UCSB



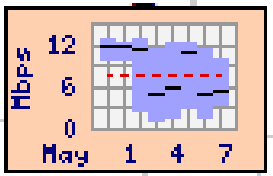
Colo State



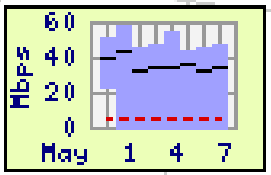
JPL-AIRS



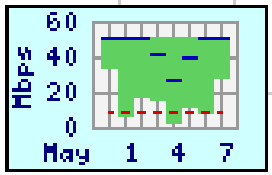
NSIDC_u



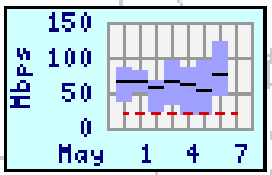
Arizona



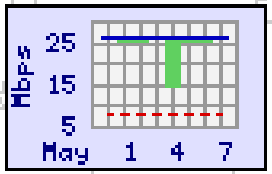
UCSD



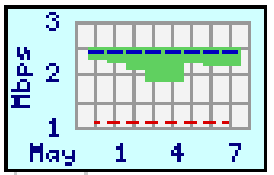
Wisconsin



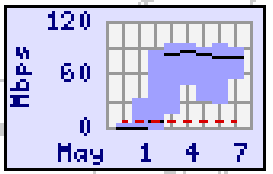
UAH-GHRC



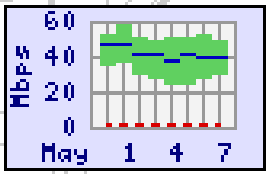
UCL



Boston U



SUNY-SB



Tested
May 2008

Internet2 Backbone is 10,000 Mbps!
Throughput is < 0.5% to End User

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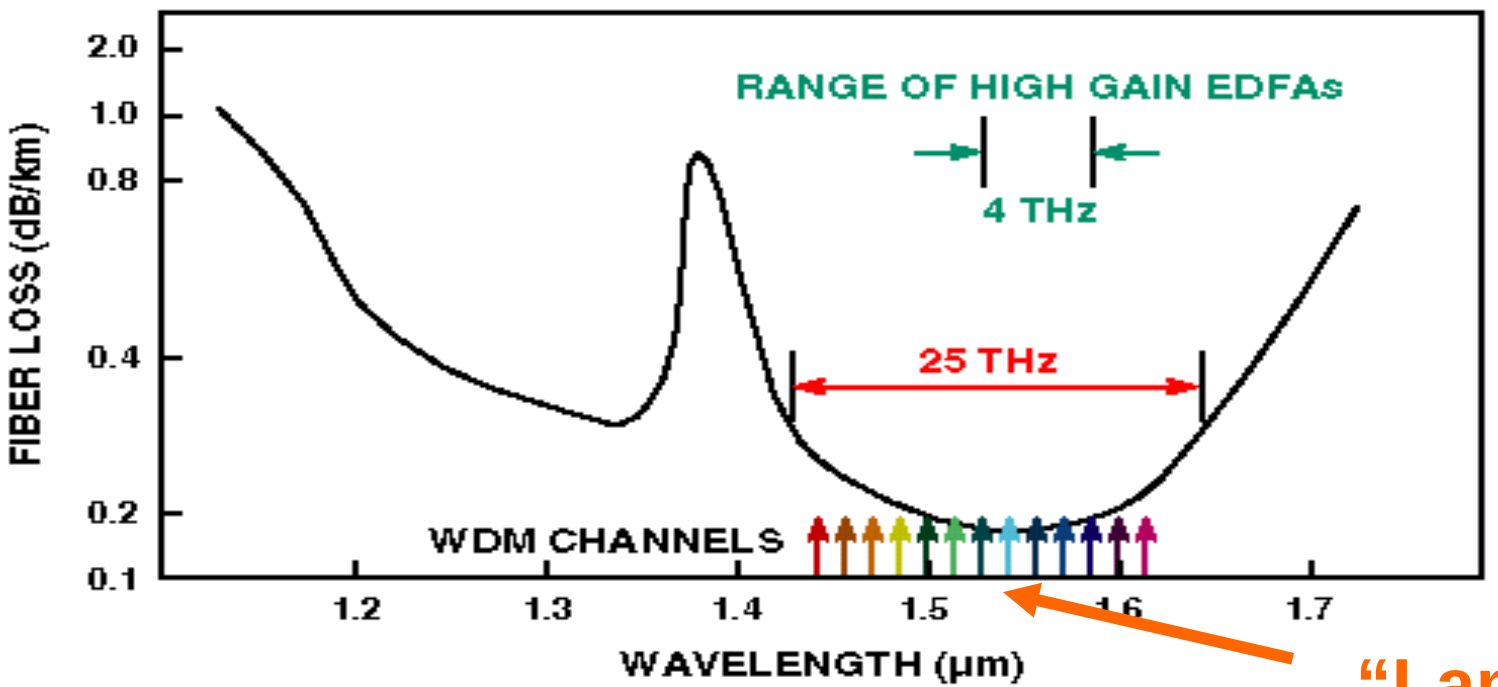
http://ensight.eos.nasa.gov/Missions/aqua/index.shtml



Dedicated Optical Fiber Channels Makes High Performance Cyberinfrastructure Possible

WAVELENGTH DIVISION MULTIPLEXING (WDM)

- EXPLOITS
  - ENORMOUS BANDWIDTH OF SILICA FIBER
  - HIGH-GAIN WIDEBAND OPTICAL AMPLIFIERS



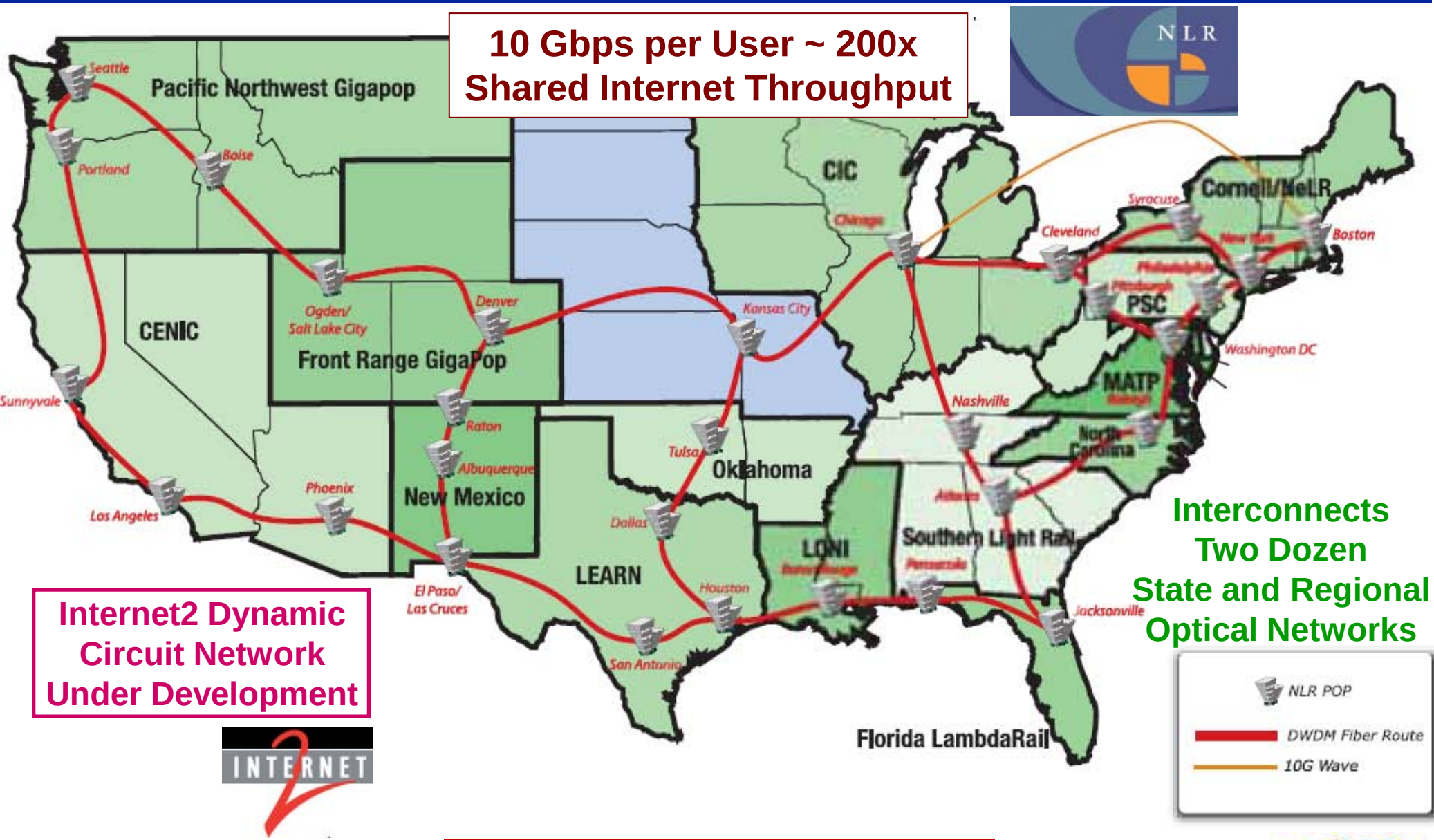
"Lambdas"

Parallel Lambdas are Driving Optical Networking
The Way Parallel Processors Drove 1990s Computing

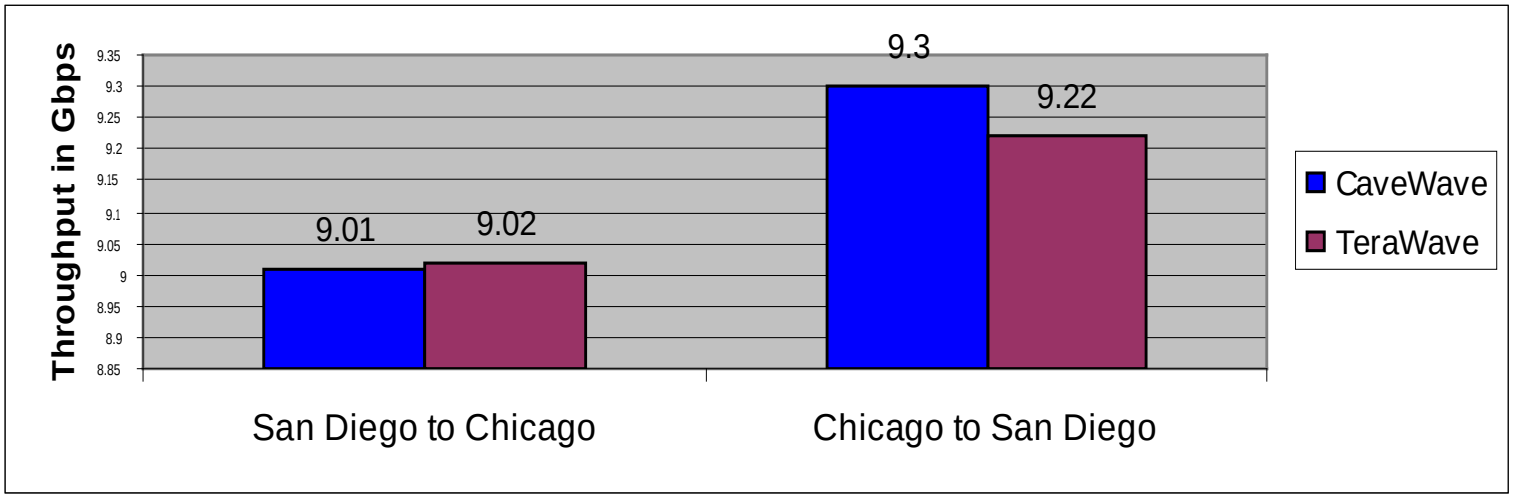
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Dedicated 10Gbps Lambdas Provide Cyberinfrastructure Backbone for U.S. Researchers



9Gbps Out of 10 Gbps Disk-to-Disk Performance Using LambdaStream between EVL and Calit2



CAVEWave:
20 senders to 20 receivers (point to point)

Effective Throughput = **9.01** Gbps
(San Diego to Chicago)
450.5 Mbps disk to disk transfer per stream

Effective Throughput = **9.30** Gbps
(Chicago to San Diego)
465 Mbps disk to disk transfer per stream

TeraGrid:
20 senders to 20 receivers (point to point)

Effective Throughput = **9.02** Gbps
(San Diego to Chicago)
451 Mbps disk to disk transfer per stream

Effective Throughput = **9.22** Gbps
(Chicago to San Diego)
461 Mbps disk to disk transfer per stream

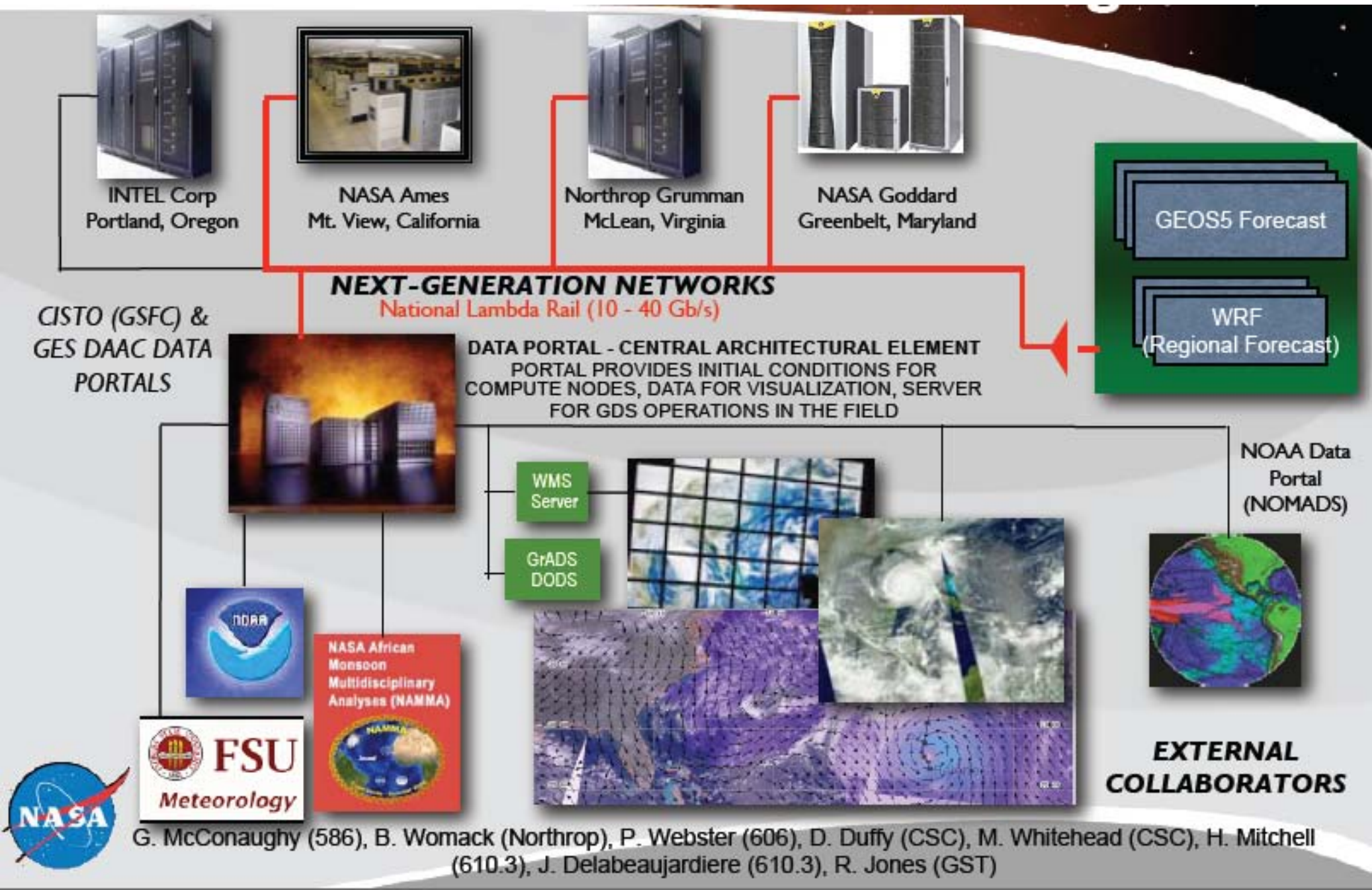
Dataset: 220GB Satellite Imagery of Chicago courtesy USGS.
Each file is 5000 x 5000 RGB image with a size of 75MB i.e ~ 3000 files

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Source: Venkatram Vishwanath, UIC EVL

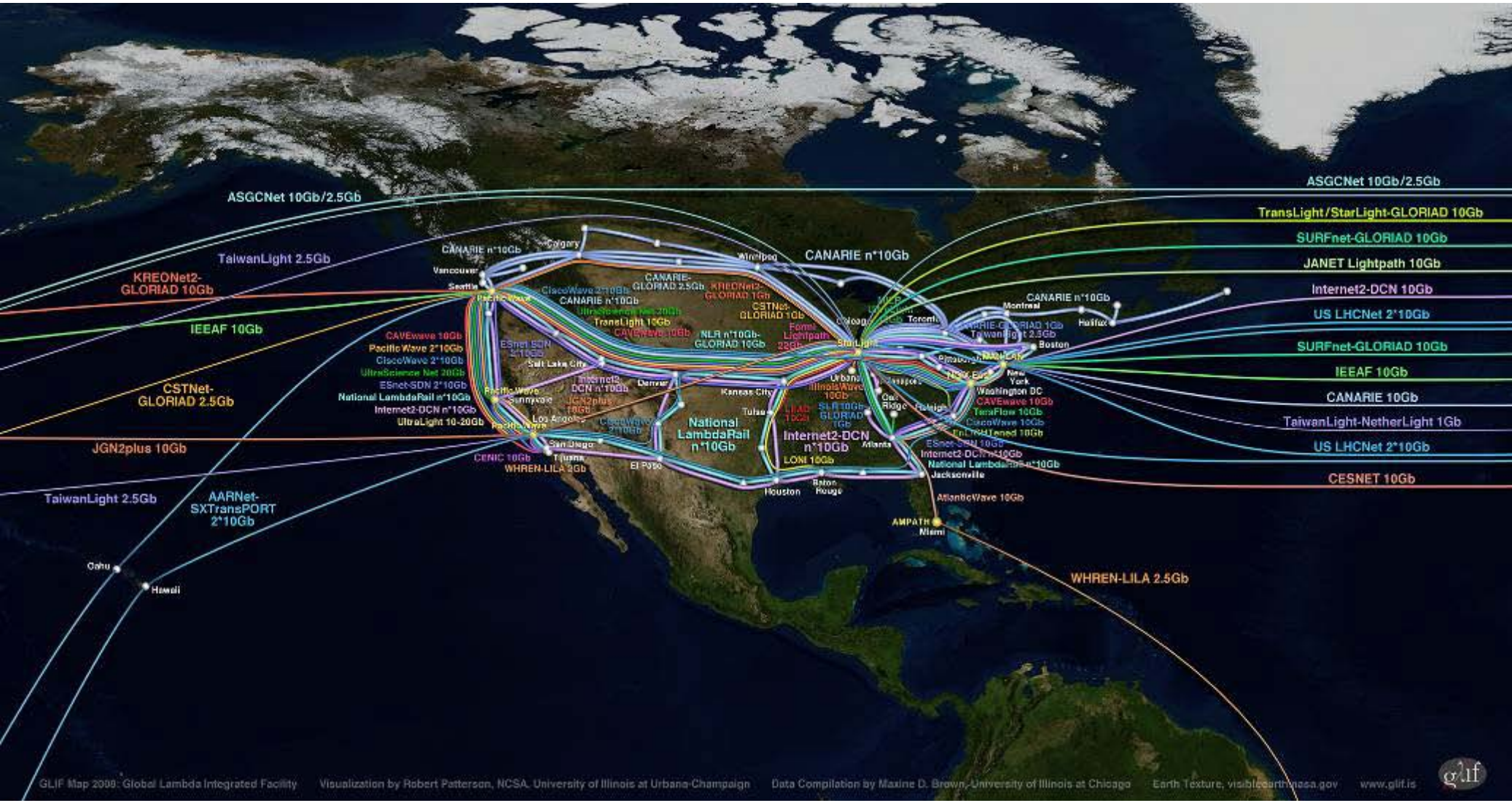
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Distributed Supercomputing: NASA MAP '06 System Configuration Using NLR



G. McConaughy (586), B. Womack (Northrop), P. Webster (606), D. Duffy (CSC), M. Whitehead (CSC), H. Mitchell (610.3), J. Delabeaujardiere (610.3), R. Jones (GST)

NLR/I2 is Connected Internationally via Global Lambda Integrated Facility

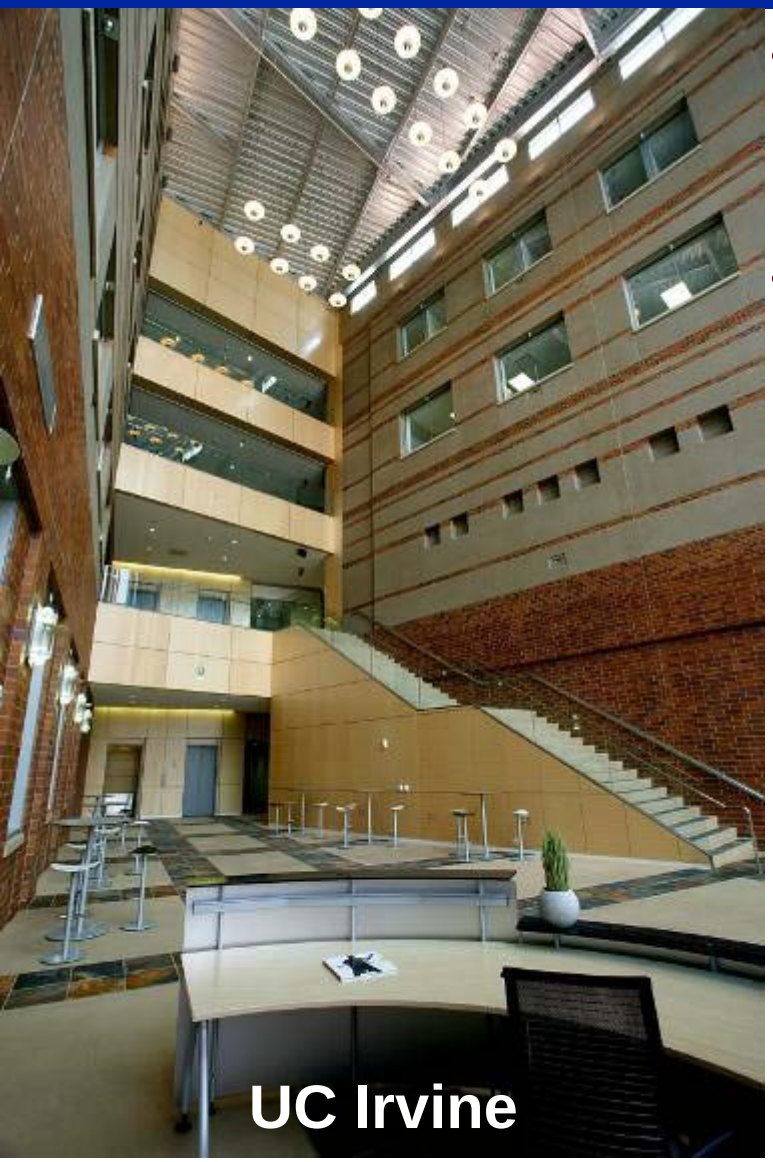


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Source: Maxine Brown, UIC and Robert Patterson, NCSA

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Two New Calit2 Buildings Provide New Laboratories for "Living in the Future"



- "Convergence" Laboratory Facilities
  - Nanotech, BioMEMS, Chips, Radio, Photonics
  - Virtual Reality, Digital Cinema, HDTV, Gaming
- Over 1000 Researchers in Two Buildings
  - Linked via Dedicated Optical Networks



www.calit2.net

Preparing for a World in Which Distance is Eliminated…

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Using High Definition to Link the Calit2 Buildings



June 2, 2008

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Cisco Telepresence Provides Leading Edge Commercial Video Teleconferencing

- **191** Cisco TelePresence in Major Cities Globally
  - US/Canada: 83 CTS 3000, 46 CTS 1000
  - APAC: 17 CTS 3000, 4 CTS 1000
  - Japan: 4 CTS 3000, 2 CTS 1000
  - Europe: 22 CTS 3000, 10 CTS 1000
  - Emerging: 3 CTS 3000
- Overall Average Utilization is 45%

- **85,854** TelePresence Meetings Scheduled to Date
  - Weekly Average is 2,263 Meetings
- **108,736** Hours
  - Average is 1.25 Hours

- **13,450** Meetings Avoided Travel Average to Date (Based on 8 Participants)

  ~$107.60 M To Date
- Cubic Meters of Emissions Saved **16,039,052 (6,775 Cars off the Road)**

Uses QoS Over Shared Internet ~ 15 mbps

Cisco Bought WebEx

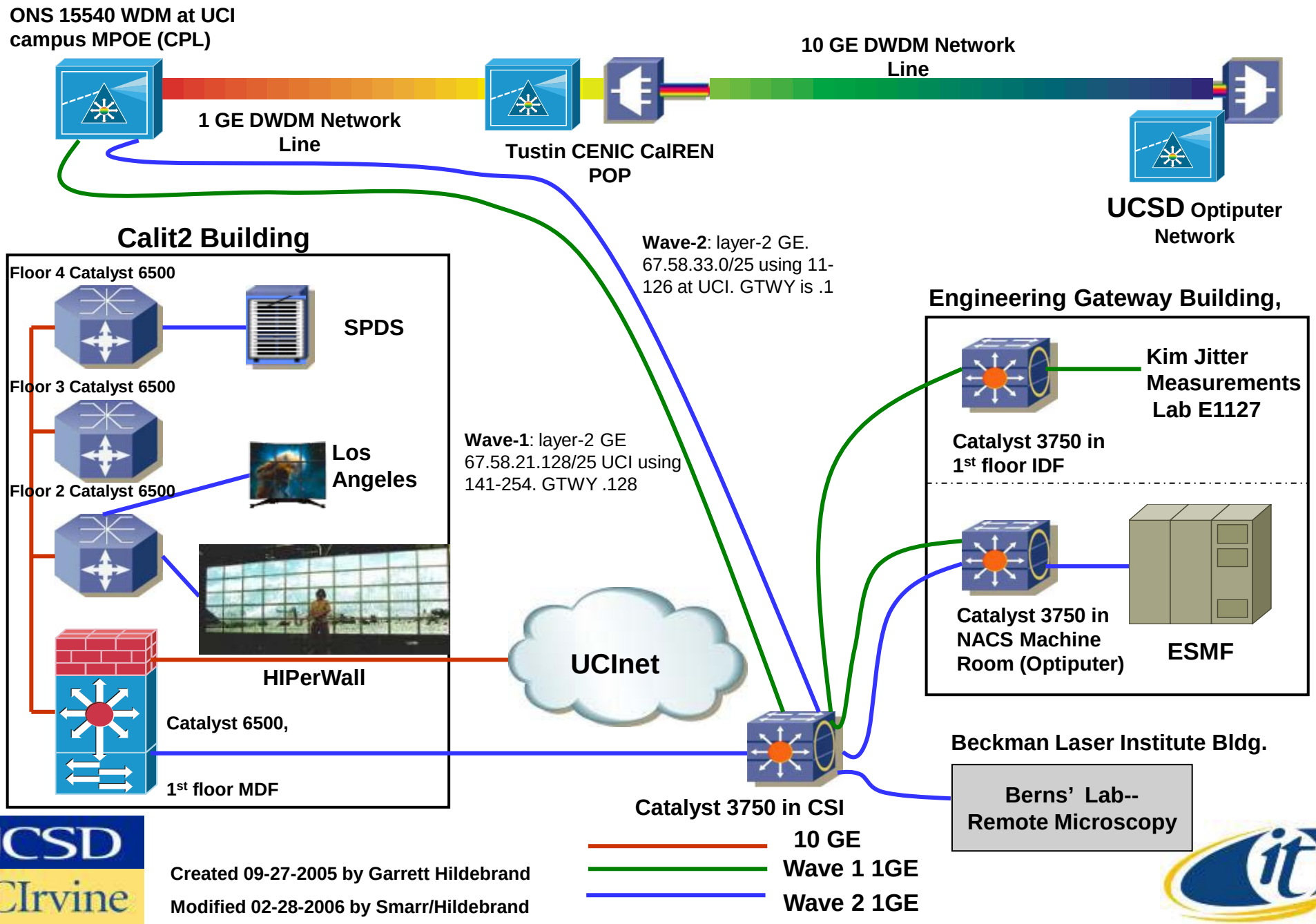




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Source: Cisco 3/22/08

Calit2 at UCI and UCSD Are Prototyping Gigabit Applications— Today 2 Gbps Paths are Used

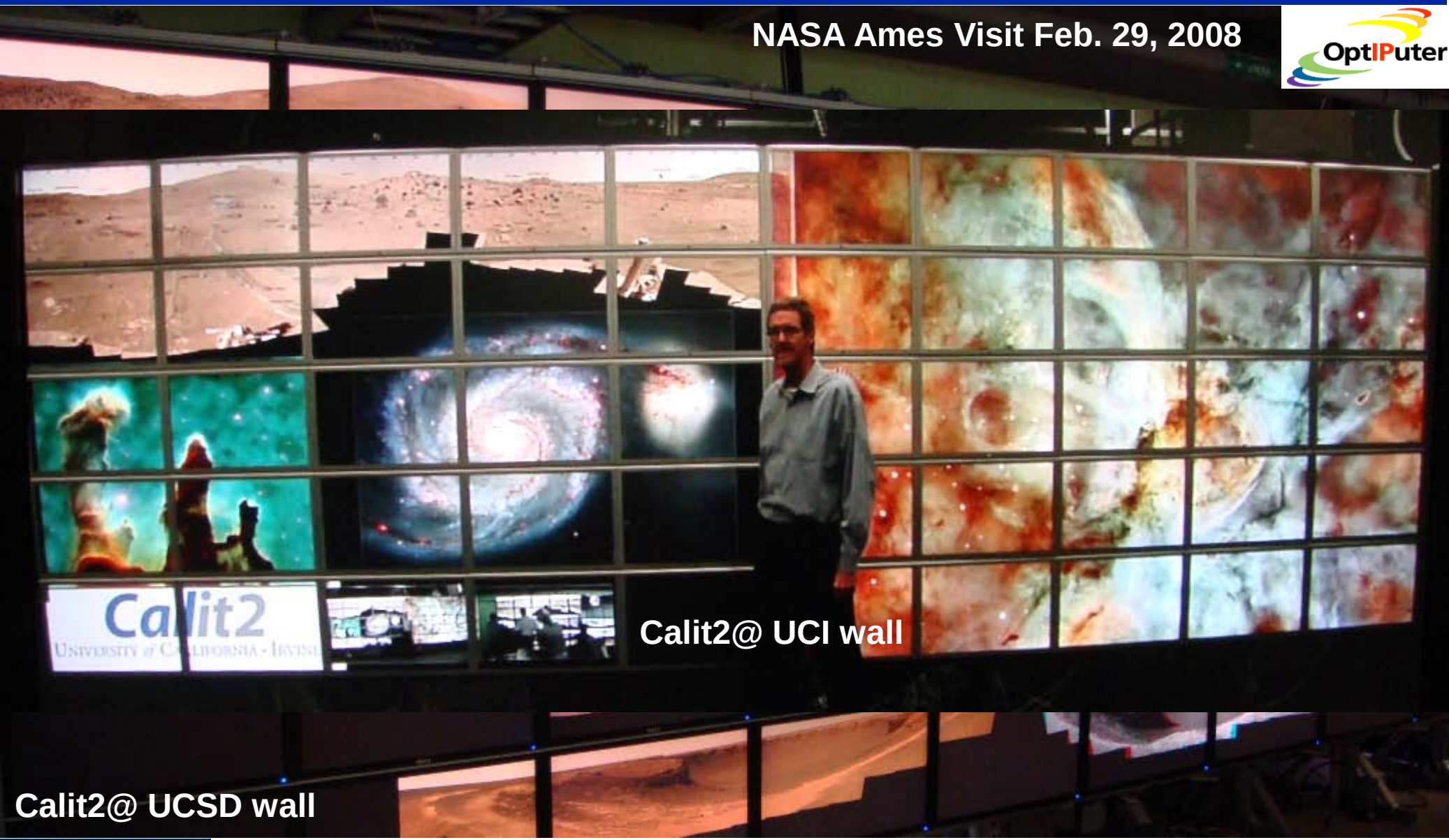


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Created 09-27-2005 by Garrett Hildebrand

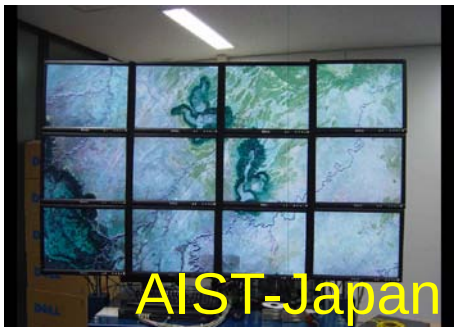
Modified 02-28-2006 by Smarr/Hildebrand

The Calit2 OptIPortals at UCSD and UCI Are Now a Gbit/s HD Collaboratory

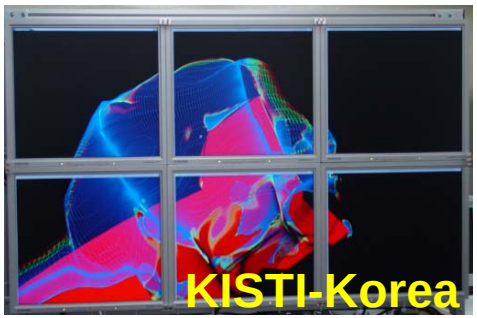


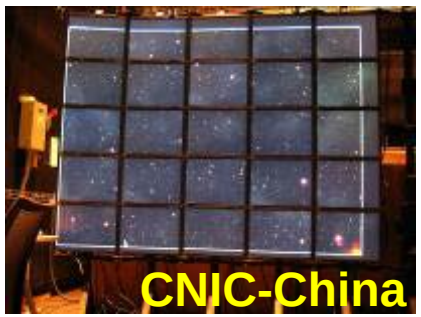
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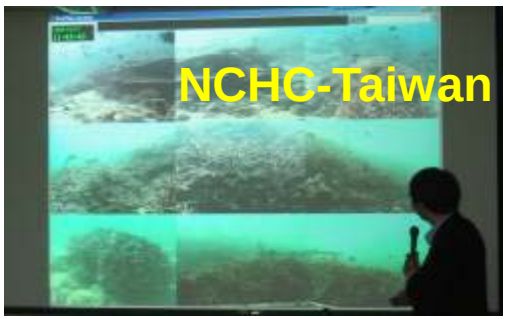
OptIPortals
Are Being Adopted Globally























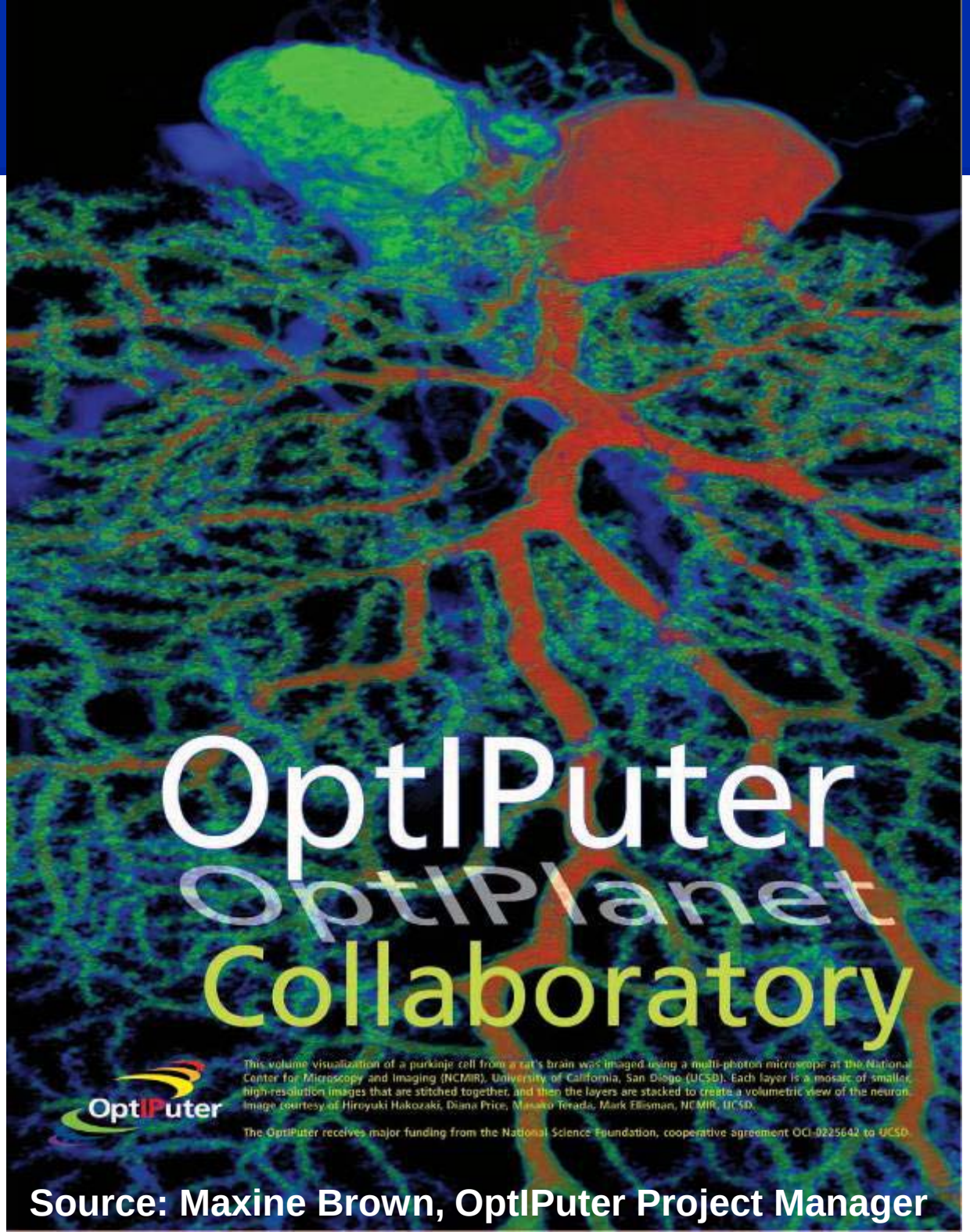


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Powered by Rocks ROCKS

evl electronic visualization laboratory

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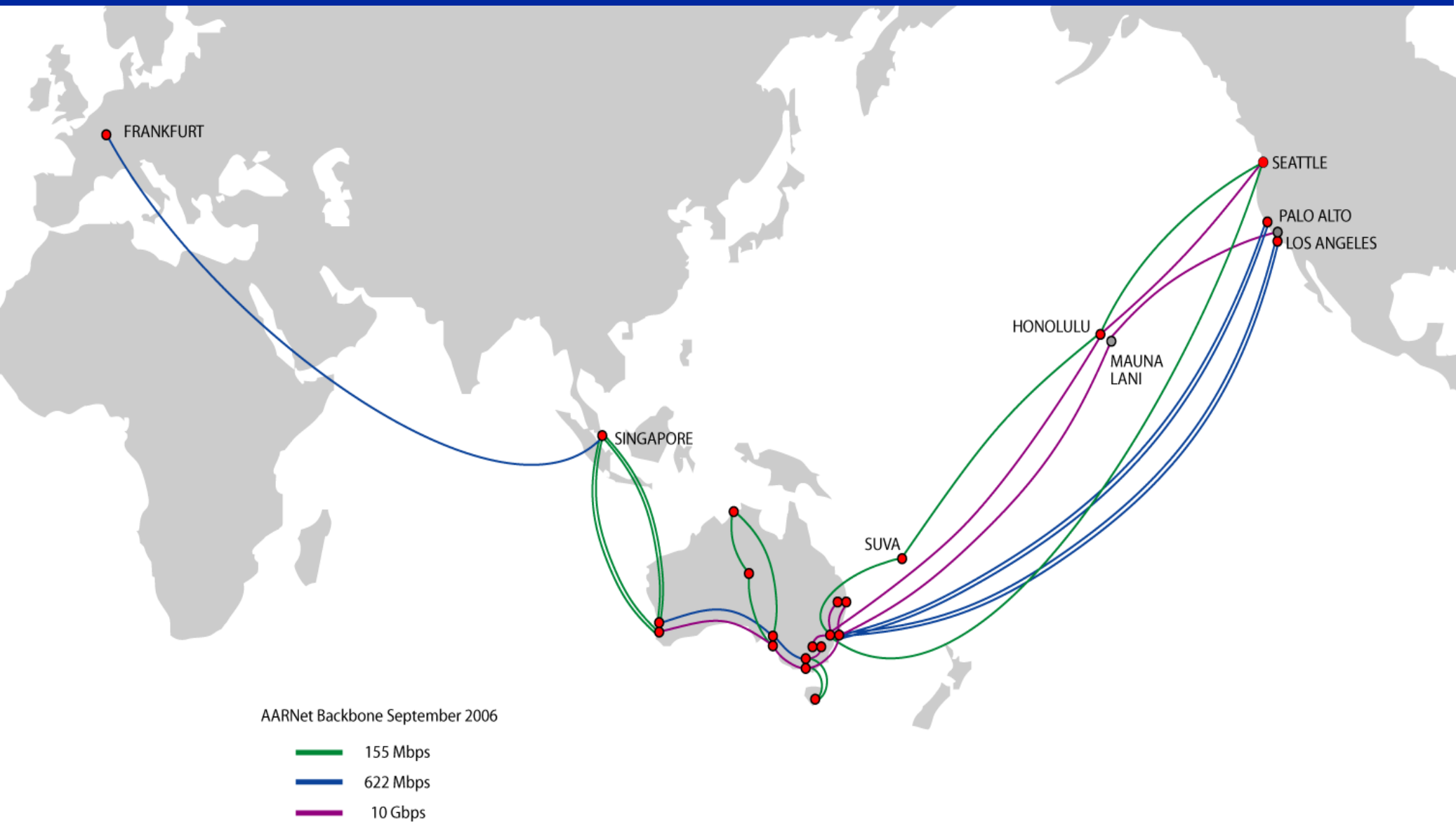
Source: Maxine Brown, OptIPuter Project Manager

Green Initiative:

Can Optical Fiber Replace Airline Travel for Continuing Collaborations ?

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AARNet International Network



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Launch of the 100 Megapixel OzIPortal Over Qvidium Compressed HD on 1 Gbps CENIC/PW/AARNet Fiber

No Calit2 Person Physically Flew to Australia to Bring This Up!



Covise, Phil Weber, Jurgen Schulze, Calit2
CGLX, Kai-Uwe Doerr , Calit2

www.calit2.net/newsroom/release.php?id=1219

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Victoria Premier and Australian Deputy Prime Minister Asking Questions



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www.calit2.net/newsroom/release.php?id=1219

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University of Melbourne Vice Chancellor Glyn Davis in Calit2 Replies to Question from Australia



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OptIPuterizing Australian Universities in 2008: CENIC Coupling to AARNet



UMelbourne/Calit2 Telepresence Session May 21, 2008

Two Week Lecture Tour of Australian Research Universities by Larry Smarr October 2008

Phil Scanlan—Founder Australian American Leadership Dialogue www.aald.org

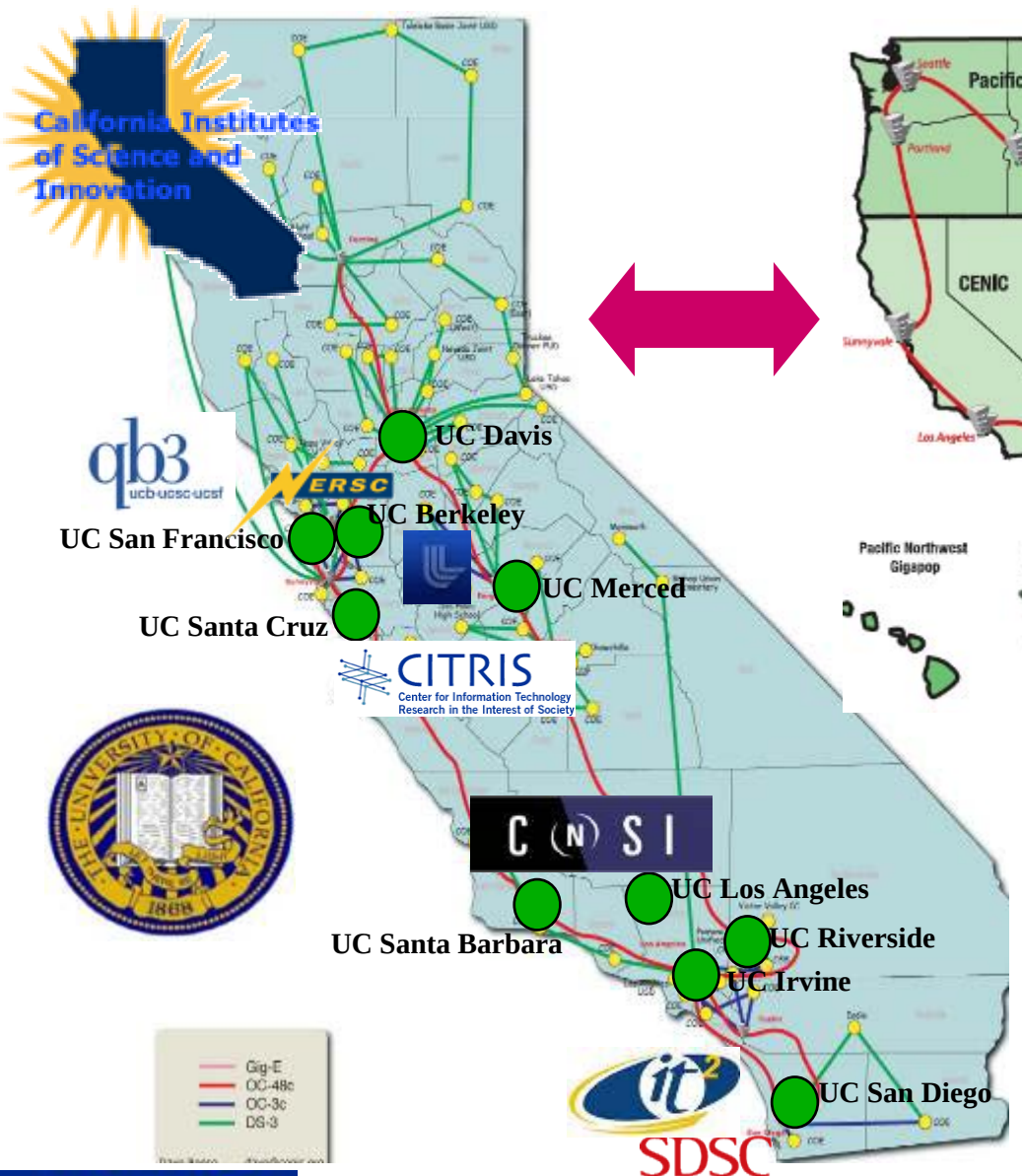


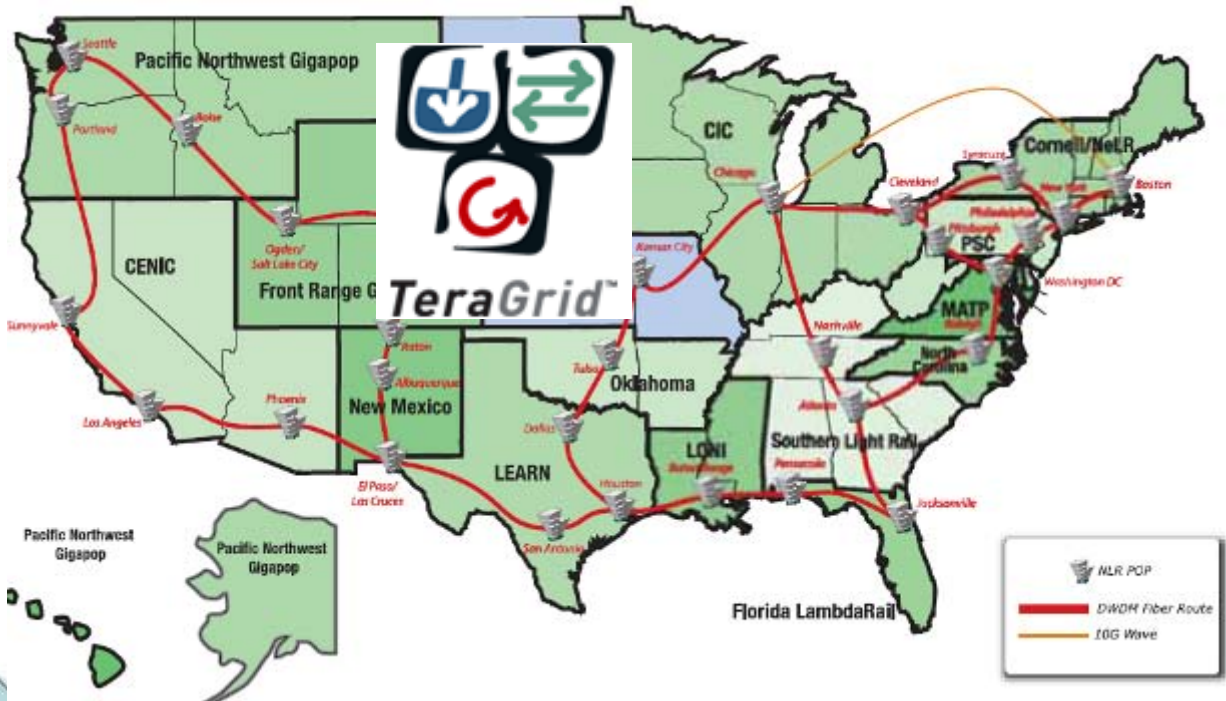
AARNet's roadmap: by 2011 up to 80 x 40 Gbit channels

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Creating a California Cyberinfrastructure of OptIPuter "On-Ramps" to NLR & TeraGrid Resources





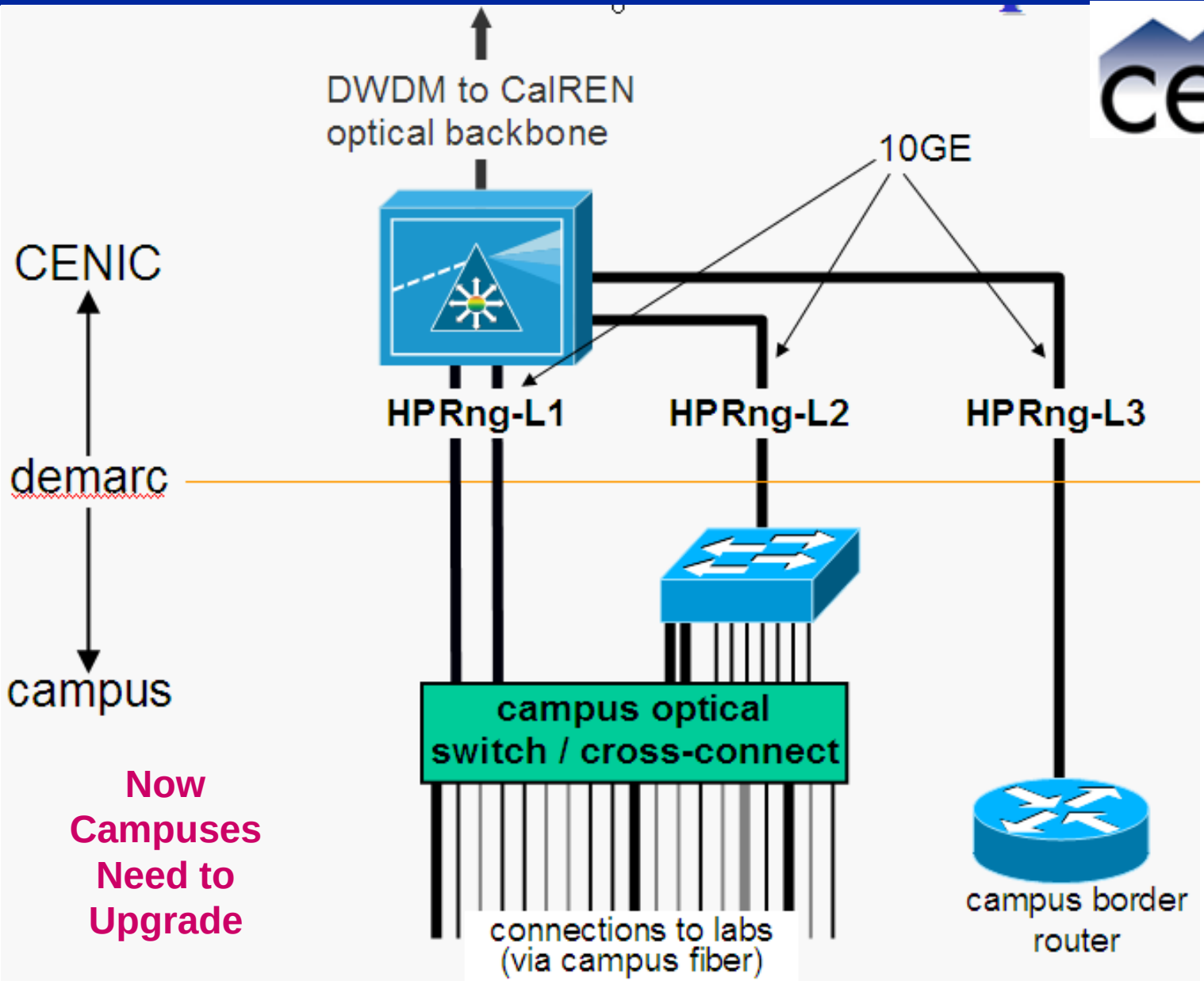
Creating a Critical Mass of OptIPuter End Users on a Secure LambdaGrid

CENIC Workshop at Calit2 Sept 15-16, 2008

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CENIC's New "Hybrid Network" - Traditional Routed IP and the New Switched Ethernet and Optical Services

~ $14M Invested in Upgrade



Now Campuses Need to Upgrade

Source: Jim Dolgonas, CENIC

The "Golden Spike" UCSD Experimental Optical Core: Ready to Couple Users to CENIC L1, L2, L3 Services



Goals by 2008:

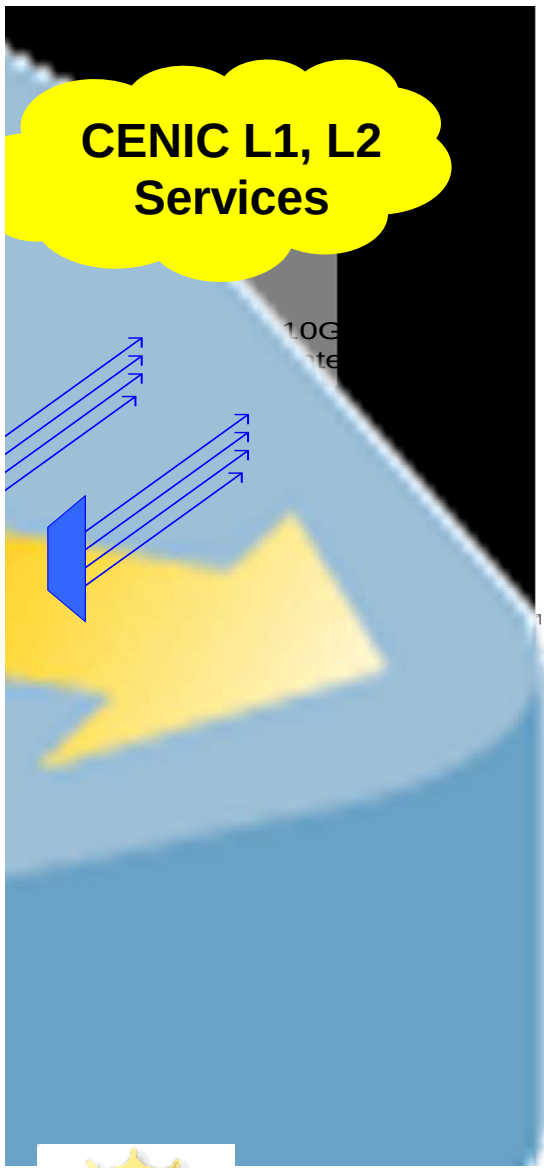
>= 60 endpoints at 10 GigE

>= 30 Packet switched

>= 30 Switched wavelengths

>= 400 Connected endpoints

Approximately 0.5 Tbps Arrive at the "Optical" Center of Hybrid Campus Switch



Funded by NSF MRI Grant

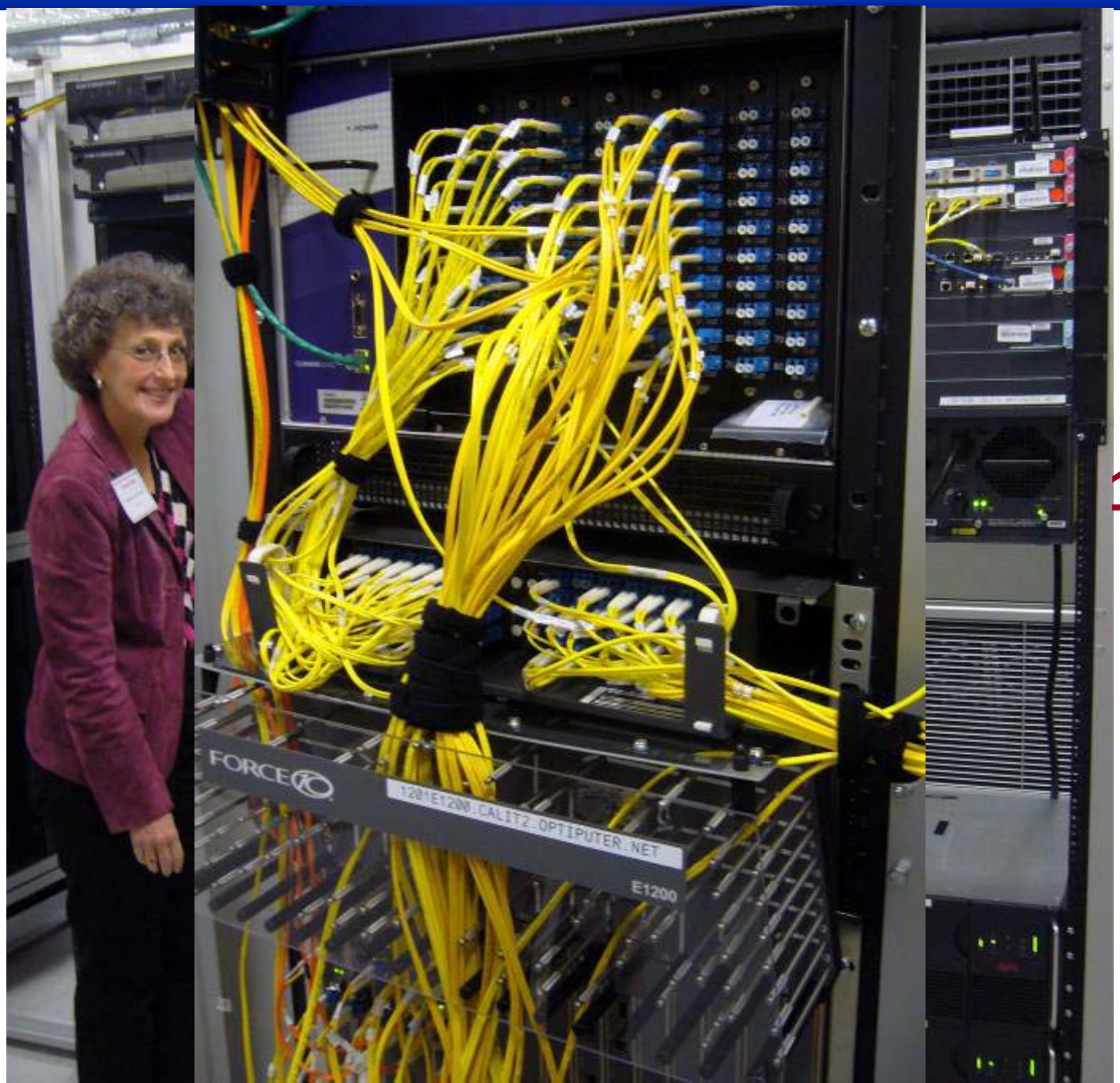
UCSD UCIrvine SDSC

Source: Phil Papadopoulos, SDSC/Calit2 (Quartzite PI, OptIPuter co-PI)

NSF

it2

Calit2 Sunlight
Optical Exchange Contains Quartzite



10:45 am Feb. 21, 2008

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Towards a Green Cyberinfrastructure: Optically Connected "Green" Modular Datacenters

UCSD Structural Engineering Dept. Conducted Tests May 2007



7 Racks plus Network | Takes up 2 Parking Spaces | Data Power Cooling

- **Measure and Control Energy Usage:**
  - **Sun Has Shown up to 40% Reduction in Energy**
  - **Active Management of Disks, CPUs, etc.**
  - **Measures Temperature at 5 Spots in 8 Racks**
  - **Power Utilization in Each of the 8 Racks**

UCSD (Calit2 & SOM) Bought Two Sun Boxes May 2008

$2M NSF-Funded Project GreenLight



Project GreenLight--Two Main Approaches to Improving Energy Efficiency by Exploiting Parallelism

- **Multiprocessing as in Multiple Cores that can be Shutdown or Slowdown Based on Workloads**
- **Co-Processing that uses Specialized Functional Units for a Given Application**
- **The Challenge in Co-Processing is the Hand-Crafting that is Needed in Building such Machines**
  - **Application-Specific Co-Processor Constructed from Work-Load Analysis**
  - **The Co-Processor is Able to Keep up with the Host Processor in Exploiting Fine-Grain Parallel Execution Opportunities**

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Source: Rajesh Gupta, UCSD CSE; Calit2

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Algorithmically, Two Ways to Save Power Through Choice of Right System & Device States

- **Shutdown**
  - Multiple Sleep States
  - Also Known as Dynamic Power Management (DPM)
- **Slowdown**
  - Multiple Active States
  - Also Known as Dynamic Voltage/Frequency Scaling (DVS)
- **DPM + DVS**
  - Choice Between Amount of Slowdown and Shutdown

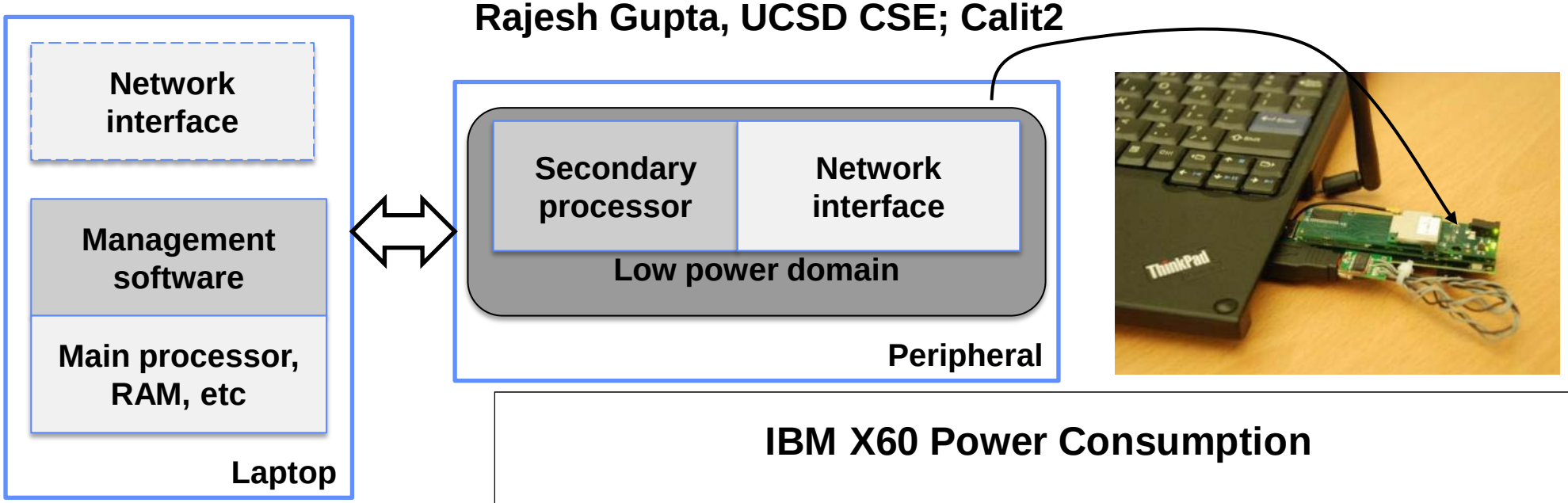
UCSD UCIrvine

Source: Rajesh Gupta, UCSD CSE; Calit2

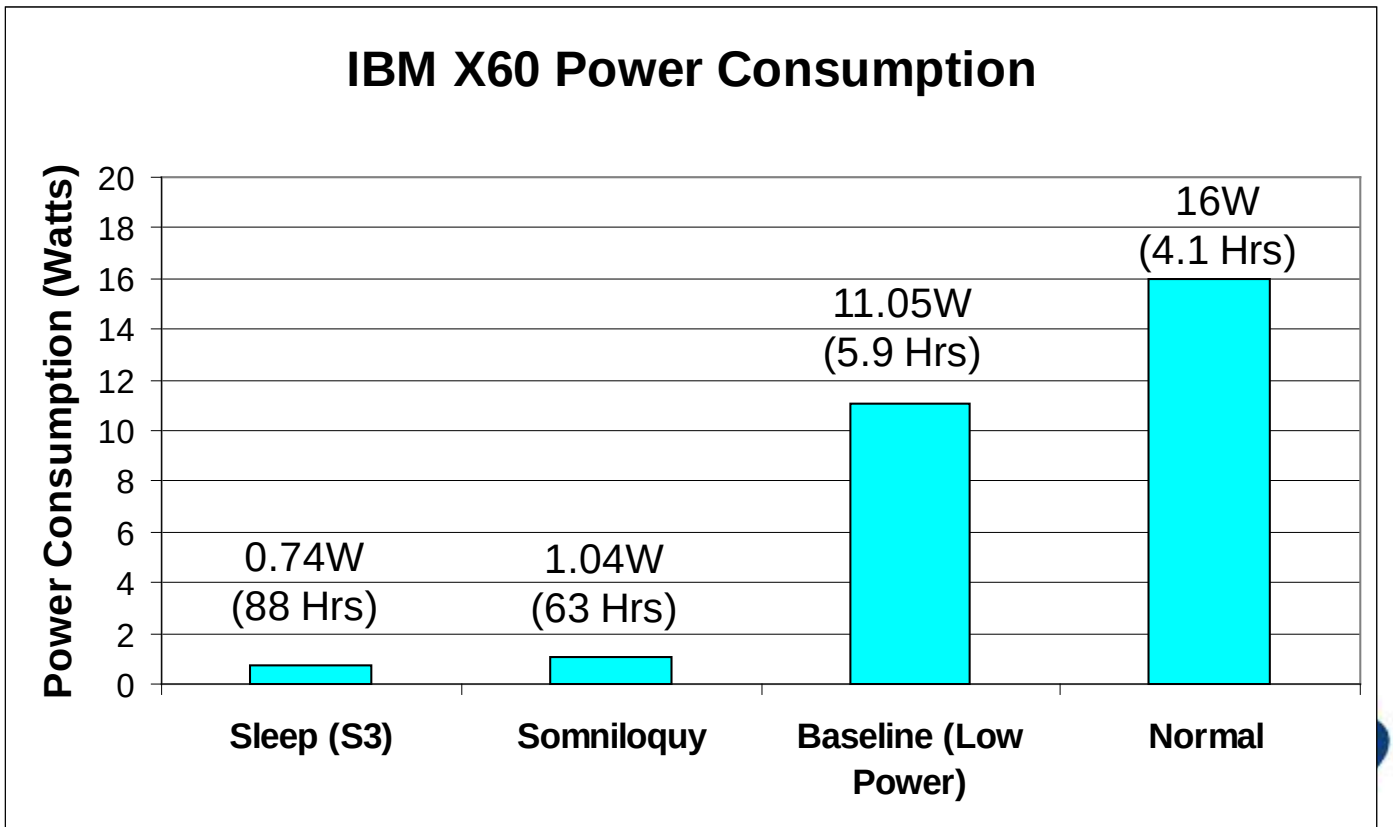
it2

GreenLight: Putting Machines To Sleep Transparently

Rajesh Gupta, UCSD CSE; Calit2



Somniloquy Enables Servers to Enter and Exit Sleep While Maintaining Their Network and Application Level Presence

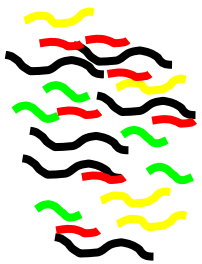


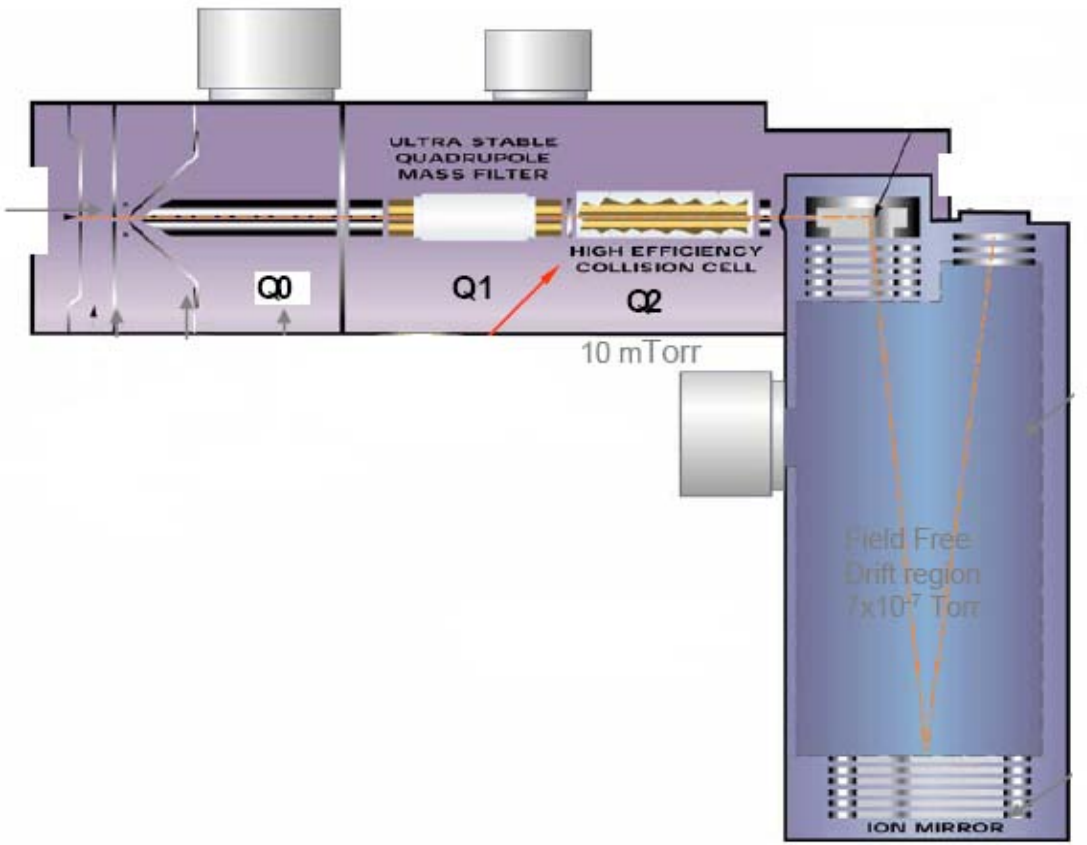
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Mass Spectrometry Proteomics: Determine the Components of a Biological Sample

Source: Sam Payne, UCSD CSE

Peptides Serve as Input to the MS





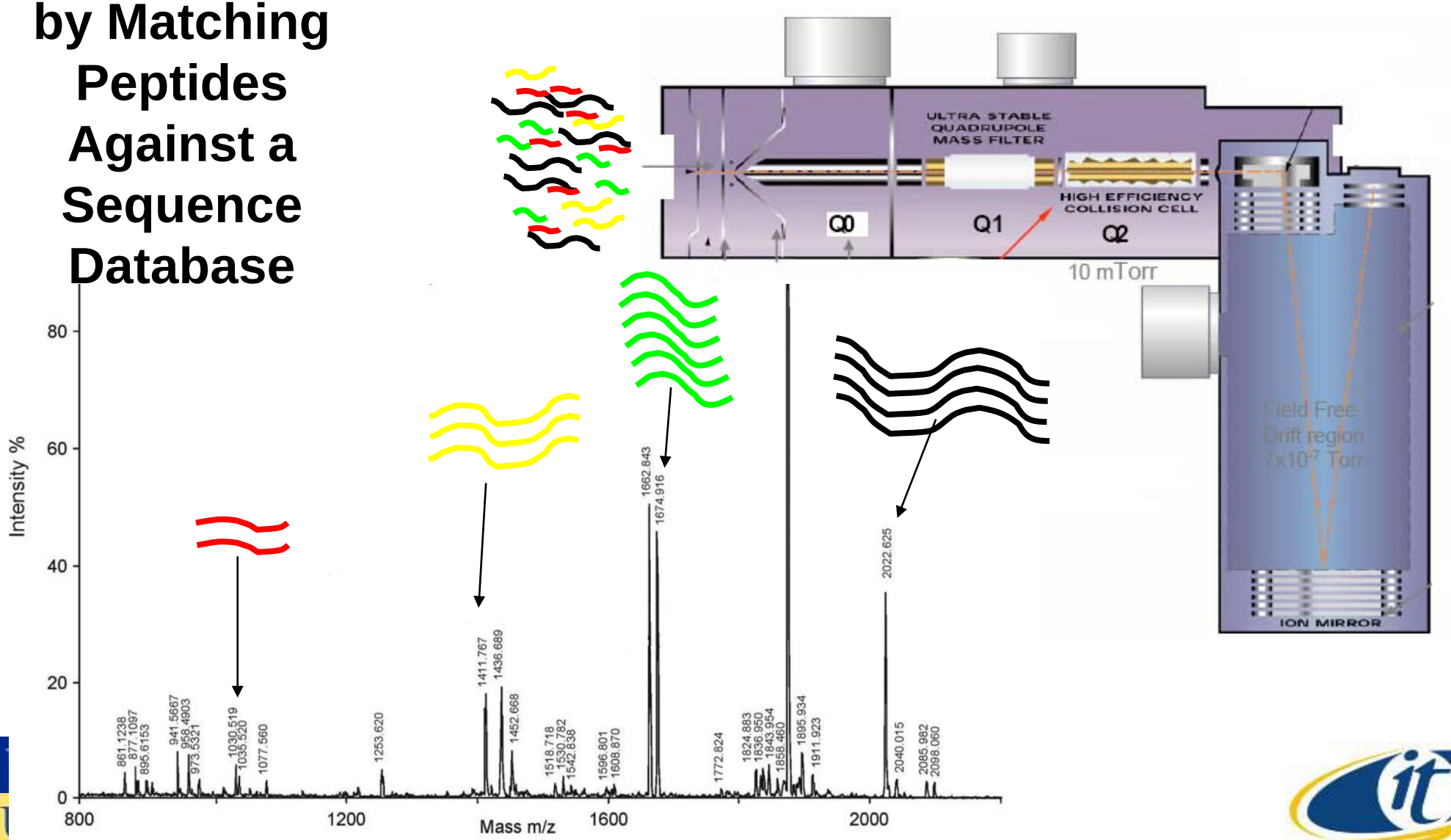
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Mass Spectrometry Proteomics: Machine Measures Peptides, Then Identifies Proteins

Source: Sam Payne, UCSD CSE

Proteins are then Identified by Matching Peptides Against a Sequence Database



Most Mass Spec Algorithms, including Inspect, Search Only for a User Input List of Modifications

- **But Inspect also Implements the Very Computationally Intense MS-Alignment Algorithm for Discovery of Unanticipated Rare or Uncharacterized Post-Translational Modifications**
- **Solution: Hardware Acceleration with a FPGA-Based Co-Processor**
  - **Identification and Characterization of Key Kernel for MS-Alignment Algorithm**
  - **Hardware Implementation of Kernel on Novel FPGA-based Co-Processor (Convey Architecture)**
- **Results:**
  - **300x Speedup & Increased Computational Efficiency**

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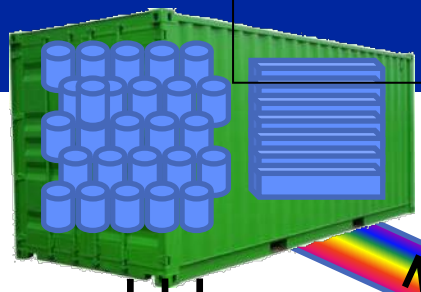
Challenge: What is the Appropriate Data Infrastructure for a 21st Century Data-Intensive BioMedical Campus?

- **Needed: a High Performance Biological Data Storage, Analysis, and Dissemination Cyberinfrastructure that Connects:**
  - **Genomic and Metagenomic Sequences**
  - **MicroArrays**
  - **Proteomics**
  - **Cellular Pathways**
  - **Federated Repositories of Multi-Scale Images**
    - **Full Body to Microscopy**
- **With Interactive Remote Control of Scientific Instruments**
- **Multi-level Storage and Scalable Computing**
- **Scalable Laboratory Visualization and Analysis Facilities**
- **High Definition Collaboration Facilities**

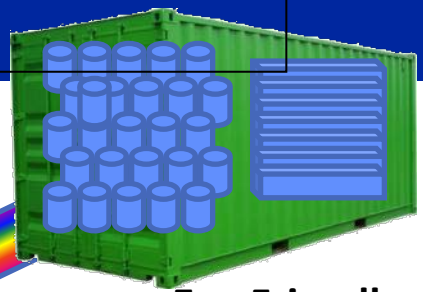
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Planned UCSD Energy Instrumented Cyberinfrastructure



Active Data Replication



N x 10 Gbit

N x 10 Gbit

Eco-Friendly
Storage and Compute

"Network in a box"
- > 200 Connections
- DWDM or Gray Optics



10 Gigabit
L2/L3 Switch

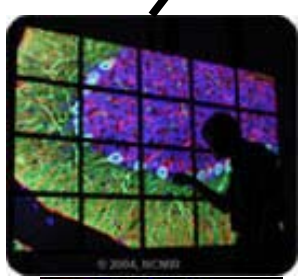
Wide-Area 10G
- Cenic/HPR
- NLR Cavewave
- Cinegrid
- …

On-Demand Physical
Connections

OptIPuter



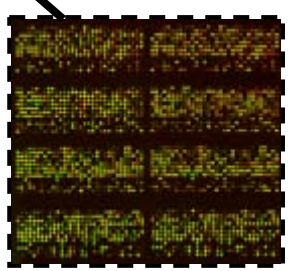
camera



NCMIR
NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH



NBCR



Microarray

Your
Lab
Here

UCSD
UCIrvine

ROCKS

Source:Phil Papadopoulos, SDSC/Calit2

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Instrument Control Services: UCSD/Osaka Univ. Link Enables Real-Time Instrument Steering and HDTV

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





TS telescience project



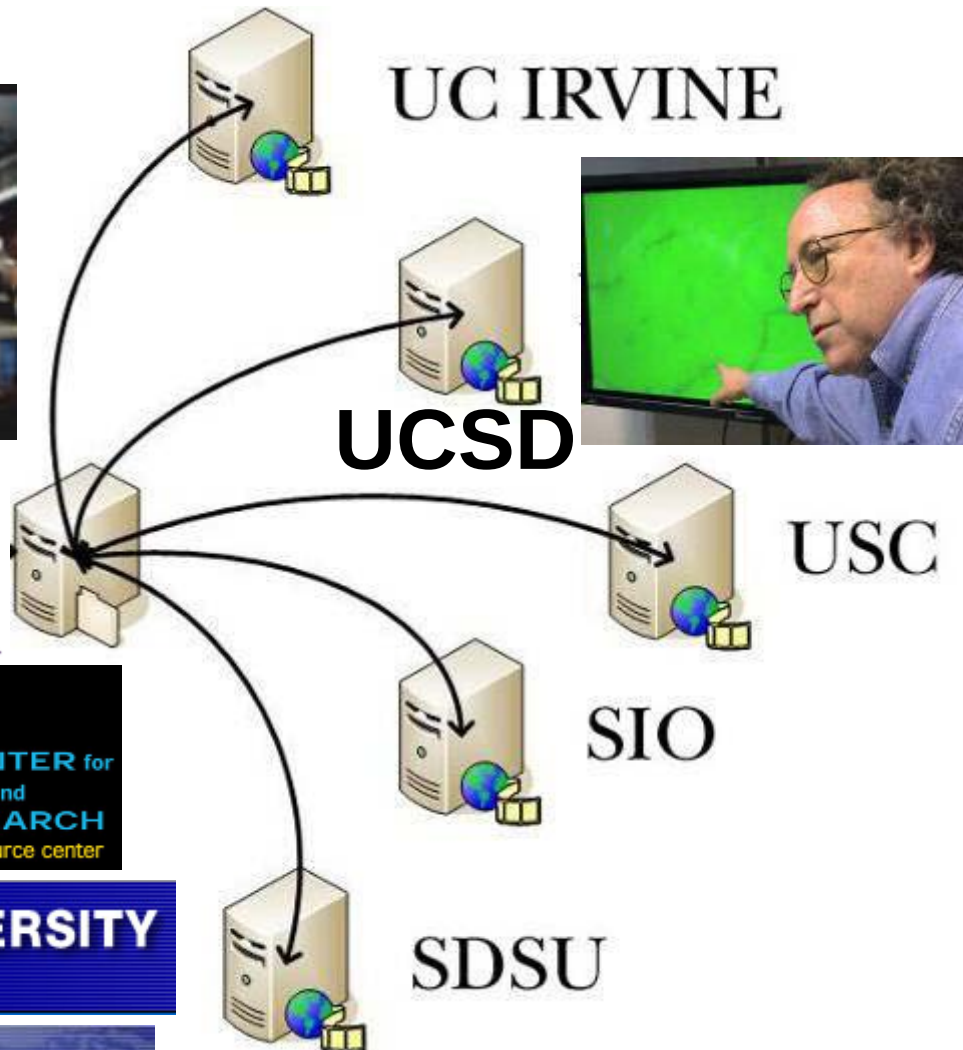
HDTV

NBCR

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

OSAKA UNIVERSITY

KDDI GROUP KDDI Labs USA



Source: Mark Ellisman, UCSD

it²

CAMERA: Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis



Paul Gilna Ex. Dir.

National LambdaRail
Direct Connect
Computation and Storage Complex

PI Larry Smarr

Funded by: Gordon and Betty Moore Foundation

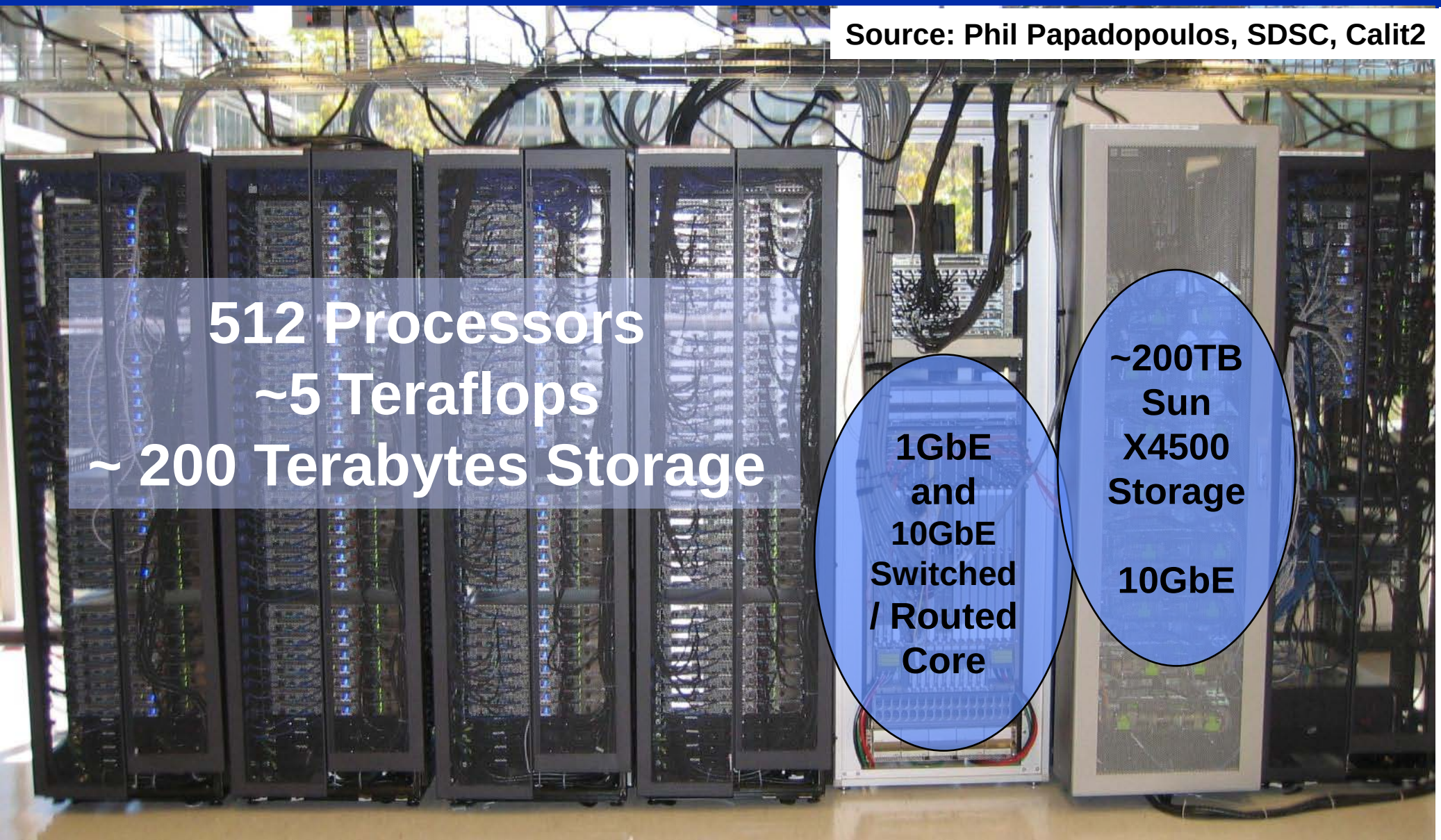
Joint Partnership of:

camera
Marine Microbial Ecology

Announced January 17, 2006
$24.5M Over Seven Years

Calit2 Microbial Metagenomics Cluster- Next Generation Optically Linked Science Data Server

Source: Phil Papadopoulos, SDSC, Calit2



UCSD UCIrvine SDSC ROCKS camera Marine Microbial Ecology J. Craig Venter INSTITUTE it2

CAMERA's
Global Microbial Metagenomics CyberCommunity

2200 Registered Users From Over 50 Countries



camera
Marine Microbial Ecology

J. Craig Venter
INSTITUTE

it²

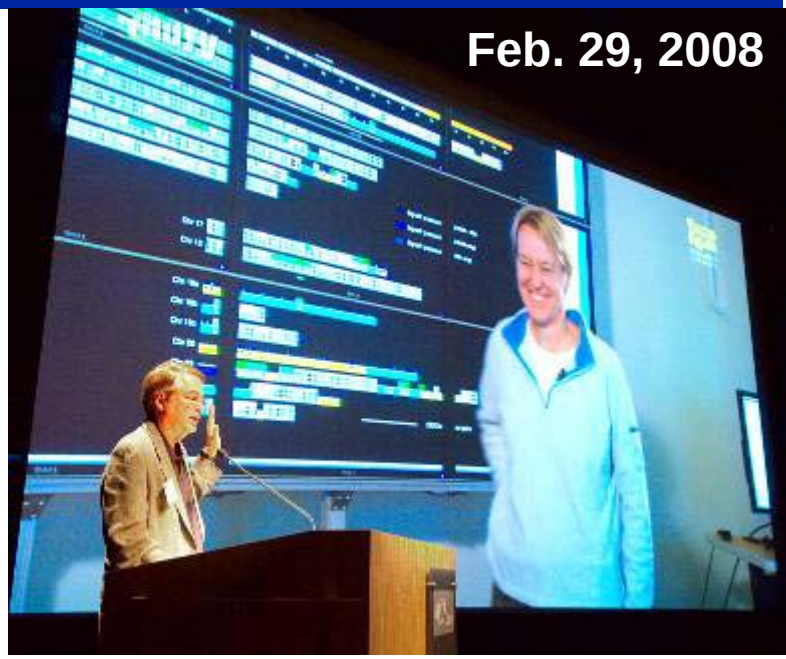
OptIPlanet Collaboratory Persistent Infrastructure Supporting Microbial Research



OptIPuter

Ginger Armbrust's Diatoms: Micrographs, Chromosomes, Genetic Assembly

ROCKS





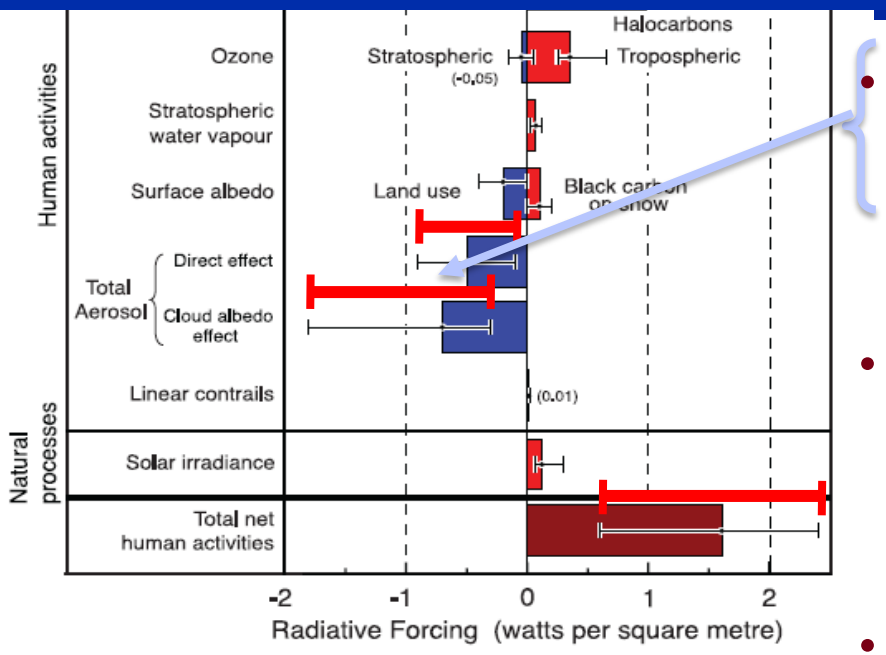


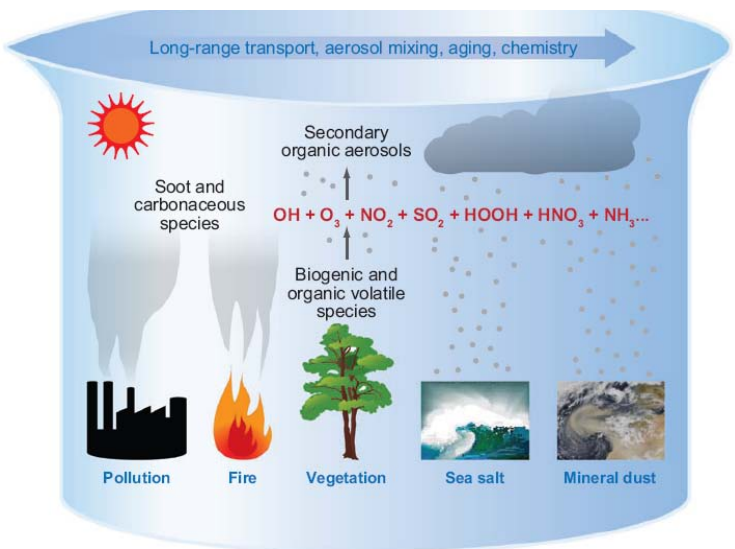
UW's Research Channel Michael Wellings

it2

Key Focus: Reduce the Uncertainties Associated with Impacts of Aerosols on Climate







- **Combine lab, field (ground, ship, aircraft), measurements, models to improve treatment of aerosols in models**
- **Link fundamental science with atmospheric measurements to help establish effective control policies**
- **Develop next generation of measurement techniques (sensors, UAV instruments)**
- **Set up SIO pier as long term earth observatory (ocean, atmosphere, climate monitoring)**
- **Develop regional climate model for SoCal, linking aerosols with regional climate**

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Source: Kim Prather, UCSD

it²